

YAKIMA FISHERIES PROJECT  
SPRING CHINOOK SUPPLEMENTATION MONITORING PLAN

Prepared by:

Craig Busack  
Todd Pearsons  
C u r t K n u d s e n  
Steve Phelps

Washington Department of Fish and Wildlife

and

Bruce Watson  
Mark Johnston

Yakama Indian Nation

Prepared for:

U. S. Department of Energy  
Bonneville Power Administration  
Environment, Fish and Wildlife  
P.O. Box 362 1  
Portland, OR 97208-362 1

Project Number 95-065  
Contract Number DE-BI79-96BP64878

AUGUST 1997

# Table of Contents

Introduction	11
Background and Current Status of Monitoring Planning	11
Philosophy of Monitoring Plan Development	12
Basic Elements of the Monitoring Plan	13
Organization and Format	17
Uncertainties	18
Section 1. Evaluation of the Spring Chinook Supplementation Effort	25
The YFP as a Test of Supplementation	25
Criteria for Success	26
Time Required for Evaluation	27
Prognosis for Successful Monitoring	28
Section 1A. Natural Production	29
Basic Concepts	29
Intrinsic Factors Affecting Natural Production	38
Hatchery Fish Quality	39
Long-Term Fitness of the Supplemented Population	41
Facility Performance	41
Extrinsic Factors Affecting Natural Production	42
Impact of Environmental Fluctuations on Productivity	42
Impacts of Limited Carrying Capacity	47
Outline of Natural Production Monitoring Measures	56
Intrinsic Factors affecting Natural Production	56
Extrinsic Factors affecting Supplementation Success	60
Section 1B. Harvest	65
Ocean Fisheries	66
Columbia River Fisheries	67
Yakima Basin Fisheries	67
Outline of Monitoring Measures for Harvest	68
Columbia River Fisheries	69
Yakima Basin Fisheries	69
Section 1C. Genetics	71
YFP Genetic Planning Documents	71
Genetic Risks and Hazards in Hatchery Operations	72
Type 1 Hazards	72
Type 2 Hazards	73

Type3 Hazards .....	75
Type 4 Hazard .....	76
Risk Assessment and Approach to Monitoring .....	78
Monitoring Addressing Type 1 Risk .....	79
Monitoring Addressing Type 2 Risk .....	81
Monitoring Addressing Type 3 Risk .....	83
Monitoring Addressing Type 4 Risk .....	84
Outline of Monitoring Measures for Genetics .....	86
Genetic Health of the Upper Yakima stock .....	86
Genetic Health of the Naches River and American River stocks .....	89
Genetic Health of other Columbia basin spring and Snake basin spring/summer chinook stocks .....	91
Section 1 D. Ecological Interactions .....	93
Interactions Affecting Supplementation Success .....	95
Interactions between Spring Chinook and Strong Interactor Taxa .....	95
Interactions between Hatchery and Wild Spring Chinook. ....	109
Interactions between Spring Chinook and Fish from Other Inbasin Artificial Propagation Programs .....	112
Interactions Affecting Stewardship And Utilization Taxa .....	114
Outline of Monitoring Measures for Ecological Interactions .....	120
Interactions affecting Supplementation Success .....	120
Interactions affecting Stewardship and Utilization Taxa (SUT) .....	126
Section 2. OCT/SNT Comparisons .....	131
Outline of Monitoring Measures for OCT/SNT Comparisons .....	135
Performance of OCT- and SNT-conditioned fish, relative to each other and to wild fish, in juvenile survival and traits strongly linked with <b>survival</b> .....	135
Performance of OCT- and SNT-conditioned fish, relative to each other and to wild fish, in adult survival to the fishery and spawning grounds .....	136
Performance of OCT- and SNTconditioned fish, relative to each other and to wild fish, in reproductive success and traits strongly linked to reproductive success .....	137
Differential performance of OCT- and SNT-conditioned juveniles in ecological interactions with naturally produced spring chinook and Nontarget Taxa of Concern .....	138
Section 3. Facility and Field Monitoring Activity Quality Control .....	141
Cle Elum Hatchery .....	143
Acclimation Raceways .....	144

Permanent Monitoring Facilities .....	145
Field Monitoring Activities .....	148
Outline of Monitoring Measures for Facilities and Field Operations .....	150
Cle Elum Hatchery .....	151
Acclimation Raceways .....	152
Permanent Monitoring Facilities .....	152
Field Monitoring Activities .....	158
Literature Cited .....	165
<b>Appendix</b> .....	<b>183</b>

## List of Tables

Table 1. Components of Recruitment Rates $R_{ww}$ , $R_{hw}$ , and $R_{wh}$ considered in the YFP spring chinook monitoring plan. . . . .	36
Table 2. Strong interactor species likely to affect the success of YFP spring chinook supplementation. . . . .	98
Table 3. Components of food competition index and relative certainty of competition. . . . .	106
Table 4. Components of space competition index and relative certainty of competition. . . . .	107
Table 5. <del>Nontarget taxa</del> of concern of <del>stewardship</del> or utilization importance (SUT) that may be affected by YFP spring chinook supplementation. . . . .	118
Table 6. Perceived overlap with spring chinook, preliminary ecological risk assessment of non-attainment of objectives, and monitoring prescription for Stewardship and Utilization Taxa (SUT). . . . .	119
Table 7. Facility-specific quality control concerns requiring monitoring at the Roza adult facility. . . . .	154
Table 8. Facility-specific quality control concerns requiring monitoring at the Roza juvenile facility. . . . .	155
Table 9. Facility-specific quality control concerns requiring monitoring at the Prosser <b>adult facility</b> . . . . .	156
Table 10. Facility-specific quality control concerns requiring monitoring at the Chandler juvenile facility. . . . .	157
Table 11. Activity-specific quality control concerns associated with electrofishing .	158
Table 12. Activity-specific quality control concerns associated with lethal sampling. . . . .	159
Table 13. Activity-specific quality control concerns associated with mobile traps. . .	160
Table 14. Activity-specific quality control concerns associated with snorkeling. . . .	161
Table 15. Activity-specific quality control concerns associated with redd surveys. .	162
Table 16. Activity-specific quality control concerns associated with other censuses. . . . .	163

## ERRATA SHEET

The attached title page replaces the one found in the Bonneville Power Administration publication:

Yakima Fisheries Project  
Spring Chinook Supplementation Monitoring Plan

Publication number: DOE/BP 64878- 1 April 1998

YAKIMA FISHERIES PROJECT  
SPRING CHINOOK SUPPLEMENTATION MONITORING PLAN

Prepared by:

Craig Busack  
Washington Department of Fish and Wildlife

Bruce Watson  
Yakima Indian Nation

Todd Pearsons  
Washington Department of Fish and Wildlife

Curt Knudsen  
Washington Department of Fish and Wildlife

Steve Phelps  
Washington Department of Fish and Wildlife

Mark Johnston  
Yakama Indian Nation

Prepared for:

U. S. Department of Energy  
Bonneville Power Administration  
Environment, Fish and Wildlife  
P.O. Box 3621  
Portland, OR 97208-3621

Project Number 95-064  
Contract Number DE-BI79-96BP643878

AUGUST 1997

## List of Figures

Figure 1. Organization of Section 1 D of the YFP spring chinook monitoring plan. . . .	18
Figure 2a. Natural-origin recruits over time in a YFP-like supplementation program with hatchery smolt-adult survival of 0.002 and log-normal survival rate variation of 0.0001. . . .	31
Figure 2b. Natural-origin recruits over time in a YFP-like supplementation program with hatchery smolt-adult survival of 0.002 and log-normal survival rate variation of 0.01. . . .	32
Figure 3. Organization of Section 1 A of the YFP spring chinook monitoring plan. . . .	38
Figure 4. Interrelationships of YFP genetics planning documents. . . . .	71
Figure 5. Organization of Section 1 C of the YFP spring chinook monitoring plan. . . .	79
Figure 6. Organization of Section 1 D of the YFP spring chinook monitoring plan. . . .	94
Figure 7. Map of Yakima River Basin, showing all major streams and dams. . . . .	97
Figure 8. Organization of Section 2 of the YFP spring chinook monitoring plan. . . .	133
Figure 9. Organization of Section 3 of the YFP spring chinook monitoring plan. . . .	143



# Introduction

## **Background and Current Status of Monitoring Planning**

The Yakima Fisheries Project (YFP), a key element in the Northwest Power Planning Council's Fish and Wildlife Program, has been in planning for more than ten years. It was initially conceived as, and is still intended to be, a multipurpose project. Besides increasing fish production in the Yakima basin, it is also intended to yield information about supplementation that will be of value to the entire Columbia basin, and hopefully the entire region. Because of this expectation of increased knowledge resulting from the project, a large and comprehensive monitoring program has always been seen as an integral part of the project. Despite the importance of monitoring to the project, monitoring planning has been slow to develop. The only general written statement of monitoring planning for the project is Chapter 9 of the current Project Status Report (PSR), written in 1993. That document is a reasonably good overview, and presents some important basic principles of monitoring, but is decidedly lacking in specifics. Throughout 1996 the Monitoring Implementation and Planning Team (MIPT), an interdisciplinary group of biologists who have worked on the project for several years, worked to develop a comprehensive spring chinook monitoring plan for the project. The result is the present document.

In reading the document it is important to realize that it is a big step, but only a step, in the process of developing a viable spring chinook monitoring plan for the YFP. Much work remains to be done. An appreciation of the work already accomplished as well as the work that remains can be gained by considering the three phases of developing a monitoring plan. The first phase is primarily conceptual, consisting of the definition of critical issues and problems and the identification of associated response variables. The second phase is quantitative, determining the scale and size of an effective monitoring effort. A critical element of the quantitative phase is assessing the precision with which response variables can be measured, the probability of detecting

real impacts, and the sample sizes required for a given level of statistical precision and power. The third and final phase is logistical. At this point the feasibility of monitoring measures is evaluated as to practicality and cost. This document marks completion of the conceptual phase'. MIPT is now beginning work on the next two phases.

The YFP began collecting spring chinook broodstock in May of 1997, so further development of the plan will be prioritized by implementation timing. Most measures applicable to adults, and those requiring a long lead time because of the need for research or new baseline information, will have the highest priority and will be completed first.

## **Philosophy of Monitoring Plan Development**

The general philosophy underlying current development of the YFP monitoring effort is rooted in a statement of project purpose by the Northwest Power Planning Council:

'In its action [giving conditional approval to the project] the Council reiterated that the purpose of the Yakima/Klickitat Production Project is to test the assumption that new artificial production can be used to increase harvest and natural production while maintaining genetic resources. It also emphasized that careful evaluation of supplementation and employment of adaptive management methods will be needed to accomplish this purpose. Such an approach should add the benefits of learning about supplementation and hatchery systems while contributing to the Council's goal of increasing salmon and steelhead runs in the Columbia River Basin." (NPPC 1990).

MIPT has drawn three strong inferences from this statement: 1) YFP monitoring should

---

<sup>1</sup> In terms of tasks identified in the 1993 Uncertainty Resolution Plan, this document reflects completion of RV-HApre, RV-LTFpre, RV-PRSpres, RV-ECOpres, and RV-RSpres.

evaluate how well production, increasing harvest, and minimizing genetic and ecological impacts; 2) YFP monitoring should be comprehensive; 3) YFP monitoring should be done in such a way that results are of use to salmon production efforts throughout the Columbia basin and the region.

## Basic Elements of the Monitoring Plan

The monitoring plan consists of three, hierarchical levels: *experimental tiers*, *high level questions*, and *topic areas*. An explanation of these levels follows:

Experimental Tiers The highest level experimental tier in the project is the supplementation effort itself. As reflected in the NPPC statement above, the YFP spring chinook supplementation effort is an experiment. Thus, the primary (highest level) experimental tier in the project is the supplementation effort itself. The project, however, also includes a rigorous experimental evaluation of the relative performance of hatchery fish reared under two different environmental regimes, the optimal conventional treatment (OCT) and the semi-natural treatment (SNT)<sup>2</sup> Half the fish released in the supplementation effort will be subjected to one treatment, and half to the other. The OCT/SNT comparison thus forms a secondary experimental tier, an experiment within the larger experiment. The two tiers are in a sense independent. One could be done without the other. OCT/SNT comparisons can be done at any hatchery capable of replicated releases of adequate size, regardless of whether the releases are for harvest augmentation or supplementation. Similarly, the YFP spring chinook supplementation does not have to include an OCT/SNT comparison. On the other hand, if the SNT treatment does result in much better adult returns, the release of fish reared under SNT conditions may make the difference between success and failure for the supplementation effort.

---

<sup>2</sup> In other project planning documents, the semi-natural treatment is referred to as the new innovative treatment (NIT) By means of this document we are formally suggesting that old term be discarded. Not only is semi-natural more descriptive, it avoids the redundancy of the old term.

**High Level Questions** The monitoring plan is designed to address basic supplementation issues that provide the experimental foundation of the project. Specifically, the plan is designed to provide answers to eight high level questions (four under each experimental tier) derived from two key statements about supplementation. The first is the NPPC statement quoted above, and the second is the definition of supplementation developed by the Regional Assessment of Supplementation Programs (RASP):

“Supplementation is the use of artificial propagation in an attempt to maintain or increase natural production while maintaining the long term fitness of the target population, and keeping the ecological and genetic impacts on nontarget populations within specified biological limits.” (RASP 1992)

The importance of the RASP definition is that it establishes the additional requirement of monitoring ecological as well as genetic impacts. The eight high level questions are as follows:

Experimental Tier 1: Evaluation of the spring chinook supplementation effort

How is YFP spring chinook supplementation performing in terms of:

- a) increasing natural production
- b) increasing harvest opportunity
- c) limiting genetic impacts to target and nontarget populations

- d) limiting ecological impacts to nontarget populations

## Experimental Tier 2: OCT/SNT Comparisons

How do fish reared under the OCT and SNT treatments compare with each other in terms of:

- a) juvenile survival and associated traits, relative to wild fish
- b) adult returns to fishery and spawning grounds, relative to wild fish
- c) reproductive performance and associated traits, relative to wild fish
- d) juvenile ecological interactions with wild fish

Topic Areas The high-level questions suggest four main topic areas: natural production, harvest, genetics, and ecological interactions. Monitoring measures in the plan are generally organized under these four topic areas. However, the extensive degree of interconnection among natural processes makes any such attempt at categorization at times a poor fit. This is reflected occasionally in broad overlap for monitoring measures proposed for different topic areas.

Early in the development of the plan we recognized that two sorts of questions had to be answered in monitoring: “what” and “why”. Answering ‘what’ questions involves determining if a phenomenon is or is not happening, or measuring a phenomenon. By contrast, answering “why” questions involves identifying and describing the causal mechanisms underlying the phenomenon. For example, we might be interested in measuring the survival rate of smolts from Roza to Prosser. This is a typical “what” question. The survival rate itself may be of great interest. But we would likely also be

interested in what factors determine the survival rate: e.g., predation, temperature, water quality, etc. This is a “why” question. Answering “what” questions inevitably suggests “why” questions, and “why” questions beget more “why” questions. Developing a monitoring plan that stays within a budget requires deciding which “what” questions have to be addressed, and then which “why” questions can be afforded. At this stage of development of the YFP monitoring effort we have tried to be conservative in proposing measures aimed at “why” questions. We considered two criteria for inclusion of “why” measures: critical information for the project, and critical information for supplementation efforts in the region. In one area, Ecological Interactions (Section 1 D), the “what”-“why” dichotomy is formalized as staged research efforts. Specifically, If an ecological interaction reaches a specified level, it triggers narrowly focussed studies to identify causal mechanisms. Although Ecological Interactions is the only section of the plan where this has been formalized, it needs to be understood that a monitoring result from any section could serve as a trigger for addressing “why” questions. The importance of the information and the cost and likelihood of success of obtaining it will determine which “why” questions are pursued immediately and which are deferred.

Although the distinction between them is sometimes blurred, proposed monitoring measures are of two general types: direct and collateral. Direct measures are efforts undertaken specifically to obtain data on a particular response variable. Collateral measures are “piggybacked” onto direct measures. There may be some added effort involved in obtaining the exact data needed, but most of the effort is expended on the “host” measure. For example, suppose the response variable of interest is redd superimposition. If a trip is made just to evaluate this, it is a direct measure. If reds are already being counted anyway, and superimposition is merely noted during the redd counts, it is a collateral measure. The distinction between the two types of measures is important in terms of cost and effort. Collateral data will usually cost very little to collect. Many collateral measures have already been identified. As plan development

proceeds through the analytical and logistical phases, an effort will be made to maximize "collateralization" as a matter of economics.

Monitoring measures in the plan nominally fall into three categories of purpose: 1) *research*, 2) *risk containment*, and 3) *quality control* ("QC") Research measures provide information that will answer the high-level questions, and often provide information that will be useful to supplementation projects elsewhere. Risk containment measures provide information that can be used by the YFP's adaptive management process to adjust operations in order to keep impacts within specified levels. Operationally, the distinction between research and risk containment measures often becomes blurred. This is because the YFP has a dual nature: it is both an experiment and an effort to increase the size of the Upper Yakima spring chinook stock. It would, for example, be an important research finding if monitoring indicated a genetic impact that lowered the fitness of the upper Yakima stock. Such a finding would obviously have equally important implications for risk containment within the YFP. Quality control monitoring is intended to ensure that hatchery and monitoring facility operations meet specifications. Although QC information is collected to ensure research data is accurate and operational risks are reduced, it is often of no scientific interest by itself. Again, however, distinctions between QC and other types of monitoring can also become blurred. There would, for example, be important research and risk containment implications if QC monitoring indicated the adult trap at Roza had a significant impact on adult passage.

In general, no attempt has been made to classify measures in the plan by purpose because of the kind of categorical overlap described above. The only exception is facility QC. These measures have been put into a separate section.

## **Organization and Format**

The document is divided into three sections, as shown below. Sections 1 and 2 are

descriptions of monitoring measures targeting the first and second experimental tiers, respectively. Section 1 is further divided into four sections, each addressing one of the high level questions associated with the primary experimental tier. Section 3 describes quality control monitoring and issues relating to facilities and field operations. For maximum readability and quick reference, intermingling of discussion with the listing of measures is kept to a minimum. The format throughout is one of introduction followed by an outline of measures. The measures are presented in bold, italicized print.

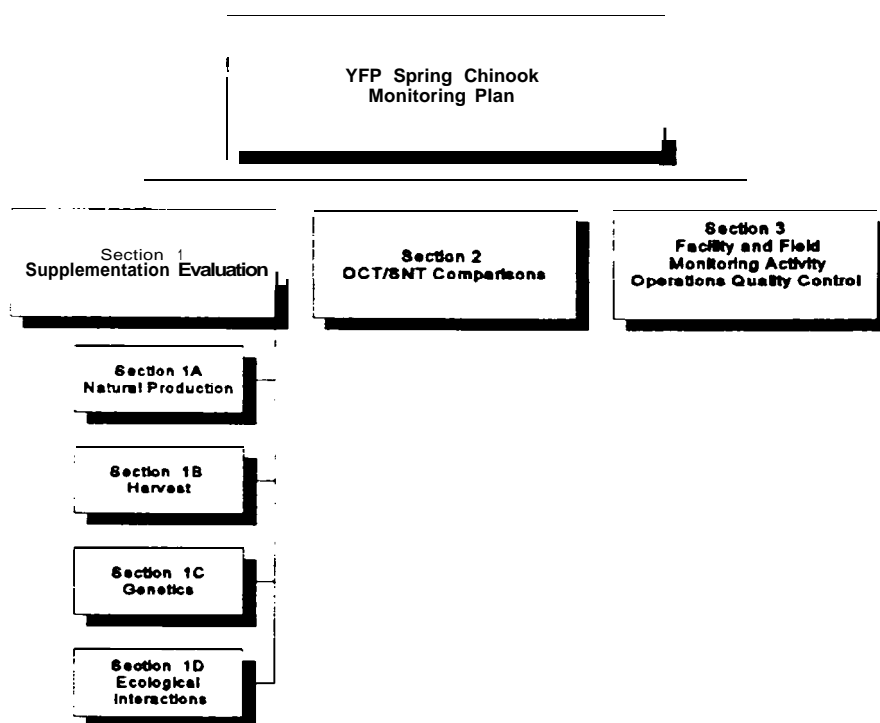


Fig. 1. Overall organization of the YFP spring chinook monitoring plan.

## Uncertainties

The success of YFP monitoring depends largely on five major factors about which considerable uncertainty exists: 1) technology, 2) statistical power, 3) logistics, 4) risk



containment constraints, and 5) cost. Obviously, the factors are interrelated. With enough funding, for example, many other uncertainties become much less significant. Some uncertainties can be cleared up simply by doing statistical power analysis, other will require a substantial research effort, and some will require policy changes. The situation will become considerably clearer in the next year as MIPT works its way through many of these issues. But the work we have completed so far has pointed out several major concerns that have considerable implications for the operational planning of the project. It is important that these concerns be introduced now because many of them require immediate action.

The ability of facilities to operate within specifications is a major source of technological uncertainty. This is a general concern with all the facilities, but is a special concern with some. We have so little knowledge of how well some facilities can be expected to operate that we cannot at this point even write clear specifications (see Facilities, Section 3). Research has to be done before we can gain a clear picture of their operation limitations for monitoring. At least one facility, the Roza juvenile trap, has to be physically modified before it can be used. In addition, for really powerful reproductive success studies, a new facility may have to be built (see Natural Production, Section 1 A). A certification process needs to be developed and implemented for all facilities.

A second major source of technological uncertainty is marking. Because being able to identify returning hatchery adults is very important, this issue warrants detailed discussion at the outset. Currently we plan to mark all hatchery smolts with visible implant jet (VIJ) **marks**<sup>3</sup> that are benignly readable under UV light. We have not planned to mark them in any other way, such as with coded-wire tags (CVVTs).

---

<sup>3</sup> A visible implant jet mark is created by imbedding a fluorescent dye into the integument of a fish's fin using pressurized gas. These marks may be visible either in ambient daylight, or only when illuminated by ultraviolet light.

Although VIJ marks look very promising for use in juveniles, there are still no data on their long-term retention – particularly for the one to three years elapsing between the outmigration of smolts and the return of jacks and **adults**.<sup>4</sup> If the tags are not readable in adults, a different tagging system must be used if our ability to monitor hatchery returns is not to be severely compromised. Even if the VIJ marks are readable in adults, several monitoring measures require identification of hatchery fish through viewing windows, where UV interrogation may not be possible. A thorough analysis of the power obtainable by partial marking and/or “partial interrogation” is needed.

Another major source of technological uncertainty is the power of DNA technology. YFP prefacility research began when DNA technology was much more primitive than it is now. Throughout the substock identification research period, the applicability of DNA technologies to population genetics, specifically the advantage of DNA data over allozyme data, was unclear. The situation has changed considerably. Preliminary results from other populations suggest that there may be enough microsatellite DNA variability in Yakima basin spring chinook populations to allow a variety of intriguing, very powerful monitoring possibilities (detailed in Natural Production [Section 1A], Harvest [Section 1 B], and Genetics [Section 1 C]). In most cases, the key difference between the DNA and allozyme methodologies lies in the fact that DNA sampling is benign, whereas allozyme sampling is usually lethal. What can be accomplished with DNA is unclear at this point. It is imperative that research into microsatellite DNA variability in Yakima basin spring chinook be done as soon as possible’.

Experimental power is also uncertain. The project was sized and designed to meet power specifications for OCT/SNT comparisons. If the survival and sampling rates assumed in earlier analyses (Hoffmann et al. 1994) actually occur, power for detecting

---

<sup>4</sup> Data on readability in adults will be available in Fall 1997 (C. Knudsen, WDFW, per-s. comm.).

<sup>5</sup> **Tiue** collections for DNA analysis were made from Upper Yakima, Naches, and American River spring chinook in 1996. These will be surveyed for DNA microsatellite variability in 1997.

many differences of interest between the two treatments should be adequate (see OCT/SNT comparisons, Section 2). These early analyses did not, however, estimate the power of tests of supplementation success. Therefore, power is in general an open question for all sections of the plan except the OCT/SNT comparisons.

Power can be estimated with simple calculations for many measures, but others require knowledge of precision, bias, and access. This is particularly true of smolt-related measures dependent on Chandler monitoring. Power to assess response variables related to supplementation success should nevertheless be high relative to other supplementation projects in the region for three reasons. First, the project is larger, which should translate to higher sample sizes. Second, the project is not being done with a critically depressed stock. Unlike other projects where supplementation efforts have had to shift to gene banking (e.g., Tucannon, Methow, and Wenatchee spring chinook), this project has a high probability of being carried out as originally envisioned. This continuity will allow replication over time. Third, the project has an impressive, probably unparalleled array of monitoring facilities at its disposal. What can be achieved in bias and precision at some of these facilities may be unclear now, but their existence creates an enormous number of monitoring possibilities.

A source of uncertainty that definitely affects statistical power is the future of other artificial programs in the basin. The number of production/supplementation projects for various species of anadromous salmonid is increasing throughout the mid-Columbia area. The Yakima is no exception to this trend. As more fish are released, and releases are made from new areas, the complexity of monitoring increases dramatically. An increase of juveniles of nontarget species in the basin requires that monitoring efforts be modified or increased in order to attain desired sample sizes of the target species without adversely the nontarget populations. In addition, the opportunity for ecological interactions may increase considerably. To be effective, the spring chinook monitoring effort must consider the sampling and ecological impacts of

all the other artificial production programs in the basin. This issue is dealt with more thoroughly in Ecological Interactions, Section 1 D.

Logistical uncertainty is high for some elements of the plan, particularly Ecological Interactions (Section 1 D). Many monitoring measures aimed at understanding impacts to Nontarget Taxa of Concern (NTTOC) in this section go far beyond anything attempted in the basin before. We truly do not know how well we can measure many of the response variables, especially when they involve species with which we have almost no experience. It is imperative that monitoring efforts on selected NTTOC be started now, both to build a presupplementation database and find out what is actually feasible.

A potentially serious conflict between risk containment and monitoring occurs in Genetics (Section 1C). Probably the most pressing issue in the perceived genetic risks of supplementation is domestication selection. The concern is that domestication selection can reduce the natural fitness of the population being supplemented. This will make the supplementation less effective and reduce the population's ability to sustain itself without supplementation. Although we can test indirectly for domestication selection, results from a direct test will be most compelling. It appears that the most powerful and direct test for domestication selection is to experimentally cross wild and hatchery fish in the hatchery, and monitor the survival and phenotypic characteristics of parents and progeny. This will have to involve essentially the entire production. The use of hatchery fish as broodstock conflicts with the longstanding risk-containment measure of using only wild fish as broodstock. Ironically, this wild-only policy was intended to reduce the risk of domestication. After further technical analysis of the risks entailed by using hatchery fish as broodstock, the YFP Policy Group must decide whether dropping the wild-only policy is warranted.

Another matter that may require policy involvement is the possible intentional

distribution of adult carcasses in the basin. Recent research (Bilby et al. 1996) points out the nutritional importance of carcasses to the ecosystem. MIPT is convinced that to not return carcasses to the river would be a net negative impact to wild spawning fish. We therefore recommend that carcass distribution be included in the project. It is currently being done experimentally in several areas of the state, but is definitely not yet a standard procedure, and implementing it may require policy involvement.

Monitoring costs are an obvious source of uncertainty in this plan. We do not know at present what this monitoring package will cost. A reasonable cost estimate will not be possible until power and logistical analyses have been completed and the opportunities for collateralization are known.

## Section 1. Evaluation of the Spring Chinook Supplementation Effort

The first experimental tier of the YFP spring chinook supplementation effort is evaluation of the supplementation effort in four areas: natural production, harvest, genetic impacts, and ecological interactions. These four areas are dealt with separately in their own subsections, but there are a few important considerations common to the four areas that need to be kept in mind.

### **The YFP as a Test of Supplementation**

The YFP has long been popularized as a project that will “test” supplementation. Accordingly, the first consideration must be the extent to which the measures in this plan actually evaluate supplementation. What usually comes to mind when a scientific test is spoken of is a controlled experiment. The optimal situation for testing the effects of YFP supplementation on harvest opportunities, natural production, genetic impacts, and ecological impacts would be one of replicated treatments, where one treatment is supplementation, and the other is no supplementation. Unfortunately, the experimental situation offered by the YFP supplementation project is far from this optimum. There is no spatial replication, and there is no control. Monitoring the unsupplemented Naches and American River stocks may provide useful correlative data, but these stocks are too different from the Upper Yakima stock in life history traits (e.g., age structure, spawning timing, juvenile migratory pattern) and habitat to serve as controls. The unsupplemented Yakima basin spring chinook stocks are thus considered reference, not control, populations.

The actual overall experimental situation the YFP offers is ‘pre- and post- “(PAP): an uncontrolled comparison of conditions before and after supplementation begins. This approach is considerably less robust than the controlled experimental approach. In a properly conducted controlled experiment, the difference in outcomes can be

unambiguously attributed to the treatments used. In contrast, in a PAP test the researcher only knows that a change has occurred. To attribute even a highly significant change to supplementation convincingly, background changes in environmental conditions have to be ruled out as a possible cause. Certainly the more changes that occur in the expected direction, the stronger is the case for supplementation being the cause. However, environmental change is almost impossible to rule out, especially with our limited ability to measure it and our limited knowledge of the interrelationships between environmental factors.

## Criteria for Success

Regardless of the exact experimental situation, a test requires some criteria by which success or failure is judged. Regionally, there is likely to be much more interest in whether supplementation is a “success” in the Yakima than in a detailed breakdown of the effects of supplementation. At this point, what constitutes YFP success has only partially been worked out for any of the four subject areas. Natural production and harvest objectives were developed in a 1993 modeling **effort**<sup>6</sup>, but these analyses did not include environmental stochasticity nor an analysis of the time required to reach objective levels. MIPT has begun work on a new stochastic supplementation model (working name YAKSIM) that can be used to identify the conditions that define success and the point in time when success has been achieved (see Section 1A). Genetic conservation objectives also have not yet been developed for the project, as there presently is no generally accepted understanding of how much genetic impact is acceptable. At this point, provisional objectives have been established only for ecological interactions involving nontarget taxa of concern (**NTTOC**)<sup>7</sup>. MIPT will develop explicit objectives in the other areas as the monitoring plan is refined.

---

<sup>6</sup> Using the RASP spreadsheet model (Lestelle et al. 1994), an early version of the Ecosystems Diagnosis and Treatment model of Lestelle et al. 1996.

<sup>7</sup> These objectives have not yet been formally adopted by the YFP Policy Group.

## Time Required for Evaluation

A fundamental problem with testing supplementation, regardless of whether it is done by controlled experiment or by PAP comparisons, is that many years are usually required before significant changes in population abundance can be detected. This is so because large, environmentally-induced fluctuations in survival may obscure the true effects of any measure impacting abundance. A good example is the evaluation of whether supplementation is increasing natural production. MIPT concluded (see introduction to Section 1A) that even a fairly successful project will take at least nine years before an increase in natural origin recruits attributable to supplementation will even be possible, and that an additional one to two decades would be needed before project effects could be distinguished from environmental fluctuation (see Introduction and Lichatowich and Cramer 1979). Since recruitment and harvest are intimately linked, it will take the same length of time to prove that the project has increased harvest. The situation is similar for ecological interactions; impacts to NTTOC may take some time to develop and will be confounded with environmental and anthropogenic factors. Genetic change may be an exception. Strong single-generation effects of domestication selection have been demonstrated (Reisenbichler and McIntyre 1977).

Because of the long time required to detect statistically significant change at key "success" variables, the monitoring measures in this section emphasize short-term measures of the "mechanics" of supplementation. This is presented in detail in Section 1A. Briefly, for change attributable to supplementation to occur, be it an increase in natural production, a displacement of a nontarget taxon, or a genetic impact due to domestication selection, there are conditions that can be monitored on a short-term basis to give an indication of the "trajectory" the project is on with respect to those large scale effects.



## **Prognosis for Successful Monitoring**

Bear in mind that all this sobering discussion probably applies equally well to all other supplementation efforts and to enhancement projects generally. The YFP is no more limited in evaluation of supplementation than any other project, and in fact has two substantial advantages over other projects. First, the stock is fairly large and stable. This means sample sizes will be large relative to what they would be for smaller stocks. It also means the project is likely to proceed as planned without risk of serious modification for stock rescue, such as being converted to a captive brood program. Recently several other supplementation efforts in the region have had to change their operations in various ways in response to a precipitous decline in stock abundance. The second major advantage of the project is the monitoring facilities for adults and juveniles that exist in the basin. Although we have concerns about the precision and bias of data we may obtain from them, having facilities to have concerns about is a luxury.

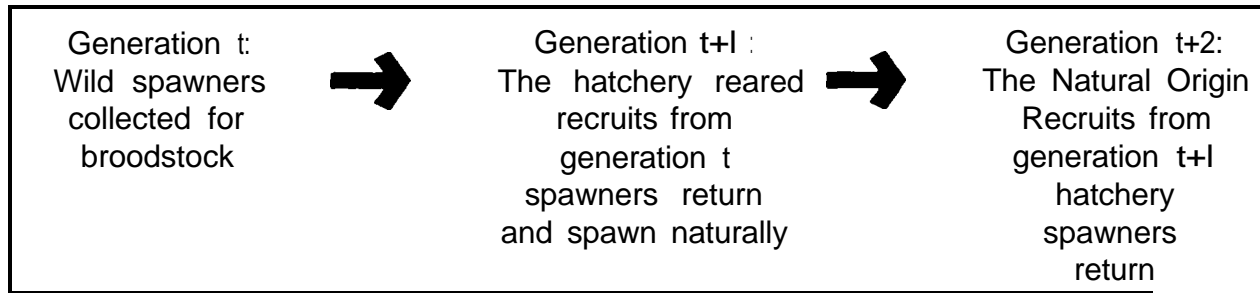
## Section IA. Natural Production

### Basic Concepts

Developing a conceptual framework for natural production monitoring was one of the most challenging tasks MIPT faced in developing the monitoring plan. Following the train of thought MIPT went through to arrive at the measures is critical to understanding the approach we have taken, and to understanding why it departs from some ideas proposed in the past. Therefore a large part of the introduction to this section is an explanation of the four key notions concerning natural production monitoring that MIPT developed.

#### **1. The appropriate response variable for supplementation success in natural production is the number of *Natural Origin Recruits* (NOR).**

This is a very important point and possibly not an obvious one. A traditional hatchery is intended only to provide fish for harvest. All that is required of the hatchery program is that it return harvestable adults. In contrast, a supplementation program is intended to increase natural production. Not only does it have to return adults, but these adults must be capable of successful reproduction in the wild. Although many decades of salmon culture have firmly established the ability of hatcheries to return adults to the fishery or spawning grounds, the record on reproductive capability of these adults is much less complete. Moreover, what is known suggests that adults of hatchery origin may have lower fitness on the spawning ground than their wild counterparts (e.g., Chilcote et al. 1986; Leider et al. 1990; Fleming and Gross 1992, 1993). Thus, the success of the YFP spring chinook program can be judged only by the return of the adult progeny of these naturally spawning hatchery fish, as diagramed below:



**2. Detecting a statistically significant increase in Natural Origin Recruits resulting from supplementation may take many years.**

As the diagram above illustrates, it takes two generations for adults taken into the hatchery to produce NOR. What this means in practical terms in supplementing the Upper Yakima stock, which has a 4-year generation time, is that if broodstock collection is begun in year 1, no YFP-induced increase in NOR can occur (besides a few age-3 males) until year 9. The actual increase in NOR depends on the survival rate of the hatchery fish, their reproductive quality (in terms of adult behavior, gamete quality, egg hatchability, etc.), and on variability in survival rates.

Variability in survival rates due to changing environmental conditions is often not appreciated in projecting production gains expected from supplementation. Indeed, Lichatowich and Cramer (1979) demonstrated that the variability of abundance of spring chinook in the Willamette, Rogue and Umpqua Rivers was so large that it would take 20-30 years before a 50% increase in productivity could be detected with 80% probability. It is significant that the variability of Yakima spring chinook abundance exceeds these Oregon rivers. It is, therefore, abundantly clear that the progress of the YFP cannot be tracked solely at the level of number of returning adults.

MIPT has begun work on a new stochastic supplementation model (working name YAKSIM) that can be used to develop clearer expectations of “success” levels for natural production and harvest. Using YAKSIM, we have demonstrated the effect of survival rate variability on NOR in Figs. 2a-b. Fig. 2a shows the results of one run of YAKSIM simulating a population with spawner-recruit dynamics similar to the

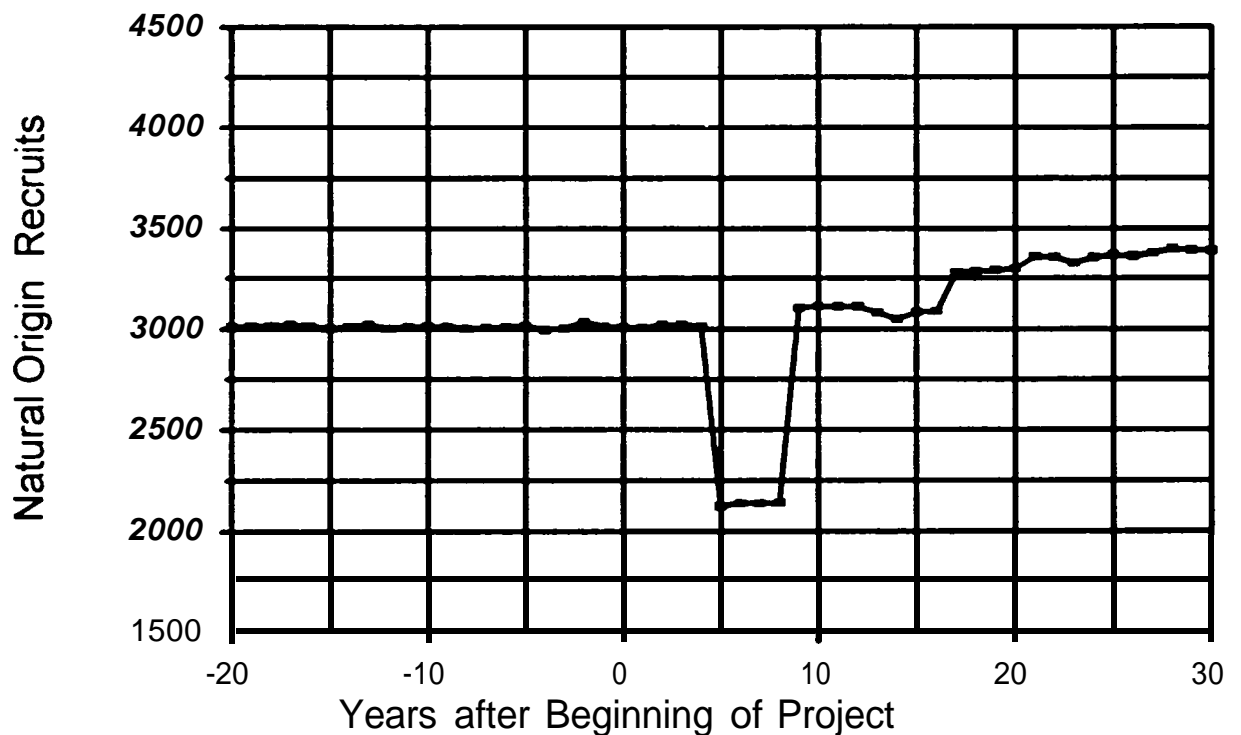


Fig. 2a. Natural origin recruits over time in a YFP-like supplementation program with hatchery smolt-adult survival of 0.002 and log-normal survival rate variation of 0.0001.

Upper Yakima stock<sup>8</sup>. The simulated stock had a generation length of four years, like the Upper Yakima stock. Under the conditions modeled, the equilibrium number of natural origin natural spawners is about 3000. The harvest rate was set to 20%, hatchery capacity to 1200 fish, a relatively low level of log-normal variation in survival of 0.0001, and YFP broodstock rules<sup>9</sup> were in place. The NOR level drops to about

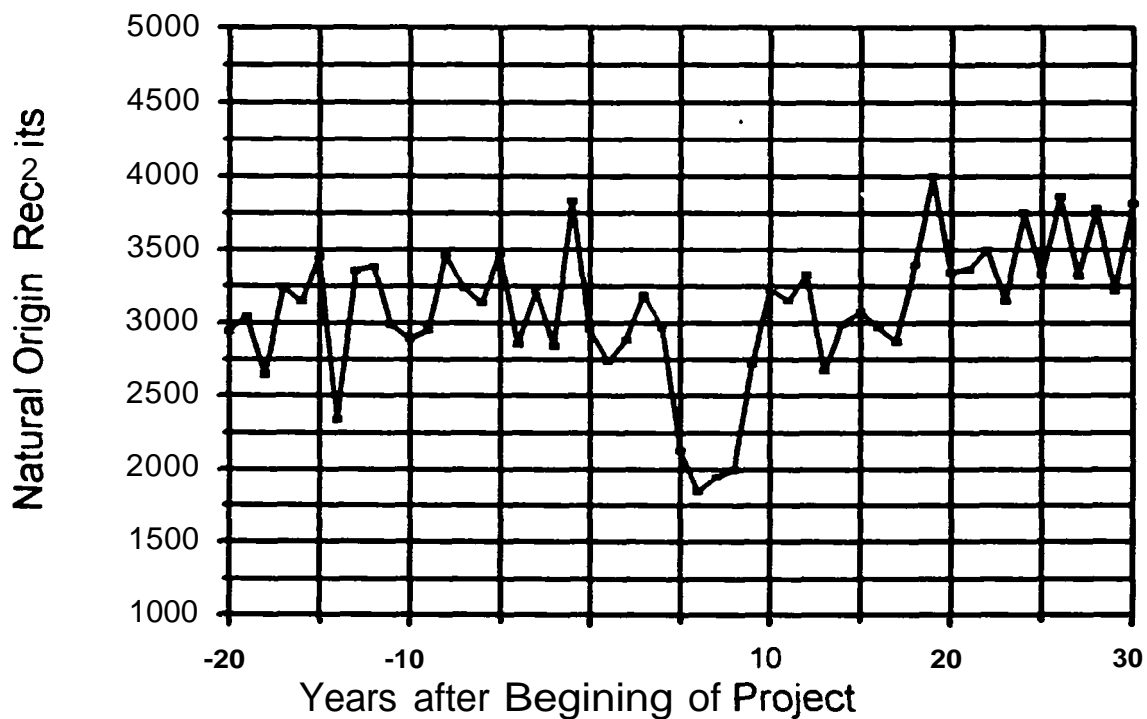


Fig. 2b. Natural origin recruits over time in a YFP-like supplementation program with hatchery smolt-adult survival of 0.002 and log-normal survival rate variation of 0.01.

---

<sup>8</sup> This modeling is not based on a rigorous calibration exercise, so should be regarded as a demonstration only, not a predicted outcome.

<sup>9</sup> Wild only broodstock, no more than 50% of the wild escapement can be taken for broodstock, and no broodstock will be taken if it will drop the natural escapement below 100 fish.

2000 in year 4, the second generation of the operation, as a result of the removal without replacement of natural spawners from the population. This deficit is made up starting in year 9, when the wild progeny of hatchery spawners begin returning, and from that point onward the NOR level continues to increase. The success of supplementation is clear in this example: from year 9 (the beginning of the third generation) onward, the NOR level is higher than before the project began.

Fig. 2b displays the results of a YAKSIM run using the same conditions as in Fig. 2a, but log-normal survival variation has been increased to 0.01. The same basic pattern holds that was seen in Fig. 2a, but the variability makes the increase in NOR more difficult to see. Detecting a statistically significant increase in NOR or a statistically significant positive trend would be unlikely over the period modeled in this example. It is important to recognize that all the parameter values modeled are quite reasonable; the survival rate variability is in fact quite modest. Such a pattern would not be unexpected in the YFP spring chinook supplementation effort. The messages from Figures 2a and b are clear: 1) an increase in NOR due to supplementation will not occur until the third generation of hatchery operations, and 2) variability in adult returns due to survival rate fluctuation may make detecting any significant positive or negative trend in NOR over a short time frame impossible.

### **3. Because of the time required to detect trends in NOR, monitoring measures should focus primarily on short term evaluation of supplementation mechanics.**

It may take many years for a supplementation program to show conclusively that it has resulted in an increase in NOR, but the mechanics of supplementation must be operating correctly during those years for the increase to occur. These supplementation mechanics can be monitored on short time scales. Monitoring them will yield critical information about supplementation that will be exportable to other projects, as well as provide information that can be used to fine tune the YFP supplementation program. A comprehensive mechanistic breakdown of

supplementation is far beyond the scope of this document. However, the following simplified discussion will illustrate the general approach MIPT used in developing monitoring measures for natural production”.

Assume there are  $N$  adult spawners that can either be left in the wild, or used as broodstock in a supplementation program. Our hope would be that if we use them as broodstock, they will end up producing more Natural Origin Recruits than they would have if we had left them in the wild. As was demonstrated earlier, this is a two-generation step. Now let  $R$  represent the recruitment rate, the rate at which spawners result in adult progeny. Assume for the moment there is no harvest, If  $R = 1$ , for example, each spawner returns (on average) one adult progeny, so this is the replacement or break-even situation. Spawners in different situations can be expected to have different  $R$  values, depending on 1) their rearing environment, 2) their reproductive quality and 3) the rearing environment of their progeny. Let  $R_{ij}$  be the recruitment rate of spawners reared in environment  $i$  and spawning in environment  $j$ , let  $w$  represent the natural environment and  $h$  the hatchery environment. Now we can rewrite the flow chart above with some quantification, comparing the results of leaving the  $N$  fish in the wild with taking them as broodstock:

Scenario	Generation $t$ Adults		Generation $t+1$ Adults		Generation $t+2$ Adults
Let fish spawn naturally	$N$	$\rightarrow$	$NR_{ww}$	$\rightarrow$	$NR_{ww}R_{ww}$
Use fish as broodstock	$N$	$\rightarrow$	$NR_{wh}$	$\rightarrow$	$NR_{wh}R_{hw}$

---

<sup>10</sup> MIPT is working on a comprehensive mathematical treatment of supplementation mechanics that will include temporal variation in harvest, broodstock collection, and recruitment rates. This model will be used to refine the monitoring plan.

Our objective would be to have more NOR production from the fish if they were taken into the hatchery than if they were left to spawn in the wild, so we would consider supplementation successful in this simple situation if:

$$NR_{wh}R_{hw} > NR_{ww}R_{ww}$$

We can further simplify this relationship by dividing both sides by **N** to yield an equation that expresses supplementation success solely in terms of these recruitment rates:

$$R_{wh}R_{hw} > R_{ww}R_{ww}$$

The key thing to notice about this relationship is that it is the product of the recruitment rates that is important, not the absolute value of the recruitment rates themselves. Although our intent would be to maximize both  $R_{wh}$  and  $R_{hw}$ , a very high  $R_{wh}$  can compensate for a low  $R_{hw}$ , and vice versa (within reasonable biological constraints, of course).

All three recruitment rates can be broken down into two basic factors, reproductive success of adults and survival of progeny, and these in turn can be broken down into many component rates and measures, on as fine a scale as is manageable for



**Table 1. Components of Recruitment Rates  $R_{\text{yfp}}$ ,  $R_{\text{m}}$ , and  $R_{\text{w}}$  considered in the YFP spring chinook monitoring plan.**

Adult Performance- Reproductive Success		
	Demographic Factors	
		Sex ratio
		Fecundity
	Prespawning survival	
		Maturation schedule (including precocialism rates)
		Fertility
		Egg-fry survival
	Behavioral Factors - Spawning Efficiency	
		Migration and spawning timing
		Homing
		Redd construction (e.g. site selection/habitat utilization, nest number and depth)
		Site selection/habitat utilization
		Intra- and intersexual spawning behavior (e.g., competition, redd construction, mate selection)
Juvenile Performance- Survival		
	Survival Rates	
		Fry-smolt survival
		Smolt-smolt survival
		Smolt-adult survival
		Winter migrant survival rates
	Traits Related to Survival	
	Predation loss	
	Residualism	
		Smolt physiology
		Smolt morphology
		Developmental profiles
		Behavioral profiles

monitoring. Table 1 presents the basic components of reproductive success and juvenile survival dealt with in this monitoring plan. Note that in both cases the components are a blend of factors directly related to the recruitment rates, such as fecundity, and important but less directly related factors such as spawning behavior. These less directly related factors are key components of the more direct ones. Perhaps the most important thing to notice about the factors listed in the table is that there is a fairly equal balance between monitoring juveniles and adults. In past discussions of YFP monitoring, thought has been given to monitoring either only juveniles or only adults. The performance of supplementation can be evaluated in a way that allows us to fully learn from it only if both adults and juveniles are monitored.

**4. In attempting to evaluate supplementation success in natural production, there are actually two types of success: mechanical supplementation success and project success.**

Supplementation can be working properly in mechanical terms and still not result in increased natural production if mortality increases due to poor environmental conditions or harvest beyond sustainable levels. This possibility is more than speculation. Recently poor ocean conditions have greatly depressed spring chinook runs in the mid-Columbia and Snake systems, and this may make it very difficult to evaluate the natural production contribution of several supplementation projects in these areas. Similarly, positive changes in external conditions can cause an increase in natural production even though the supplementation effort is not functioning properly. These two situations may seem extreme, but one needs only to refer to Fig. 2b to see how easily a counter indication of supplementation success can arise. In the YAKSIM run that resulted in this figure, supplementation was working correctly in mechanical terms, but a modest fluctuation of hatchery and wild survival rates caused substantial fluctuations in NOR. At times it appears the project is performing poorly, and at other times it appears to be performing spectacularly.

*If we are to learn from supplementation or determine its success or failure correctly, we must be able to discriminate between the intrinsic and extrinsic factors influencing the project.* By intrinsic factors we mean all aspects of the project directly under control of YFP personnel: the biological and physical environment provided by the hatchery and associated fish culture and monitoring facilities (see Section 3). In contrast, extrinsic factors are factors influencing recruitment rates that are not under YFP control: the biological and physical environment outside the hatchery and associated facilities. The monitoring measures in this section are organized around the intrinsic-extrinsic dichotomy, as shown in Fig. 3.

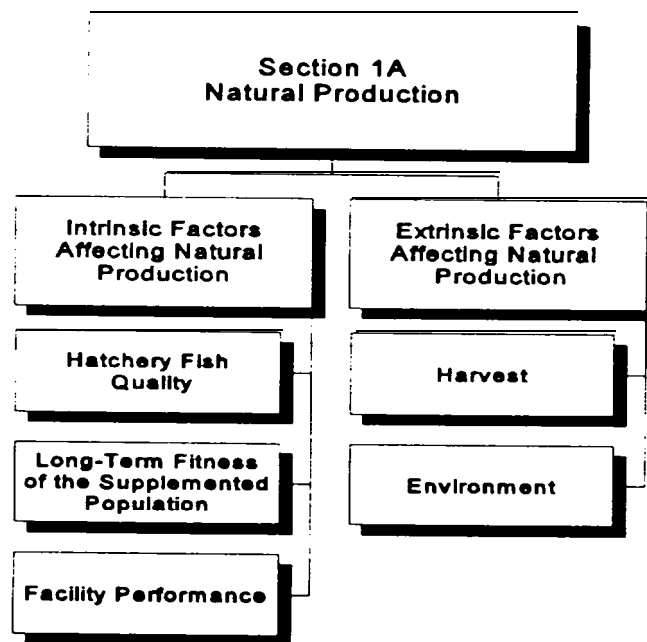


Fig. 3. Organization of Section 1A of the YFP spring chinook monitoring plan.

### **Intrinsic Factors Affecting Natural Production**

Monitoring measures dealing with intrinsic factors fall into three main groups: hatchery

fish quality, long term fitness of the supplemented population, and facility performance:

### **Hatchery Fish Quality**

Measures dealing with hatchery fish quality are further divided into two subsections corresponding to  $R_{wh}$  and  $R_{hw}$ , one dealing with juvenile quality and survival, and one dealing with adult reproductive success. The monitoring measures for juveniles deal basically with the recruitment rate components listed in Table 1, but most of them will be done as simultaneous comparisons of wild and hatchery fish to control for environmental variability. An important element of hatchery fish quality monitoring is consideration of residuals and precocials.

Residuals are fish that do not migrate during the normal migration period, whereas precocials do not migrate but also participate in spawning<sup>11</sup>. Precocials are invariably males. Many authors have documented the occurrence of precociously maturing spring chinook salmon (Robertson 1957, Gebhards 1960, Flain 1970, Taylor 1989, Mullan et al. 1992, Bernier et al. 1993). Frequencies of precocialism generally range from 0-29% of the population, but 1-10% seems most common (Mullan et al. 1992). Precocial males have been observed on the spawning grounds with anadromous females (Gebhards 1960). High incidences of precocialism may skew sex ratios of anadromous adults (by precocial “dropout”), decrease survival of hatchery fish (again, by dropout), and increase interactions with wild fish (Mullan et al. 1992). Recent observations in the Upper Yakima (T. Pearsons, WDFW, pers. comm.) suggest that precocial fish may constitute a small but significant part of the natural spawning population.

Hatcheries have the potential to significantly alter the abundance of residuals and precociously maturing spring chinook parr (Mullan et al. 1992). Even low frequencies of precocial chinook salmon in a hatchery release may be high relative to the number of

---

<sup>11</sup> Thus, a residual fish that matures precocially but does not survive to participate in spawning would not be considered precocial.

wild anadromous males. For example, if 2% of the planned YFP release of 810,000 spring chinook salmon are precocial males, then 8,100 are potentially available to spawn with wild anadromous females. This is approximately five times the number of wild anadromous males (e.g., 1500) that might return to spawn during an average year. However, during years of low escapements (e.g., 150 males) precocial males may outnumber anadromous males by more than 50 to one.

A unique element of the YFP monitoring plan is the attempt to assess reproductive success of individual spawners directly, by DNA fingerprinting adults and determining the parentage of their progeny (e.g., Colburne et al. 1996, Olsen et al. 1996). We propose three possible levels at which this could be done: micro, **meso**, and macro. The micro level will evaluate small numbers of fish in a semi-natural stream arena. A portion of the slough at Cle Elum hatchery could be used for work similar to Berejikian et al. (In press). Alternatively, test enclosures such as those being used by NMFS and WDFW at Manchester, WA, could be used. The **meso** level will deal with larger numbers of fish in a restricted-entry stream reach. Success of this method obviously requires existence of such a stream reach. Currently we know of no reaches that are clearly suitable for **meso-level** experiments, although the Yakima river between **Easton** and Keechelus dams appears promising. The macro level method entails fingerprinting the entire Upper Yakima spawning population and estimating the smolt production of the entire basin by pedigree at Chandler two years later. This may seem ambitious but it may be entirely feasible if the current rate of development in DNA **microsatellite** technology continues. The critical limitation to the macro approach could be the necessity to genotype all spawners. If untyped precocial males make up a significant portion of the spawning population, then experimental power to estimate male contribution and performance may be compromised. The micro approach is feasible today. The progeny of individual spawning coho have been monitored by DNA **microsatellites** in test arenas at Manchester and Lilliwaup (L. Park, NMFS, pers. **comm.**). The only theoretical limitation to the number of parents whose progeny can be

enumerated by DNA pedigreeing is the amount of detectable DNA variability. **MIPT** intends to evaluate the DNA variability of upper Yakima spring chinook in 1997 with 1996 fin-clip samples. With this information, we can more accurately address the relative feasibility of the three approaches<sup>12</sup>.

### **Long-Term Fitness of the Supplemented Population**

Up to this point supplementation mechanics have been presented solely in terms of demographic factors. There are, of course, essential genetic considerations. Perhaps the most critical genetic issue is the degree to which supplementation can avoid domestication selection. Data are sparse but there are indications (Reisenbichler and McIntyre 1977, Chilcote et al. 1986, Leider et al. 1990, Mendel et al. 1993) that reduced fitness attributable to domestication may limit the success of supplementation projects. In the extreme theoretical case, the stock may have its fitness reduced to the point where it is dependent on the hatchery (Busack and Currrens 1995, Reisenbichler 1997). It is therefore essential that domestication selection be monitored. Section 1 C presents the measures we have developed to assess this phenomenon.

### **Facility Performance**

The final type of intrinsic monitoring measure deals with the hatchery and associated acclimation and monitoring facilities. Obviously, these facilities have a major impact on fish quality. They must therefore be monitored to determine their impact on the survival and reproductive success of the naturally spawning population (all facilities) and to ensure that they meet biospecifications (hatchery and acclimation facilities). Measures for monitoring facilities are presented in Section 3.

---

<sup>12</sup> If DNA microsatellite marker variability is high, this technology can potentially be used in several other areas of monitoring. For example, it could totally replace allozyme electrophoresis as a method of determining substock composition in harvest sampling or juvenile passage.

## **Extrinsic Factors Affecting Natural Production**

Measures dealing with extrinsic factors fall into two major categories: harvest and environment. A major objective of the YFP is increased harvest opportunity, but there is a risk of over harvesting once returns begin to rise (or appear to rise) as a result of the supplementation. Harvest rates influence the rate of increase of natural production because they reduce spawning escapements directly. At extreme harvest rates, where the harvest exceeds the added production attributable to supplementation, NOR will decline rather than increase. Measures for monitoring harvest are detailed in Section 1B.

Environmental monitoring includes measures that focus on conditions that occur both inside and outside the Yakima **Subbasin** (“local” and “nonlocal” conditions respectively). The nonlocal environment is obviously very important to the survival of Upper Yakima spring chinook, but direct monitoring outside the basin is clearly outside the **scope** and logistical capabilities of the YFP. Nonlocal conditions will be “monitored” by using other monitoring efforts specifically targeting the Columbia River and ocean environments.

Local environmental monitoring will address both productivity and carrying capacity, which together determine recruitment rates and the ultimate abundance of a naturally spawning population.

### **Impact of Environmental Fluctuations on Productivity**

There are three objectives to productivity monitoring under the YFP spring chinook program:

1. To assess the true impact of supplementation on productivities of upper Yakima cohorts in pre- and post-supplemented eras and between years by adjusting for differences in productivity that can be attributed to environmental fluctuation.

2. To assess the productivities of Naches and American River cohorts as described above. Estimating stock-specific environmental impacts on productivity is necessary to: a) make Naches and American stocks useable as unsupplemented reference populations for the upper Yakima stock, and b) make it possible to determine whether environment- or supplementation-related factors are primarily responsible for changes in the productivity of Naches and American River spring chinook.
3. To guide future efforts to protect and enhance habitat critical to major life history types within all stocks and/or to restore vestigial life history types.

The logistical impossibility of directly monitoring environmental impacts outside the Yakima has led us to concentrate on local conditions. Locally the influence of biotic and abiotic factors on productivity is most clearly and completely expressed as smolts per returning female adult. In this section of the monitoring plan we address only abiotic factors. Biotic factors (e.g., interspecific competition and predation, disease, etc.) are dealt with in Section 1 D (Ecological Interactions). This separation of monitoring measures for biotic and abiotic factors is made only for purposes of organizational clarity and readability. While actually monitoring the project, it will be necessary to integrate the data on biotic and abiotic factors.

### *General Approach*

We define productivity as *density-independent survival*. Productivity may be measured across any series of life stages, from egg-to-fry to the ultimate measure, adult recruitment rate (adult returns to the Yakima per female spawner). In the absence of any change in reproductive potential (viable gametes per spawner), the productivity of a population is determined by *environmental quality*. Carrying capacity, in contrast, is determined by a combination of environmental quality and (especially) environmental *quantity*. These two parameters – productivity and carrying capacity – totally determine production and define the mathematical production function for the stock.



As stated above, productivity is also affected by the reproductive potential of the stock. More specifically, any measure of productivity that spans generations (e.g., adult recruitment, smolts per spawner) will be affected by reproductive potential. We define reproductive potential as the mean number of eggs per female spawner. A change in sex ratio, female age at maturity, fecundity at size, or viability of gametes in either sex would obviously change the progeny/parent ratio independently of environmental factors.

Interannual fluctuations in the natural productivity of all stocks of Yakima spring chinook will be monitored by tracking correlations between productivity and a suite of environmental and reproductive variables. Productivity will be assessed over three distinct portions of the life cycle: pre-spawner to smolt (as smolts per female spawner or “gross smolt production rate”), egg to smolt (egg-to-smolt survival), and adult to adult (adult returns per female spawner). It is important to note that empirical estimates of survival are possible for all three of these portions of the life cycle. Abiotic variables have been chosen by dissecting the inbasin life history into ecologically distinct life stages, and listing the abiotic factors known to affect survival at the specific times and places in which each life stage occurs. Candidate factors were listed for each of the two known life history types of Yakima spring chinook: the “upriver smolt” type, which rears continuously in the upper basin until smolting; and the “winter migrant” type, which moves to the lower Yakima the winter before smolting. This compilation of data points – pairs of environmental observations and productivity estimates, sets of observations of environmental factors, indices of reproductive success and empirical estimates of productivity – will include all historical, pre-supplemented years for which data exists (brood years 1981-1998) as well as post-supplementation years. Those variables with the greatest impact on productivity will be identified by these correlations.

In time, an increasingly refined description will be developed relating productivity and

environmental/reproductive variables. This relationship will probably take the form of a multiple regression of both abiotic and biotic factors related to productivity. We can then compare observed productivities in pre- and post-supplemented eras (or between arbitrarily defined eras) free of the confounding effect of fluctuations in environmental and reproductive factors. For example, productivity in the pre- and post-supplementation eras could be compared by an analysis of variance of annual productivity estimate residuals (observed productivity minus productivity predicted by the environmental/reproductive multiple regression).

Detecting impacts on specific life stages requires investigation of correlations between environmental factors that occur at times and in places where fish of the life stage in question reside. Factors suspected of affecting pre-spawning survival in the Yakima should be correlated with gross smolt production; factors suspected of affecting all subsequent life stages (incubation, egg-to-fry, fry-to-Parr, par-r-to-smolt and outmigrating smolt) should be correlated with egg-to-smolt survival, for two reasons. First, it is most important to track *net* inbasin productivity, the survival from pre-spawner or egg-to-smolt entering the Columbia. Density-independent decreases in survival for any pre-smolt life stage are important only insofar as they are not compensated for by increased *density-dependent* survival in a subsequent life stage (and *vice versa*). Second, factors affecting the survival of adults before spawning (with sufficient intensity to impact net inbasin productivity) will be reflected in the gross smolt production rate (GSPR)<sup>13</sup>, but not in egg-to-smolt survival because those eggs are not actually deposited. Factors affecting net productivity via impacts on life stages from incubation through smolt will be most clearly reflected by changes in egg-to-smolt survival. In

---

<sup>13</sup> Gross smolt production rate (GSPR) for brood year *i* is explicitly defined by the following equation:

$$GSPR_i = \frac{(smolts)_{i+2}}{(Returns - Yakima Harvest)_i}$$

summary, we must monitor the determinants of net productivity. Given the available monitoring facilities (see Section 3), we propose to monitor three measures of net productivity: adult recruitment rate, egg-smolt survival, and smolts per spawner (GSPR).

### *Disaggregating Survival*

Identifying the determinants of productivity entails estimating the degree of correlation between specific measures of environmental quality and density-independent survival. Unfortunately, density-independent survival is not easily measured in natural systems because total mortality always includes a density-dependent component.

The density-independent component of gross smolt production, egg-to-smolt survival or adult recruitment rate can be disaggregated from the density-dependent component if a production function is fitted to the appropriate series of life stages (Moussali and Hilborn 1986). Survival through any series of life stages is the product of **density-independent** and density-dependent elements. If, for example, all density-dependent life stages are described by a Beverton-Holt (B-H) relationship, composite survival across a series of density-dependent and density-independent life stages will also be a Beverton-Holt **relationship**<sup>14</sup> (Mousalli and Hillborn 1986).

To get at productivity, the density-independent component of survival from one life stage to another must be estimated from an empirical survival estimate (which is the product of both density-independent and density-dependent elements). This can be done with a standard Beverton-Holt production function. Suppose we want to estimate egg-to-smolt survival. Let  $K$  and  $s_0$  be estimates of the carrying capacity and maximum possible egg-to-smolt survival, respectively, let  $survival_j$  be an empirical estimate of egg-to-smolt survival for brood year  $j$ , and  $S_j$  be the estimated egg deposition for brood

---

<sup>14</sup> Similarly, composite survival for series of density-independent and Ricker-type density-dependent life stages would also be described by a Ricker relationship.

year  $j$ . Then the density-independent component of survival ( $S_{d,i,j}$ ) will be given by:

$$S_{d,i,j} = survival, \left( 1 + \frac{S_j s_0}{K} \right) \quad (1)$$

Derivation of equation 1 is presented in the Appendix.

in equation 1, estimates of  $K$  and  $s_0$  will come from empirical stock specific Beverton-Holt production functions incorporating lognormal error (Hilborn and Walters 1992). In the specific case of egg-to-smolt survival, the function will be generated using all existing brood-year specific data on egg deposition and resulting smolt production. Stock-specific production functions for adult recruitment and gross smolt production can be generated in the same way from both historical and future **data**<sup>15</sup>. Such estimates tend to be quite imprecise, but will become more refined over time, as more years of data become available, and as more specific monitoring is done. This is especially true of estimates of carrying **capacity**<sup>16</sup>. Refinement of estimates of carrying capacity is the second major objective of extrinsic factor monitoring, and is discussed in the next section.

### Impacts of Limited Carrying Capacity

Even if YFP supplementation were perfect – producing smolts and adults identical to wild fish in every way – the project could fail if existing production actually represented the carrying capacity of the Yakima basin. It is therefore necessary to discriminate between overcrowding and a flawed supplementation program in the event natural production does not increase as intended.

---

<sup>15</sup> Historical estimates of adult recruitment are already explicitly stock-specific, and stock-specific production functions for gross smolt production and egg-to-smolt survival can be derived from the adult relationships. Future estimates (from 1998 on) of smolt production will be explicitly stock-specific.

<sup>16</sup> Especially if escapements are allowed to vary over the entire range of the stock recruitment relationship, especially in the upper "over-escapement" range (Hilborn and Walters 1992)

Unfortunately, carrying capacity is an extremely difficult parameter to estimate. Given relatively constant environmental conditions, moderate levels of exploitation, a long record of escapements, a wide size range of escapements, and a homogenous stock with a single life history type, carrying capacity can arguably be estimated by a straightforward, one-dimensional stock-recruitment analysis". Virtually none of these conditions exist in the Yakima. Environmental quality is subject to both substantial interannual variability and long term trends, exploitation rates (of adults, smolts or both) have been high throughout the period of record, the range of escapements is narrow, especially when compared with any existing estimate of historical production", and each genetic stock of Yakima spring chinook is composed of two or three life history types of different productivity. Therefore we reject the notion that one-dimensional stock-recruitment analysis can yield a meaningful estimate of carrying capacity, and that downward trends in productivity can be explained by simply comparing abundance to such estimates. Our approach to monitoring the impact of "density-dependent constraints" on natural production must be both indirect and multidimensional.

### *Indirect Monitoring*

As explained below, it will take some time before a meaningful estimate of the carrying capacity of the Basin for upper Yakima spring chinook can be generated. In the meantime, we propose to monitor carrying capacity effects indirectly by tracking the specific impacts expected of a population subjected to intense density-dependent pressures.

---

<sup>17</sup> Calculated by these methods, mean carrying capacity would be the asymptote of the Beverton-Holt recruitment curve or the intersection of the recruitment curve and the replacement line for the Ricker recruitment curve. The use of fitted recruitment curves in managing specific salmon populations is, however, exceedingly risky. An excellent summary of the pitfalls and risks may be found in Chapter 7 of (Hillborn and Walters 1992). A description of the difficulty of developing any meaningful estimate of carrying capacity is found in Neitzel and Johnson (1996).

<sup>18</sup> Estimates of the historical production of spring chinook in the Yakima River range from 76,000 combined spring and fall chinook (Kreeger and McNeil 1993) to 200,000 (Fast et al. 1991). The average spring chinook return over the past 16 years is 3,630 (Yakama Indian Nation adult monitoring data).

Given the restricted distributions of spawning areas in the upper Yakima and the likelihood of compensatory adjustments at later life stages, our “indices” of carrying capacity constraint (crowding) will emphasize early freshwater life stages, especially spawning and incubation, and the parr life stages.

Overcrowding (approaching or exceeding carrying capacity) will most clearly reveal itself as a decline in egg-to-smolt survival or gross smolt production rate (smolts per female spawner; see section above on productivity) with increasing population size. Measures taken over a shorter period (e.g., egg-to-Parr survival) ignore subsequent compensation and might overestimate the net impact on smolt production. Focusing on adult recruitment obscures the essential inbasin relationship by including a host of density-independent and possibly density-dependent mainstem and oceanic factors.

Useful indices of crowding should be significantly correlated with estimated egg deposition and either not correlated or weakly correlated with appropriate abiotic factors. We will consider it probable that a decline in egg-to-smolt survival or gross smolt production rate was caused by overtaxed carrying capacity when:

- brood year egg deposition was significantly higher than average
- good indices suggest density-dependent impacts
- the depression cannot equally well be explained by established relationships between productivity and environmental conditions or by reduced viability associated with demographic or genetic degradation (see Genetics, Section 1C)

Our provisional list of carrying capacity indices is as follows:

- 1) Length, weight and condition factor of early Parr. If egg deposition and subsequent fry and parr production approached or exceeded carrying capacity in

the upper Yakima, the size and condition factor of early (July and August) parr should be depressed. The converse is also true: one would expect a significant increase in size and condition factor when escapements are unusually small relative to the current average". This will require adjusting for annual changes in the mean size of spawning females because egg and fry size (Foerester and Pritchard 1941, Fleming and Gross 1990, Fleming 1996, Ojanguren et al. 1996) and survival (Bagenal 1969, van den Berghe and Gross 1984) are positively correlated with the size of the spawning female. Length, weight and condition factor of smolts will also be monitored, although high mortalities at early life stages and subsequent growth compensation may blur a densitydependent relationship.

- 2) Mean gut fullness of early parr. Densities of spring chinook juveniles at or exceeding carrying capacity ("excessive densities") should occasion intense food competition. Accordingly, the average gut **fullness**<sup>20</sup> of parr should decline when densities approach carrying capacity. Gut fullness and mean size/condition should fluctuate in synchrony when excessive densities cause severe food competition.
- 3) Expanded rearing distribution of parr At excessive densities, competition for food and space between parr should result in the downstream displacement of many individuals. Spring chinook parr are now rarely found in the Yakima River below the Naches confluence. Significant densities of parr in the middle and lower river and/or significant increases in the passage of parr observed at Roza Dam will be taken as a sign of increased intraspecific competition.

---

<sup>19</sup> The 1995 brood year should provide an excellent test of this hypothesis. Basin-wide spawning escapement in 1995 was only 584, less than a fifth of the average (3,076) of the last 16 years. In addition, a 50-year flood occurred the winter after spawning, scouring and burying a large number of redds.

<sup>20</sup> Percent stomach fullness or weight of stomach contents expressed as a proportion of body weight.

- 4) Incidence of redd superimposition. If spawning habitat is more limiting than rearing habitat, the constraints of excessive densities might be due primarily to redd superimposition and reduced egg-to-fry survival. Accordingly, the proportion of all upper Yakima redds suffering superimposition by later spawners will be monitored. If the incidence of redd superimposition is high, it is likely that the progeny of early spawners would suffer significantly higher mortalities than later spawners. We will therefore also monitor the mean size of parr and smolts, and the outmigration timing of smolts, from cohorts with a high incidence of redd superimposition: later-spawned, later-emerging fish might be smaller as parr and smolts, and might need more time to reach threshold smolting size<sup>21</sup>.
- 5) Lipid content, size, condition factor of fall parr Overwinter survival is inversely correlated with the size, condition factor and lipid content (bioenergetic reserves) of fall parr (Smith and Griffith 1994) and these feeding-related factors should be depressed by excessive densities. Accordingly, size, condition factor and lipid content of fall parr in the upper Yakima and of winter migrant<sup>22</sup> at Chandler will be monitored.
- 6) Altered patterns of microhabitat utilization by early parr. The preference of small spring chinook parr for shallow, low velocity habitats with abundant woody debris has been well documented (Bjornn and Reiser 1991, Steward and Bjornn 1990). Under excessive densities, a significant proportion of a population of spring chinook parr might be displaced into faster, deeper waters with less structural complexity. Accordingly, we will monitor the relative incidence of early spring chinook parr in "typical" and "atypical" microhabitats as a function of estimated egg deposition and/or spawning escapement.

---

<sup>21</sup> Growth compensation might well eliminate the impacts on smolt size and outmigration timing.

<sup>22</sup> A "winter migrant" is a subyearling spring chinook that migrates to the lower Yakima River the fall and winter preceding its smolt outmigration.



- 7) Density-dependent predation on smolts. Density-dependent predation on spring chinook smolts is not the same kind of thing as the previous six factors: it is not an index of ecological overcrowding. However, the size and dynamics of predatory smolt losses can change the qualitative relationship between stock and recruitment. Thus, it is appropriate to discuss density-dependent predation in a section dealing with carrying capacity. It is theoretically possible for a population of resident predators to increase prey consumption so rapidly with increasing smolt densities (a functional response) that net smolt production below some escapement level will be limited by the consumption capacity of the predators (Peterman and Gatto 1978). This “predator trap” will be effective until circumstances result in the production of more prey than the predators can consume, or until the predator population is significantly reduced. Several studies have documented fluctuations of abundance in salmon populations that are consistent with the operation of a predator trap (McIntyre et al. 1988, Peterman 1987). Watson (1993) suggested these populations include Yakima spring chinook. Accordingly, we will estimate spring chinook smolt consumption by middle and lower river predators as a function of the density of spring chinook smolts and of the smolts of all anadromous salmonids collectively. This data will be analyzed to determine the possibility of “predator trapping” and, if appropriate, the size of the smolt outmigration necessary to break out of the trap.

### *Multidimensional Monitoring*

The relationship between spawners and recruits, which gives carrying capacity as a special case, is determined by a combination of spawner quality, habitat quality and habitat quantity (Mousalli and Hillbom 1986). In addition, recruitment is almost certainly lognormally distributed (Peterman 1981, Hillbom and Walters 1992). Therefore, our approach to describing “real” stock/recruitment relationships (“production functions”) is concisely expressed by the following stock-recruit

relationship (Hilbom and Walters 1992):

$$R = \left[ \frac{Ss_0}{1 + \left(\frac{s_0}{K}\right)S} \right] e^{\left(\sum_{i=1}^n \epsilon_i (E_i - \bar{E}_i) + w\right)} \quad (2)$$

As in the material above on productivity,  $R$  represents the “recruits” to the next life stage as a function of  $S$ , the “stock” in the antecedent life stage.  $S$  and  $R$  can be any antecedent and subsequent life stages, but in our analysis, we will focus on adult recruitment rate, gross smolt production rate and egg-to-smolt survival. Although eq. 2 is written for the Beverton-Holt relationship, an analogous equation can be written for the Ricker production function, which we will also examine.

The bracketed part of eq. 2, is one form of the familiar Beverton-Holt production function. The variables  $s_0$  and  $K$  are, respectively, the maximum recruitment rate (mean eggs per female multiplied by survival to recruitment stage at optimal low-density conditions), and the maximum number of recruits (the carrying capacity).

Many stock-recruitment analyses, and some targeting Yakima spring chinook, have stopped here, fitting observational stock and recruitment data to an expression that does not provide for environmental modulation or for lognormal variance. In our view, this is a fatal error. The remainder of the equation accounts for these factors. In the exponent term:

$$\sum_{i=1}^n c_i (E_i - \bar{E}_i) + w \quad (3)$$

$E_i$  is some environmental factor, such as streamflow during smolt outmigration,  $c_i$  is a coefficient expressing the magnitude of its effect, and  $w$  is the unexplained normally distributed residual. Note that environmental impacts are expressed as a deviation from average conditions, and that more than one environmental factor may be included. The net effect is essentially a multiple regression. Multiplying the basic Beverton-Holt relationship by  $e$  exponentiated by expression 3, applies environmentally modulated lognormal error.

To see why environmental modulation is so critical, one must consider how carrying capacity is defined mathematically. Mousalli and Hillborn (1986) express carrying capacity from life stage  $i$  to  $n$  as:

$$K_n = \frac{\prod_{i=1}^n p_i}{\sum_{i=1}^n \frac{\prod_{j=1}^i p_j}{c_i}} \quad (4)$$

where  $p_i$  is the density-independent survival or productivity of life stage  $i$ , and  $c_i^{23}$  is the capacity of life stage  $i$ . Here life stage productivity is determined solely by environmental *quality*, while life stage capacity is determined solely by environmental

---

<sup>23</sup> The  $c_i$  in this equation should not be confused with that in expression 3.

*quantity*<sup>24</sup>. Note also that *cumulative* carrying capacity over a series of life stages,  $K$ , is a function of both environmental quantity and environmental quality over all antecedent life stages. To the degree that fluctuations in some density-independent environmental factor, such as streamflow, cause substantial changes in productivity for one or more life stages, this factor should be included as an environmental modulator in eq. 2.

Examination of eq. 4 should make it clear how thoroughly productivity, and the environmental factors that determine it, are enmeshed in the determination of carrying capacity. In a basin as subject to large-scale anthropogenic impacts as the Yakima, it is essential that environmental variability be explicitly addressed by any production function.

Our general approach to multidimensional modeling will involve identifying environmental factors that affect density-independent survival at three scales: gross smolt production rate, egg-to-smolt survival and adult recruitment rate. The methods by which these factors will be identified are described in the section above on productivity. As mentioned earlier, inbasin carrying capacity will be reflected most clearly as gross smolt production or egg-to-smolt survival. Historical and current data will be fitted iteratively to eq. 2 using nonlinear methods. With time, the environmental factors that most affect smolt production and adult recruitment will be identified, and realistic smolt and adult production functions will be generated. These functions can then be used to estimate the fraction of any decline in production rates attributable to excessive density (ecological overcrowding) and adverse environmental conditions explicitly.

---

<sup>24</sup> To be precise, capacity is a function of habitat area or volume, species-specific space requirements, and the “trophic richness”( the food availability) of the habitat. Thus, of two streams of equal area, the stream with the more abundant food supply would have the larger capacity.

## Outline of Natural Production Monitoring Measures

### I. Intrinsic Factors affecting Natural Production

#### A. Hatchery Fish Quality

##### 1. Survival of released smolts

- a. **Hatchery *smolts/spawner*** as fish leave acclimation ponds
- b. ***Relative smolt-adult survival*** rates of three groups of natural spawners: Upper Yakima, Naches, and American
- c. ***Relative hatchery/wild smolt-adult survival*** rates from Roza to **Prosser**<sup>25</sup> (extrapolating to upper basin if possible)
- d. ***Relative hatchery/wild smolt-smolt survival rates*** from Roza to Chandler and McNary (and if possible, points further downstream in Columbia basin such as John Day and Bonneville)
- e. ***Relative hatchery smolt/wild winter migrant survival*** rates from Chandler to McNary (and if possible points further downstream in Columbia basin such as John Day and Bonneville)
- f. ***Developmental profile of hatchery fish*** from preceding

---

<sup>25</sup> Prosser is used here as a surrogate for the mouth of the Yakima River.

winter through smoltification (e.g., growth rates, temperature units to reach specified developmental stages)

- g. ***Comparative hatchery/wild smolt morphology (e.g.,***  
length, weight, truss measurements, coloration)
- h. ***Comparative hatchery/wild smolt physiology (e.g.,*** lipid,  
ATPase, thyroxine, cortisol, sodium, and glucose levels)
- i. ***Comparative hatchery/wild smolt behavior -gross /eve/***  
(e.g., migration rate and timing)
- j. ***Comparative hatchery/wild smolt behavioral profile***  
***change*** over ***time*** evaluated in test aquaria (e.g., agonistic  
behavior, predator avoidance, feeding)
- k. ***Relative hatchery/wild residualism*** rates (e.g., densities  
of residuals in index sites, subsampling fish leaving  
acclimation ponds)
- l. ***Relative hatchery/wild precocialism rates*** (e.g., number  
of precocials on redds)
- m. ***Relative hatchery/wild smolt /oss due to predation***  
inbasin below Chandler by squawfish, smallmouth bass,  
channel catfish, piscivorous birds, and possibly other  
species

## 2. Reproductive Success of Hatchery Fish

- a. **Hatchery/wild comparison of gamete quality measured in hatchery test crosses (h<sub>x</sub>h<sub>i</sub>,w<sub>x</sub>w<sub>i</sub>,h<sub>x</sub>w<sub>i</sub>,w<sub>x</sub>h<sub>i</sub>) (e.g., fertilization rates, viability, temperature units to hatch, fry size/egg size)**
- b. **Comparative hatchery/wild performance of adults for the following demographic and life history characteristics: age, size at age, sex ratio, fecundity at size, migration timing, spawning timing (both in hatchery and on spawning grounds), spawning distribution/habitat utilization, and straying**
- c. **Comparative hatchery/wild reproductive behavior of adults on spawning grounds** (e.g., spawning site competition, redd construction, mate selection)
- d. **Comparative hatchery/wild reproductive behavior of adults in semi-natural test arena** (e.g., spawning site competition, redd construction, mate selection)
- e. **Comparative hatchery/wild performance of juveniles in semi-natural test arena for parentally determined life history traits** (e.g., distribution, size, emergence timing, migration timing, growth)
- f. **Direct hatchery/wild reproductive success comparisons measured as fish produced by individuals or individual pairs in natural or semi-natural test arenas**

- (1) **MACRO level- measure production (as returning adults) by individual pairs for entire upper Yakima population** (will require complete DNA profile of population)
- (2) **MESO level- measure production (as outmigrating juveniles) by individual pairs in a restricted-entry natural stream reach** (will require complete DNA profile of spawners in stream reach)
- (3) **MICRO level- measure production (as outmigrating juveniles) by individual pairs in a semi-natural stream arena** (will require DNA profile of all spawners tested)

## B. Long-Term Fitness of Supplemented Population

1. **Monitor domesticating effect of hatchery environment on the Upper Yakima stock.** Description of monitoring measures is presented in Genetics section of Monitoring Plan (Section 1 C).

## C. Facility Performance

1. **Monitor operations at hatchery, acclimation ponds, monitoring facilities to insure compliance with biological specifications.** Description of monitoring measures is presented in Facility Quality Control section of Monitoring Plan (Section 3).



## II. Extrinsic Factors affecting Supplementation Success

### A. Harvest

1. ***Monitor contribution of Upper Yakima stock (both hatchery and wild components) in all fisheries in which they are intercepted.*** Description of monitoring measures is presented in Harvest section of Monitoring Plan (Section 1 B).

### B. Environment

1. Local

- a. Productivity

- (1) ***Recruits/ female spawner for naturally spawning Upper Yakima fish and the two reference populations***
    - (2) ***Egg-smolt survival rates for naturally produced fish in Upper Yakima stock and the two reference populations***
    - (3) ***Egg-smolt equivalent survival rates for winter migrants in Upper Yakima stock*** (depends on Roza smolt trap being calibrated)
    - (4) ***Monitor selected inbasin abiotic environmental***

*elements ( temperature, flow, upwelling, structural complexity of habitat, and substrate quality)” to determine relationship to density-independent survival*

*(a) prespawning adults*

*(b) incubating eggs*

*(c) emergent fry*

*(d) gross smolt production rate (smolts per female spawner)*

*(e) egg-to-smolt survival*

*(f) adult recruitment rate*

- (5) ***Monitor ecological interactions between Upper Yakima stock and species that are likely to be "strong interactors"*** Full description of monitoring measures is presented in Ecological Interactions section of Monitoring Plan (Section 1 D).

b. Capacity.

All the measures proposed below will be done for the Upper Yakima population, but should also be done for the two reference stocks wherever feasible. In some cases data on these measures in the reference populations will be available from other monitoring already planned for them (e.g., redd superimposition data will be available for the

---

26 For all three spring chinook stocks, if possible.

reference populations because spawning ground surveys will be done on them anyway).

- (1) ***Relationship between spawner abundance and redd superimposition in Upper Yakima.***
- (2) ***Relationship between abundance and length, weight, condition factor of ear/y Upper Yakima aprr***
- (3) ***Relationship between abundance and size, condition factor, and lipid content of Upper Yakima fall parr***
- (4) ***Relationship between abundance and rearing distribution of Upper Yakima juveniles***
- (5) ***Relationship between abundance and microhabitat usage of Upper Yakima juveniles.***
- (6) ***Relationship between abundance and gut fullness of Upper Yakima juveniles.***
- (7) ***Relationship between abundance and predation on smolts***

## 2. Nonlocal Productivity and Capacity

- a. ***Pertinent outbasin productivity and capacity data from***

***other (i.e., nonYFP) monitoring and research efforts will be utilized as appropriate to explain survival rate variation of Yakima spring chinook.*** Although nonlocal (mainstem Columbia, estuary, and ocean) environmental conditions will profoundly affect the success of the project, directly monitoring outbasin environmental conditions is clearly outside the scope of this project, so none is proposed.

## Section 1 B. Harvest

Accurate monitoring of harvest of YFP spring chinook is critical for several reasons. First, increased harvest opportunity is a goal of the project. Second, harvested fish are a component of the productivity of a supplemented population and must be accounted for to give a realistic picture of how many fish the supplementation effort is producing. Third, harvest must be monitored to control genetic risk (see Genetics, Section 1 C) to the Naches and American River spring chinook stocks. Since these stocks are commingled with the Upper Yakima stock in harvest areas, increased harvest resulting from supplementation success may cause their exploitation rate to increase. Harvest may have to be controlled (scaled back, relocated or targeted on hatchery fish) to avoid reducing these stocks to excessively low levels. Additionally, the harvest of OCT and SNT hatchery fish must be monitored to estimate productivity for the treatment groups accurately.

The ideal harvest monitoring situation would be one in which wild Yakima basin spring chinook harvested can be properly assigned to substock, all YFP hatchery fish can be identified as such, and hatchery fish can be assigned to treatment group. What can be achieved, however, depends greatly on how the fish are marked and the fishery in which they are intercepted.

Wild fish are unmarked, but genetic differences at allozyme loci exist between the Upper Yakima stock and the Naches and American stocks (Busack and Marshall 1991). Although these differences are not large enough to allow assignment of individual fish to substock, they do allow a precise estimate of the stock composition of mixtures. Thus, mixed stock analysis of a sample from a fishery in which wild Yakima chinook are present will yield stock contribution estimates from which estimates of harvest of the three substocks can be made. Even more accurate estimates may be possible using microsatellite DNA information (see Introduction). This is currently being investigated.

The current marking plan for YFP hatchery fish is to mark 100% of them with unique VIJ marks for each treatment/acclimation site/brood year replicate. No other marking is planned. The benign readability of VIJ marks makes them clearly superior to coded-wire tags (CWTs) in that it allows extensive analysis of live fish, which is essential to many aspects of monitoring. As already mentioned in the Introduction, however, it is not clear now how readable VIJ marks will be in adults. Moreover, even if adult mark retention and readability is 100%, VIJ marks will be visible only under UV light. As will be seen, the necessity of UV interrogation may complicate monitoring the harvest of YFP hatchery fish.

There are three general harvest areas to be considered for monitoring- the ocean, the Columbia River, and the Yakima basin:

### **Ocean Fisheries**

At present, ocean catch data is available only from coded-wire tag recoveries. Yakima basin spring chinook have never been heavily tagged to evaluate their contribution to ocean fisheries, but their contribution can be expected to be low, based on experiences with spring chinook released from the federal Leavenworth, Entiat and Winthrop hatcheries. CWT tag recoveries in the ocean fisheries from fish released from these hatcheries have been very low, indicating a harvest rate of 0.6% from 1978 to 1993 (Chapman et al. 1995). In addition, of the approximately 1.3 million CWT-tagged spring chinook (mainly Leavenworth stock but some native Yakima spring chinook as well) released between 1982 and 1987 during the YIN spring chinook enhancement study, only two tags were recovered from ocean fisheries (Pacific Fishery Management Council database search of tag codes listed in Fast et al. 1991, Table 55). The cost of tagging to get data on ocean catches, and the probable low yield of data makes monitoring harvest of YFP fish in ocean fisheries unfeasible. We have therefore not proposed monitoring measures for this component of harvest.

## **Columbia River Fisheries**

There are three Columbia River fisheries in which YFP spring chinook may be harvested: the winter lower river gill-net fishery, the winter sport fishery, and the treaty ceremonial and subsistence (C&S) fishery in Zone 6<sup>27</sup>. The sport fishery is very small and lightly monitored, so the possibility of obtaining useful information from it is low. No monitoring of this fishery is currently proposed. The winter gill-net fishery targets large Willamette hatchery stocks, and is regulated to avoid take of upriver stocks (which includes Yakima basin stocks), but it is heavily monitored genetically (e.g., Marshall et al. 1991) so has the potential to yield useful **information**.<sup>28</sup> This fishery has been severely limited in recent years (in 1994 it was not even held) by the listing of Snake River spring and summer chinook under the ESA, but it should be monitored. The bulk of YFP fish harvested in Columbia River fisheries will be harvested in the Zone 6 fishery. Harvest in this fishery should also be monitored. This fishery has on occasion been evaluated using genetic stock identification, so substock-specific harvest rates are possibilities, but getting this information routinely may require a heavy project involvement in the overall monitoring process. For monitoring both the gill-net fishery and the C&S fisheries a major uncertainty is detection of YFP hatchery fish. Unless sampled fish are routinely interrogated with a UV light source, YFP hatchery fish will go undetected, and will be accounted for only in genetically determined stock estimates.

## **Yakima Basin Fisheries**

At present the only fishery in the basin intercepting spring chinook is a tribal C&S fishery on the mainstem Yakima River downstream of Roza Dam. Harvest can be as

---

<sup>27</sup> The Columbia River from Bonneville Dam to McNary Dam.

<sup>28</sup> Sampling is done by ODFW and WDFW personnel, and the genetic evaluation of catch is done by the WDFW Genetics Unit. Currently, individual estimates for the three substocks are not reported, but this can be done (C. Busack, WDFW, pers. comm.)

high as 20% of the run, so sampling this fishery is critical. Although there is agreement in principle this fishery will be intensively sampled, many details need to be worked out. Probably the biggest problem will be a reluctance to let genetic samples be taken that will deface the fish, which is normally a requirement of allozyme **sampling**.<sup>29</sup>

Resistance to this type of sampling could seriously limit sample sizes for mark recovery, and demographic and genetic analysis. This is a strong argument for the development of DNA technology to accomplish the same purpose (see introduction). We have assumed all sampled fish can be UV interrogated, but if this is not possible, the same detection problem mentioned earlier will occur.

Because of the potential problems with UV interrogation, consideration should be given to applying an external, readily visible tag that would identify YFP hatchery fish to be identified as such. A 100% application would be best, but a smaller tagging proportion may be quite useful. This would avoid or greatly ameliorate the UV interrogation problems, as the need to interrogate all fish with adipose fins would be eliminated. There are several other monitoring needs besides harvest where identification of hatchery fish is important, but UV interrogation is unlikely or impossible. One is identification of fish as they pass viewing windows at Prosser and Roza. Another, described in the Genetics section (IC), is the need to be able to identify YFP hatchery fish as they are encountered in other basins on spawning grounds or in hatchery broodstocks. CWT-tagging is the most obvious method that would serve this purpose, but there may be others.

## Outline of Monitoring Measures for Harvest

---

<sup>29</sup> Routine allozyme work requires samples of skeletal muscle, heart, liver, and eye. It is possible that the genetic information required for substock-specific estimates can be obtained from only a fin clip, but this has not yet been evaluated.



I. Columbia River Fisheries

- A. ***Total harvest in lower Columbia gill-net fishery by substock (determined genetically), of Yakima basin wild spring chinook, and Upper Yakima hatchery spring chinook (determined by UV interrogation of VIJ marks or coded-wire tag recoveries)***
- B. ***Total harvest in Zone 6 C&S fishery by substock (determined genetically), of Yakima basin wild spring chinook, and Upper Yakima hatchery spring chinook (determined by UV interrogation of VIJ marks or coded-wire tag recoveries)***

II. Yakima Basin Fisheries

- A. ***Total harvest in Yakima basin C&S fishery by substock (determined genetically), of Yakima basin wild spring chinook, and Upper Yakima hatchery spring chinook (determined by UV interrogation of VIJ marks or code&wire tag recoveries)***

## Section 1 C. Genetics

### YFP Genetic Planning Documents

Genetic conservation issues have always figured prominently in the development of the YFP. The 1990 YKFP Preliminary Design Report (PDR) (Anonymous 1990) strongly committed the project to conserving genetic resources in the basin. The PDR also included the first genetic risk assessment of any project in the region (Busack 1990). This commitment to genetic conservation was repeated in the charge given the project by the NPPC quoted in the Introduction. Although this section will describe genetic risks and genetic monitoring in some detail, the high profile of genetic issues in this project has prompted the development of three additional documents (all now in preparation) relevant to genetic monitoring: the Genetic Monitoring Plan (GMP), the Genetic Culture Guidelines (GCG), and the Genetic Risk Assessment (GRA). The Genetic Monitoring Plan will be an expansion of this section, with details on alternative methods, and power analysis. The Genetic Culture Guidelines will be a distilled, highly applied version of an earlier culture guidelines document produced for the project (Kapuscinski and Miller 1993). The Genetic Risk Assessment will expand on genetic risk issues presented in brief here, and attempt to quantify risks and evaluate the risk containment efficacy of monitoring measures. It will build on the earlier genetic risk

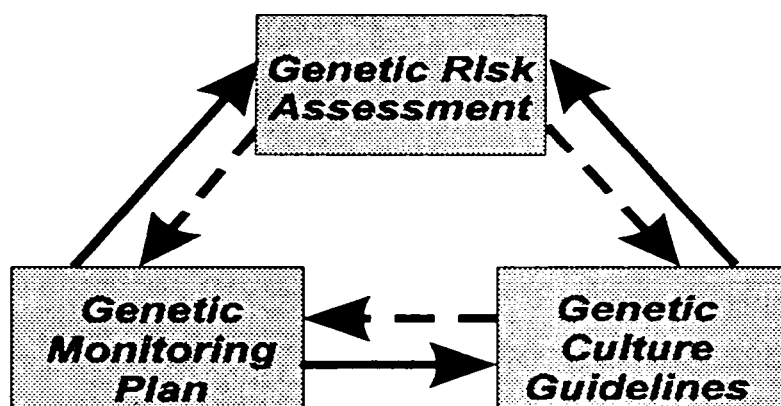


Fig. 4. Interrelationships of YFP genetics planning documents. The dotted arrows denote feedback paths.

work done on the project by Busack (1990) and Currens (1993). Culture guidelines, monitoring, and risk assessment are essential elements of a comprehensive genetic risk management strategy (Shaklee et al. 1993). The three documents are tightly linked, as diagrammed in Fig. 4. Monitoring

measures done during fish culture are incorporated into the GCG. The cultural measures and genetic monitoring measures are assessed for their risk containment value in the **GRA**. There is a feedback mechanism operating between the **GRA** and GCG and GMP in that the latter two documents may be modified because of risk assessment. There is also feedback between the GCG and the GMP; implementation of the culture guidelines and associated monitoring may cause monitoring plans to be modified. As with all other aspects of YFP planning, this is a dynamic process. These documents will be updated periodically, but at no time can any of them be said to be the final word on these topics.

## **Genetic Risks and Hazards in Hatchery Operations**

Development of genetic monitoring measures began with the genetic hazard categorization system of Busack (1990) and Busack and Currens (1995). Four types of hazard are recognized: 1) extinction, 2) loss of within-population genetic variability, 3) loss of between population genetic variability, and 4) domestication selection. A description of the four hazard types follows, much of it taken from Busack and Currens (1995).

### **Type 1 Hazards**

A Type 1 hazard risks losing the entire population due to small population size. It is the most serious hazard, because once a population is gone, all the unique aspects of the diversity it contained are also lost. Because different populations have different gene pools, extinction of any population also reduces overall genetic diversity of the species.

Extinction differs significantly from the other hazards in hatcheries because it is mostly caused by nongenetic mechanisms: demographic variation, environmental variation, and catastrophes (Shaffer 1981). Genetic mechanisms that reduce reproductive success, such as inbreeding in very small populations and low levels of genetic variability (Newman and Pilson 1997), can also contribute to an “extinction vortex” (Gilpin 1987). Extinction is the primary focus of most risk assessment in conservation

biology (e.g., **Burgman** et al. 1993), but it has been overlooked in hatchery programs. In fact, one attraction of artificial propagation is that it can reduce environmental variation. However, hatchery programs can still be abundant sources of uncontrolled demographic, environmental and catastrophic changes. Disease, power failures, and dewatering can be catastrophic in even the best hatchery programs. Ecological interaction between released hatchery fish and wild fish that may depress populations (e.g., Sholes and **Hallock** 1979, Nickelson et al. 1986) is another uncontrolled source of demographic variation.

### **Type 2 Hazards**

Type 2 hazards risk loss of within-population genetic variability. A population's current fitness and ability to adapt to new environments depends on its store of genetic variability. Though studies directly linking amounts of genetic variability to fitness are uncommon, at least one (Leberg 1990) has shown a relationship between population productivity and genetic variability in fish. Also, inbreeding, an extreme form of variability reduction, can reduce fitness in fish populations considerably (reviewed by Tave 1993, Waldman and McKinnon 1993). Loss of variability occurs through two mechanisms: genetic drift and nonrandom sampling. Genetic drift is a random process that occurs in all populations. It occurs because many more gametes are produced by parents than actually unite to become new zygotes. Each new generation is a sample of the quantity and variety of alleles present in the gametes of the previous generation. The genetic variability in the progeny will not be an exact copy of that in the parents. Over time, variation will be lost, and the smaller the population, the faster variability is lost. The relationship between loss of genetic variability and population size can be expressed as

$$\Delta F = \frac{1}{2N_e} \quad (1)$$

where  $\Delta F$  is the increase (or decrease) in homozygosity caused by loss of variability, and  $N_e$  is the genetically effective population size. The genetically effective size is the census size corrected for departures from a genetically “ideal” state of random mating, unequal sex ratio, unequal family size, and temporal fluctuations in population size (Falconer 1981)<sup>30</sup>.  $N_e$  is typically considerably smaller than the census size in fish (Waples et al. 1993, Bartley et al. 1992) and this appears to be the case in Yakima spring chinook (C. Busack, WDFW, unpublished data).

Reduced genetic diversity in hatchery stocks compared with their wild counterparts (Allendorf and Phelps 1980, Ryman and Stahl 1980, Waples et al. 1990) suggests the potential for random genetic drift in hatcheries. Many potential sources of small effective populations size in artificial propagation have been documented. These include using small numbers of brood fish, using more females than males (or the alternative) and pooling gametes, changing age structure, and allowing progeny of some matings to have greater survival than others (Simon 1981, Gharett and Shirley 1985, Simon et al. 1986, Withler 1988). The most important source of small effective population size is the variance of family size, or variation among families in the number of offspring that survive to reproduce (Falconer 1981). This factor may lead to serious overestimates of effective population size in natural populations where hatchery fish mingle with wild fish and there is an overall survival difference between hatchery and wild fish (Ryman and Laikre 1991, Ryman et al. 1994)— exactly the situation we hope to see occur in the Yakima. Here the overall effective size  $N_T$  is determined by hatchery ( $N_H$ ) and wild ( $N_w$ ) components:

$$\frac{1}{N_T} = \frac{x^2}{N_w} + \frac{(1-x)^2}{N_H} \quad (2)$$

where  $x$  is the proportion of the breeding population consisting of wild fish. Cuenco

---

<sup>30</sup> For example, a broodstock of 4 males and 100 females will lose as much variability due to drift as a population of 8 males and 8 females, everything else being equal.

(1994) used this relationship to show how the proportion of fish taken as broodstock affects effective size.

The other major cause of loss of genetic variability is biased (nonrandom) sampling or sampling “error”. This can happen during any stage of hatchery operation where genetic variability might be excluded. For example, a common source of biased sampling is during broodstock collection. Ideally fish would be chosen randomly. More often, however, fish are chosen to represent the distribution of spawning timing, size, age, or some other trait of the source population. If sampling errors are random or involve traits that do not respond strongly to selection, little or no genetic change would result. If sampling errors are systematic and involve traits that respond easily to selection, variability is lost. The potential for genetic change in hatchery operations because of sampling error has been demonstrated by **Leary et al. (1986)**, who found that **electrophoretically** detectable allele frequencies in a rainbow trout hatchery stock varied during a spawning season.

In practice, the distinction between this kind of type 2 situation and domestication selection is blurred. Additional material on sampling error is provided below under Monitoring Addressing Type 4 Risk.

### **Type 3 Hazards**

Type 3 hazards risk loss of adaptation or genetic variability among populations. There is only one cause: interbreeding with other populations. For management purposes, we often consider populations as reproductively isolated units. In many fish species, however, naturally occurring gene flow is an important factor in maintaining genetic diversity. Consequently, the standard for judging gene flow is natural levels and from natural sources. Excessive gene flow may reduce performance of a population by disrupting its genetic organization (Shields 1982). There are two possible genetic sources (Templeton 1986). The first is simple erosion of adaptation. Introduced

alleles from other populations that have evolved in different environments may be less beneficial than the native ones. The net result is that the recipient population becomes less well adapted. The second cause of loss of fitness is outbreeding depression, the breaking up of favorable combinations of alleles called **coadapted** complexes. As immigrating alleles replace existing alleles in the population, new, less favorable allelic combinations may be formed, leading to less favorable phenotypes. Whereas fitness depression caused by loss of adaptations can be expected to become evident the first generation after the gene flow occurs, outbreeding depression may not be apparent until the second generation (Gharrett and Smoker 1991, Lynch 1991).

Conditions for gene flow are a fundamental part of past and present hatchery practices in this country (Philipp et al. 1993) and in the region (Howell et al. 1985). Stocking programs commonly release fish into streams outside the original distribution of the introduced fish, resulting in gene flow if stocked fish survive to reproduce with native fish. Several Columbia basin hatchery stocks of mixed ancestry are used over broad areas, such as the Carson spring chinook stock (Howell et al. 1985).

Although evidence exists for local adaptation, especially in salmonids (reviewed by Taylor 1993) there is little data for fitness depression in fish due to interbreeding. In fact we know of only two studies. Gharrett and Smoker (1991) detected fitness depression in crosses between even- and odd-year pink salmon. Gordon and Gordon (1957) found that interpopulational hybrids of platyfish (*Xiphophorus maculatus*) tended to develop melanomas. The paucity of data makes prediction of risk due to interbreeding very speculative, as was demonstrated at a recent workshop on the subject (Grant 1997).

#### **Type 4 Hazards**

Type 4 hazards are situations in which the direct or indirect selective effects of the hatchery environment cause genetic change in the populations they culture. Such

change is called **domestication**<sup>31</sup>. Domestication is typically expressed as changes in quantitative traits (such as size, fecundity, etc.). There are two types of domestication selection: intentional or artificial selection, and unintentional selection. In practice, it may be nearly impossible to distinguish and control these separately. Artificial selection is the deliberate effort to alter a population to suit management needs, such as development of rainbow trout stocks with specific spawning timing (e.g., Busack and Gall 1980). Artificially selected fish may perform well in the hatchery, but poorly in the wild, because of divergence from their source population at the intended traits or correlated changes in other traits (Tave 1993). This is an obvious **concern** in a supplementation effort, where it is very important that hatchery fish perform well in the wild.

Although intentional selection may be easy to avoid, the other source of domestication, unintentional selection is not. Genetic change due to unintentional selection results from uncontrolled, differential mortality over the entire life cycle of the fish imposed by the hatchery environment and rearing protocols. The fundamental reason for operating hatcheries is to achieve a survival advantage by altering the environment. Consequently, fish in hatchery environments may be exposed to higher densities, different food and drift, flow, substrate, protective structure, photoperiod, and so on. These changes allow more fish to survive in the hatchery than survive in the wild, which shifts mortality to later ages (Waples **1991a**), and produces the opportunity for genetic change.

Theoretical argument for domestication selection exceeds empirical evidence. This is not surprising, because domestication selection is measurable in quantitative, rather than qualitative traits (such as allozyme markers), and it is difficult to separate genetic

---

<sup>31</sup> Domestication tends to connote farmlike tameness, but this is not our intent. By domestication we simply mean changed through genetic selection to a condition more compatible with an anthropogenically imposed environmental conditions.



and environmental effects on the phenotype (Hard 1995). Many arguments for domestication are based on evidence of selection regimes. Captive propagation of any organism poses very different selection regimes than the wild (Frankham et al. 1986), selective changes are expected to be strong (Kohane and Parsons 1988). Indeed, Doyle (1983) showed that high selection differentials exist in hatchery environments. Many studies have demonstrated phenotypic differences between hatchery and wild fish (summarized by Hindar et al. 1991) but in relatively few are the effects clearly genetic. The best study to date is that of Reisenbichler and McIntyre (1977) who compared early survival of a two-generation old hatchery steelhead stock with the wild stock from the same stream, and found a statistically significant survival advantage for hatchery fish over wild fish in hatchery environments; the situation was reversed in natural environments. Swain and Riddell (1990) noted that hatchery juvenile coho salmon exhibited more agonistic behavior than wild juveniles. Hatchery x wild steelhead juveniles differ in foraging behavior from wild fish (Johnsson and Abrahams 1991).

## **Risk Assessment and Approach to Monitoring**

Vulnerability to the four hazard types was evaluated for three population groups: the target stock, Upper Yakima spring chinook; the two nontarget stocks in the same basin as the target stock, Naches and American River spring chinook; and nontarget stocks outside the basin, other Columbia spring and Snake spring/summer stocks. Note that risk was assessed only for spring chinook populations. Monitoring measures are organized below first by population group, and then by hazard category. Note that the only nontarget groups considered are those in which gene flow with the supplemented stock is likely. Obviously, other chinook stocks and even other species could be affected demographically by the supplementation effort, causing type 1 and possibly type 2 risks. At this point genetic risk and ecological risk become indistinguishable. Therefore, all monitoring of ecological interactions of taxa other than spring chinook is dealt with in the Ecological Interactions section (Section 1 D). An organizational overview of genetic monitoring measures is presented in Fig. 5.

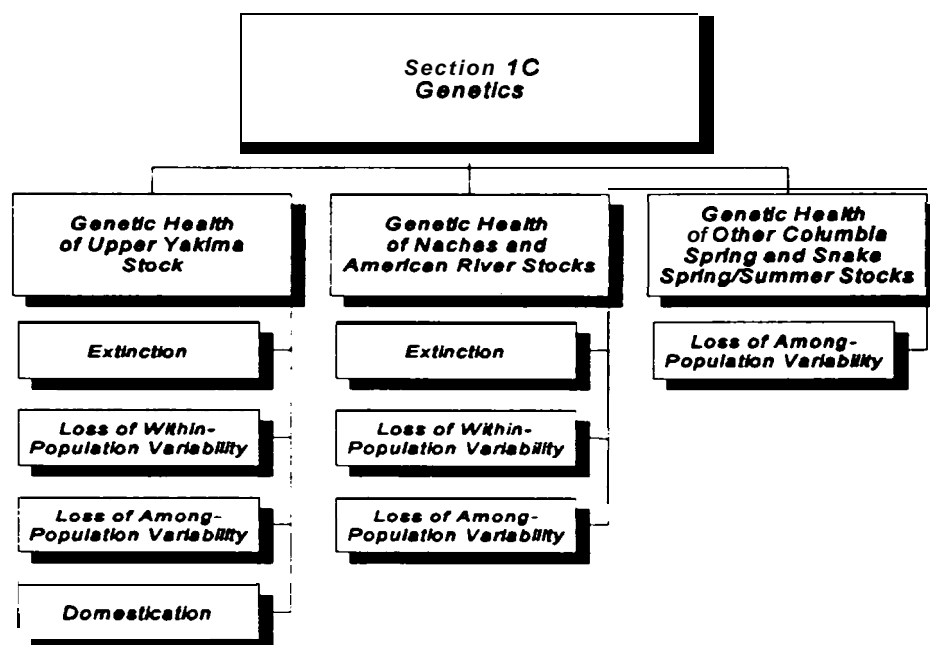


Fig. 5. Organization of Section 1C of the YFP spring chinook monitoring plan.

### Monitoring Addressing Type 1 Risk

The supplementation effort may have large demographic impacts on both the Upper Yakima and Naches/American groups. The Upper Yakima stock should increase in abundance, but could actually decrease if the supplementation effort achieves much lower than expected survival, due to either intrinsic or extrinsic causes. The Naches and American stocks could also possibly increase, but the greater risk is that they will decrease due to increased fishing harvest effort, since all areas in which Yakima spring chinook are harvested are mixed-stock areas. Also noteworthy is the historical fluctuation in escapement of these three stocks, which suggests substantial survival rate variation. Perhaps the three stocks are already at a nonnegligible risk of extinction.

The primary monitoring measurers for gauging extinction risk are spawner-recruit relationships, harvest rates, and other sources of mortality. Long-term declines in recruitment rates signal increased extinction risk, especially once values under 1 are

commonplace. A trend of hatchery spawner-recruit relationships of less than 1 indicates that the hatchery is decreasing rather than increasing production. Harvest rates are important because excessive harvest rates can endanger even populations with healthy spawner-recruit relationships. Other sources of mortality, such as hatchery mortalities or trapping mortalities, are important for the same reason.

Our secondary method for gauging extinction risk is population viability analysis (PVA), a modeling effort in which demographic and survival rate data are used to indicate the probability of the population's extinction over a set time horizon (Gilpin and Soule 1986). The strength of PVA depends on the completeness and accuracy of the database used in the modeling, and results are always subject to debate because of the assumptions used. PVA does, however, require a comprehensive examination of demographic and environmental data and therefore is always a valuable reality check. The YAKSIM model(see Section 1A) being developed by MIPT, or a close derivative of it, will be used for this purpose. The three Yakima spring chinook stocks will be modeled separately.

The basic form of the PVA model for wild fish will be a Beverton-Holt production function with lognormal error term (Peterman 1981, Hilborn and Walters 1992), e.g.:

$$R = \frac{aS}{1 + \left(\frac{a}{b}\right)S} e^w \quad (3)$$

where R is the number of recruits, S is the stock size producing the recruits, a is the survival rate at very low densities, b is the carrying capacity, and w is a normal random variable with mean 0 and variance  $\sigma^2$ . The production function will be disaggregated by life-history stage (Moussali and Hilborn 1986) and the model will be age-

**structured**<sup>32</sup>. Autocorrelation of lognormal error over years will be included as appropriate. Hatchery production will be added by specifying density-independent survival rates with lognormal variation. Harvest and other known density independent sources of mortality will be included. One serious problem with production functions of this form is that the survival rate becomes very high as the population declines, when in reality it is likely that compensatory survival- the Allee effect (Allee et al. 1949)- sets in because of animals having difficulty finding mates, etc. We will attempt to model this compensatory effect as suggested, for example by Akcakaya and Ferson (1990).

### **Monitoring Addressing Type 2 Risk**

Type 2 risk will also be monitored for the Upper Yakima and Naches/American groups. The potential causes of small population size in these stocks are the same as those associated with type 1 risk. The biggest potential problem is small effective size. There are two basic approaches to monitoring within population genetic variability: monitoring effective size or its components, and monitoring the variability itself. Effective size will be monitored by monitoring the effective number of breeders ( $N_b$ ).  $N_b$  is a per-year accounting of  $N_e$ . The relationship between  $N_b$  and  $N_e$  is (Waples and Teel 1990):

$$N_e = g\tilde{N}_b \quad (4)$$

where  $g$  is the generation length (average age of spawners) and  $\tilde{N}_b$  is the *harmonic* mean effective number of spawners. There are two straightforward techniques to estimate  $N_b$  from allozyme or DNA data. The first is the linkage disequilibrium method of Hill (1981). In finite populations, associations will form between alleles at different loci (linkage disequilibrium), and the smaller the effective size, the stronger the associations. In this method,  $N_b$  is estimated as

---

<sup>32</sup> The Upper Yakima stock matures almost entirely at age 4, but the Naches and American stocks have a substantial proportion of age 5 qxwnerr (Knudsen 1991).

$$\hat{N}_b = 1/[3(\hat{r}^2 - 1/S)] \quad (5)$$

where  $\hat{r}^2$  is an estimate, based on all possible unlinked pairs of loci, of the squared correlation of allele frequencies (a variant of the linkage disequilibrium **coefficient**)<sup>33</sup>, and  $S$  is the sample size. Eq.5 is correct for a situation of “no permanent pair bonds”; for single-pair mating, the denominator is 2 (Weir and Hill 1980).

The other method is the temporal method of Waples (1989, 1990). This method capitalizes on the fact that random variation in allele frequencies (genetic drift) is directly related to effective size

$$\sigma^2_q = q(1-q)/2N_e \quad (7)$$

where  $q$  is an allele frequency. By observing the allele frequency shift between two samples taken at different times,  $N_b$  can be estimated (Waples 1990) as

$$\hat{N}_b = b/[2(\hat{F} - 1/\tilde{S})] \quad (6)$$

where  $\tilde{S}$  is the harmonic mean sample size,  $b$  is an appropriate coefficient reflecting age structure and time between the samples (Tajima 1992) and  $\hat{F}$  is the mean standardized allele frequency change over all loci.

Unfortunately, the precision of these methods drops off dramatically with increasing effective sizes. The methods may be quite useful for **very** small populations, but for moderate ones the confidence intervals may be too large to be useful (Waples 1991 b). Attempts to use these methods with existing Yakima spring chinook data routinely

---

<sup>33</sup> For detail on these statistics see a standard population genetics text such as Hedrick (1983).

result in confidence intervals including infinity (C. Busack, WDFW, unpublished data). However, the power of these techniques may increase considerably over time as more DNA loci are identified, and confidence intervals may shrink considerably. We will use these techniques, but will not collect data specifically for them. As backup for rigorous  $N_b$  estimation, we will also consider escapement data, and direct measurements of genetic variability such as heterozygosity and alleles/locus will also be made. It is, however, unclear how sensitive these direct measurements will be to  $N_b$  fluctuations. Another method for evaluating within-population genetic variability is asymmetry of selected meristic characters (e.g., Leary et al. 1985). This technique shows considerable promise, but it has yet to be shown how useful it will be for monitoring. It will be considered experimental, and used only in the Upper Yakima stock, where individual juveniles of known stock can be easily collected at the Roza Dam juvenile trap.

One experimental approach to gaining insights into effective size will be attempted, separate marking of individual full-sib groups. Family size variance is the biggest component of effective size (Falconer 1981) and this will give us a chance to estimate it in the Upper Yakima population.

The second source of loss of variability is nonrandom sampling. This will be monitored by comparing means, ranges and variances of selected traits with baseline values. It is unclear how powerful this approach will be.

### **Monitoring Addressing Type 3 Risk**

Three specific types of gene flow events must be addressed: 1) immigration of Naches and American spring chinook (and possibly other stocks) through broodstock trapping; 2) gene flow from the supplemented Upper Yakima stock into the Naches and American stocks; 3) gene flow from the supplemented Upper Yakima stock into non-Yakima stocks. The latter phenomenon would probably not be directly monitored by YFP

personnel, but it may be a concern, in view of existing and pending ESA listings.

There are several approaches to estimating migration rates of genes into populations by use of genetic data: e.g., admixture analysis (Long 1991) evaluation of  $F_{ST}$  (Ryman 1991) and linkage disequilibrium analysis (Waples and Smouse 1990). All these techniques will be evaluated for feasibility, but our initial impression from working with them is that because of the relatively small genetic differences involved, the possible episodic nature of straying, the low levels of straying we wish to detect, and the sizable influence of genetic drift on allele frequency change, these approaches will not allow us to detect gene flow until a substantial amount of it has **occurred**<sup>34</sup>. We feel the most powerful monitoring approach to gene flow is likely to be determination of stray rate direct directly through recovery of strays. Moreover, this is the only reasonable approach to determining stray rates of Upper Yakima fish out of basin.

Direct determination of stray rates will depend on the identifiability of the strays and the intensity of spawning ground surveys. Upper Yakima hatchery fish will all be marked, so estimating stray rates should be straightforward on Naches and American spawning grounds if marks are readable. Outside the Yakima, the same problems discussed under Harvest (Section 1 B) may be encountered. Estimating straying rates to other subbasins would be much easier if some proportion of YFP hatchery fish were coded-wire tagged. Immigration of Naches and American fish into the Upper Yakima may be impossible unless some Naches and American fish are marked, or unless some natural diagnostic feature (such as elemental composition of otolith primordia) can be found.

### **Monitoring Addressing Type 4 Risk**

A simple expression for phenotypic change at a quantitative trait (such as size, age at maturity, fecundity, etc.), such as might occur under domestication selection is given by

---

<sup>34</sup> The power of this method may increase as more genetic variability becomes available for use through DNA analysis.

Falconer (1981):

$$R = ih^2\sigma_p \quad (8)$$

Here it is assumed that the phenotypic of the trait is normally distributed with variance  $\sigma_p^2$ , and that selection is by truncation; i.e., animals not selected do not become part of the breeding population.  $R$  is the response, the amount the phenotypic mean changes in the next generation as a result of the selection;  $i$  is the selection intensity, the difference in standard deviations between the mean and the mean of the selected individuals; and  $h^2$  is the heritability, the proportion of the phenotypic variance accounted for by additive genetic variance<sup>35</sup> ( $\sigma_A^2/\sigma_p^2$ ). The expression  $i\sigma_p$  is called the selection differential.

Monitoring domestication selection is a challenge. Sufficiently powerful designs to allow the separation of genetic effects from environmental effects are expensive and logistically challenging (Hard 1995). At this point we propose three classes of monitoring measures to deal with this type of genetic change. Some are direct in that they will detect genetic change, and others are indirect and will detect only the potential for genetic change. The first class is measurement of selection differentials – measuring phenotypic differences between wild and hatchery adults and juveniles at traits that are likely to impose or reflect significant selection pressures. Many of these measurements will already be taken for other monitoring purposes. The second class of measures is genetic trend. This involves comparing means, ranges, and possibly variances of phenotypic traits of the Upper Yakima stock over time with baseline values and with values in the unsupplemented reference stocks. This class of measure is extremely important for evaluating the results of “sampling error” the hatchery operation may impose. Several possibilities for “sampling error” exist in the YFP. A good

---

<sup>35</sup> For a complete discussion of these concepts, see Falconer (1981).



example is winter migration. Although most upper Yakima fish do in fact migrate to the lower Yakima the winter before smolting, the degree to which this life history type will be supplemented is **unknown**<sup>36</sup>. Supplementation may cause the relative abundance of winter migrants to decline. Since this type of variability is encoded by quantitative genes, we would not expect to see genetic losses of this sort reflected in allozyme data. Thus the approach to monitoring it is simply to monitor means and variances of selected quantitative traits over time and compare them to corresponding baseline values or frequencies observed in the reference stocks. Another example, already mentioned elsewhere, is the frequency of precocial parr in the population. The third and last class of domestication selection measures is direct measurement of genetic change by comparing several traits in fish produced in the hatchery by hxh, hxw, and wxw matings. This approach, a variation on the design of Reisenbichler and McIntyre (1977) is undoubtedly the most powerful method we have proposed to monitor domestication. It may also be the most risky and is definitely the most controversial in light of the longstanding policy of excluding hatchery fish from broodstock. Modeling is underway to evaluate the genetic risk likely to be imposed by relaxation of this broodstock rule.

## Outline of Monitoring Measures for Genetics

### I. Genetic Health of the Upper Yakima stock

#### A. Type 1 Risk- Extinction

---

<sup>36</sup> The degree to which the winter migrant life history type is genetically (as opposed to environmentally) determined is unknown, and returning adults cannot now be identified to life history type when they are collected for broodstock. If the winter migrant life history type is highly heritable, and returning "winter migrant adults" are not distributed uniformly throughout the run, current broodstock collection procedures may disproportionately favor the subdominant (and probably less productive) spring smolt life history type.

1. ***Spawner-recruit relationship for wild and hatchery fish***
  2. ***Harvest rates for wild and hatchery fish***
  3. ***Other sources of mortality for wild and hatchery fish***
  4. ***Population viability analysis***
- B. Type 2 Risk- Loss of within-population genetic variability
1. ***Effective number of breeders, estimated from escapement counts and genetic data (allozyme and/or DNA)***
  2. ***Genetic variability measures (e.g., heterozygosity, alleles/locus, etc.) (allozyme and/or DNA data)***
  3. ***Fluctuating asymmetry of selected meristic traits in juveniles***
  4. ***Comparison of means, ranges, and variances of selected quantitative traits (e.g., size, age at maturity, spawning and migration timing, percentage of winter migrants) with baseline values in this stock***
  5. ***Separate marking of full-sib family groups to estimate family size variation in returning adults***

C. Type 3 Risk- Loss of adaptation and among-population genetic variability

1. *Stray rate of the **Naches** and American River stocks (and possibly other stocks) into Upper Yakima broodstock by ageing, scale **pattern** analysis and CWT recoveries*
2. *Decrease over time in a/e/e frequency profile (**allozyme and/or DNA**) differences between Upper Yakima and **Naches/American fish** (also listed under **Naches** and American)*

D. Type 4 Risk- Domestication

1. Selection potentials
  - a. ***Distribution by sex, size, age, and date of capture of prespawning mortality***
  - b. ***Comparison of wild and hatchery spawners at selected traits that are likely to impose or reflect significant selection pressures (e.g., size, age at maturity, fecundity, geographical spawning distribution)***
  - c. ***Comparison of wild and hatchery juveniles at selected traits that are likely to impose or reflect significant selection pressures (e.g., size, migration timing)***
2. Genetic trend

- a. ***Comparison of means and variances of selected quantitative traits (e.g., size, age at maturity, spawning and migration timing, percentage of winter migrants) with baseline values in this stock and with contemporaneous data in reference stocks***
  - 3. Direct measurement of genetic change
    - a. ***Performance of juveniles generated by test crosses in hatchery (h<sub>xh</sub>, h<sub>xw</sub>, w<sub>xw</sub>) at selected traits<sup>37</sup>***
    - b. ***Performance of adults generated by test crosses in hatchery (h<sub>xh</sub>, h<sub>xw</sub>, w<sub>xw</sub>) at selected traits<sup>12</sup>***
- II. Genetic Health of the Naches River and American River stocks
  - A. Type 1 Risk- Extinction
    - 1. ***Spawner-recruit relationship***
    - 2. ***Harvest rates***
    - 3. ***Other sources of mortality***

---

<sup>37</sup> This monitoring measure would require a relaxation of the long-standing broodstock collection guideline of wild-only broodstock.

4. *Population viability analysis*

B. Type 2 Risk- Loss of within-population genetic variability

1. *Effective number of breeders, estimated from escapement counts and genetic data (allozyme and/or DNA)*
2. *Genetic variability measures (e.g., heterozygosity, alleles/locus, etc.) (allozyme and/or DNA data)*
3. *Comparison of means, ranges, and variances of selected quantitative traits (e.g., size, age at maturity, spawning and migration timing, percentage of winter migrants) with baseline values in this stock and with contemporaneous data in Upper Yakima stock*

C. Type 3 Risk- Loss of adaptation and among-population genetic variability

1. *Stray rate of Upper Yakima hatchery fish onto Naches and American spawning grounds, determined by spawning ground survey*
2. *Decrease over time in allele frequency profile (allozyme and/or DNA) differences between Naches/American and Upper Yakima fish (also listed under Upper Yakima)*

III. Genetic Health of other Columbia basin spring and Snake basin spring/summer chinook stocks

A. Type 3 Risk - Loss of among-population genetic variability

1. ***Stray rate of Upper Yakima hatchery fish onto out-of-basin spawning grounds and into out-of-basin hatchery broodstocks, determined by spawning ground surveys and examination of broodstock for Upper Yakima marks<sup>38</sup>***

---

<sup>38</sup> Would almost certainly require that the YFP releases be marked with CWTs, or some other mark that would identify them as YFP fish to out-of-basin samplers.

## Section 1 D. Ecological Interactions

A few general remarks about monitoring ecological interactions are necessary to describe the context and limitations of the measures we propose. First, we address only *biotic* interactions in this section. The direct effects of *abiotic* factors are considered in the part of Section 1A dealing with productivity. It is, however, essential to bear in mind that biotic interactions are strongly influenced by the *abiotic* environment. In particular, the impacts of predators, competitors, and pathogens can all be exacerbated by *anthropogenic* changes in the *abiotic* environment (Steedman 1991). An example of this kind of relationship with particular relevance to the Yakima basin is the intensification of biotic interactions caused by anthropogenic increases in water temperature. The warming that follows removal of riparian vegetation or irrigation diversion can increase the metabolism and feeding rates of predatory fish (Vigg and Burley 1991), can cause juvenile salmon to become competitively inferior to warm-water fishes (Reeves et al. 1987), and can dramatically reduce the disease resistance of both juvenile and adult salmon (Snieszko 1974, Bucke 1993). Therefore, *abiotic* and biotic factors must be monitored simultaneously because many impacts to salmon populations have biotic proximate causes and *abiotic* (and often anthropogenic) ultimate causes. Accordingly, an appropriate suite of *abiotic* factors will always be monitored when biotic interactions are assessed.

Second, as previously mentioned in the Introduction, ecological interactions will be monitored in phases. The measures described below represent phase 1 monitoring. Phase 1 monitoring answers “what” questions, and is intended merely to detect the existence and severity of biotic interactions. Phase 2 monitoring, on the other hand, answers “why” questions, and is intended to identify causal mechanisms. Phase 2 monitoring will be triggered only by the detection of threshold impacts in phase 1.

Finally, we ~~have~~ divided biotic interactions into two major classes: those that affect the

natural production and harvest objectives that define the success of upper Yakima spring chinook supplementation, and those that caused by YFP hatchery fish and affect other **taxa**. The organization of this section (Fig. 6) reflects this simple dichotomy. Other **taxa**, except for hatchery releases, that may impact or be impacted by the spring

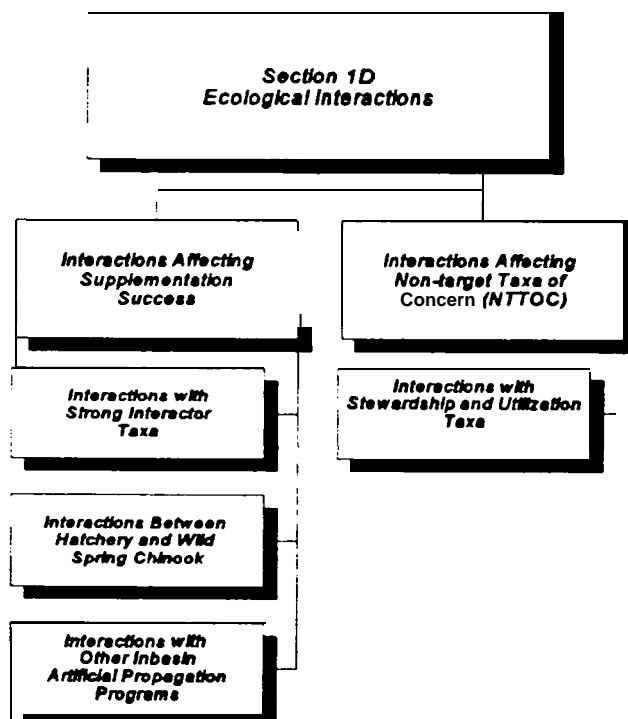


Fig. 6. Organization of Section 1D of the YFP spring chinook monitoring plan.

chinook supplementation effort are termed “Nontarget **taxa** of concern” (NTTOC). There are two broad classes of NTTOC: strong interactor **taxa** (SIT), which are capable of influencing the success of the project because of a predatory, competitive, pathogenic or **mutualistic** relationship to spring chinook; and stewardship and utilization **taxa** (SUT), which are ecologically or socially important are potentially impacted by YFP hatchery fish.



## Interactions Affecting Supplementation Success

### Interactions between Spring Chinook and Strong Interactor Taxa

Interactions involving strong interactor **taxa** are classed in terms of five “**interactor** guilds”: predators, pathogens, *competitors*, *mutualists*, and prey. All five guilds may be important. If phase 1 monitoring indicates strong relationships between the abundance of strong interactor **taxa** and survival rates for spring chinook, controlled experiments will be conducted to determine if the suspect **taxa** is in fact limiting the success of the project. If suspicions are confirmed, appropriate remedial actions may be implemented. Such actions might include suppression of predators in selected predation “hot spots”, restoration of riparian vegetation, reestablishment of beaver colonies, the addition of non-Yakima salmon carcasses to infertile rearing areas, and so on. A final kind of action that might plausibly be attempted, that differs in kind from the preceding examples, directly targets an **abiotic** condition that qualitatively worsens a negative biotic interaction. An example would be an effort to release salmon from competitive suppression by a warm-water species by reducing water temperatures in rearing areas. This kind of measure would be appropriate when an unacceptable biotic impact occurs *only* under specific **abiotic** conditions. Similar remedies for other **abiotic** factors that “catalyze” negative biotic interactions are also possible, such as reconnecting **diked-off** side channels to the **mainstem** to provide cover for rearing juveniles and thereby reduce losses to predatory birds.

Again, the intensity with which strong **interactors** will be monitored will be determined by the size of the impact they are suspected of having on spring chinook. Intense phase 2 studies will be initiated only when phase 1 studies demonstrate negative impacts to spring chinook that are most reasonably attributed to a biotic interaction.

Table 2 identifies the major suspected interactor species for Yakima spring chinook.

Following Table 2 are five subsections, one for each guild, that describe strong interactions that are most likely to be capable of limiting project success. Our phase 1 monitoring will be based on these hypothesized interactions.

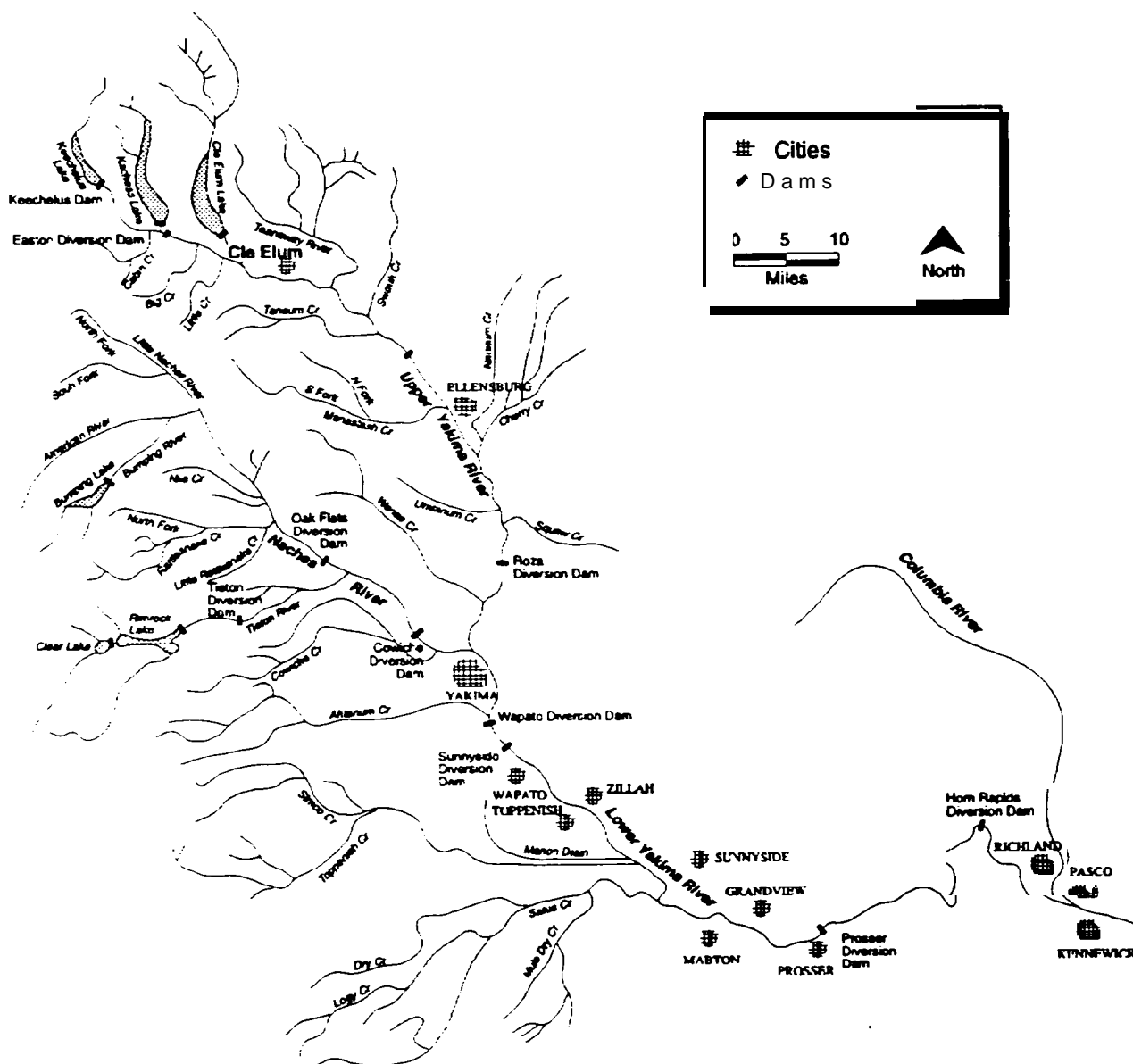
## Predators

Various species of fish, birds, and mammals have been shown to be significant predators on **salmonids** (White 1939, Ricker 1941, Alexander 1979). Northern squawfish (Rieman et al. 1991, Poe et al. 1991, Ward et al. 1995) rainbow trout/steelhead (Hillman and Mullan 1989, Beauchamp 1995) sculpins (Ricker 1941, Hunter 1959, Patten 1975, Hillman 1989a, Berejikian 1995) smallmouth bass (Tabor et al. 1993) channel catfish (Vigg et al. 1991) gull (Ruggerone 1986) common merganser (Wood 1987a, Wood 1987b), great blue heron (Krebs 1974) double-crested cormorant (Modde et al. 1996) common loon, western grebe (Modde et al. 1996) and river otter (Dolloff 1993, Reid et al. 1994) are known to prey substantially on salmonids. They are also quite abundant in the Yakima River basin (Patten et al. 1970, Pearsons et al. 1996, WDFW unpublished data).

Initial monitoring efforts will include a heavy emphasis on piscivorous fish, with specific interactions and interactors being distributed along a longitudinal gradient. One published report (Patten et al. 1970) and many anecdotal reports from anglers and local biologists indicate that channel catfish are most abundant near the Columbia River confluence, that smallmouth bass are most abundant from roughly the upstream margin of McNary pool to Prosser Dam, that northern squawfish are most abundant from Prosser Dam to Roza Dam, and that sculpins and trout are most abundant upstream of Roza Dam (and in the Naches drainage). Fig. 7 shows many of these sites. We have therefore organized our monitoring to investigate the significance of predatory impacts along this confluence-to-headwaters/catfish-to-trout continuum.

The impact of northern squawfish, smallmouth bass, channel catfish and piscivorous

birds in the middle and lower Yakima will receive heavy initial emphasis. As mentioned, these predators are believed to be quite abundant in the lower drainage. There is also evidence of a negative correlation between several abiotic factors and



Yakima River Basin

Fig. 7. Map of Yakima River Basin, showing all major streams and dams.

**Table 2. Strong interactor species likely to affect the success of YFP spring chinook supplementation.**

Guild	Species	Life Stage Influenced
<b>Predators</b> Other predators which <i>should also be considered but are currently not abundant enough to warrant special attention are:</i> <i>crappie, largemouth bass, bullheads, welleye, hooded merganser, belted kingfisher, common bittern, and osprey</i>	Northern squawfish Rainbow trout/steelhead Torrent sculpin Mottled sculpin Shorthead sculpin Smallmouth bass Channel catfish  Gulls. Common merganser Great blue heron Double-crested cormorant Common loon Western grebe Common tern  Otter	parr-smolt fry-smolt fry fry fry migrant-smolt migrant-smolt  migrant-smolt parr-smolt parr-smolt migrant-smolt smolt smolt migrant-smolt  parr-adult
<b>Pathogens</b>	Viruses Bacteria Fungi Parasites	smolt-adult smolt-adult smolt-adult smolt-adult
<b>Competitors</b>	Redside shiner Rainbow trout/steelhead Mountain whitefish	parr parr parr
<b>Mutualists</b>	Riparian vegetation (e.g., cottonwood, willow, alder) Beaver	egg-adult fry-parr. adult
<b>Prey</b>	Ephemeroptera Plecoptera Trichoptera Diptera Coleoptera	fry-smolt fry-smolt fry-smolt fry-smolt fry-smolt

lower river predations, as well as data showing that smolt losses are quite high in the region. High water temperatures (above 21° C) during the later stages of the smolt outmigration are common (Fast et al. 1991). Below some species-specific limit, high water temperatures increase the metabolism and gastric evacuation rates of piscivorous fish (Beyer et al. 1988, Vigg and Burley 1991) resulting in higher predation rates. Predators are aided by the not-infrequent combination of low spring runoff and large irrigation withdrawals, which can dramatically lower instream flows during the smolt run. Low instream flows not only exacerbate temperature problems but increase smolt travel time and the duration of exposure to predators (B. Watson, YIN, unpublished data, Cada et al. 1994, Fish Passage Center 1997) as well as causing larger proportions of the outmigration to pass through irrigation canal bypass systems at the three major diversion dams on the lower Yakima River: Wapato, Sunnyside and Prosser (Fast et al. 1991). Dams and fish bypasses concentrate and disorient outmigrating smolts, increasing their vulnerability to the piscivorous fish and birds that often congregate at such places (Brown and Moyle 1981, Ruggerone 1986, Mesa 1994, Ward et al. 1995). Based on data from Chandler Canal (Mundy and Watson, in preparation), cumulative losses to predators at bypass outfalls alone could range from 22% to as much as 95% during hot, dry periods like late May of 1992. Existing YIN data indicates that smolt survival is poor below Sunnyside Dam, especially during years with high water temperature and low flows (Fast et al. 1991, Sandford and Ruehle 1996). Therefore, temperature- and flow-mediated predation by piscivorous fish, especially below smolt bypass outfalls in the lower river, has been identified as a factor with a strong potential to limit project success.

A substantial early effort will also be directed at fry and parr predators in the upper Yakima. Like the lower river, the upper river suffers from many abiotic conditions that could greatly magnify the impact of predation. Foremost among these factors are high flows in the spring and summer, a pronounced lack of woody debris, and a drastic loss of historical side channels (Johnson 1994). Flows are high in the late spring and

summer because of the need to convey large volumes of water from the three upper Yakima storage reservoirs to lower river irrigation diversions. Combined with the extreme scarcity of velocity and security cover, these high flows may disorient, weaken and concentrate spring chinook, increasing their vulnerability to piscivorous birds and fish. Moreover, anecdotal reports suggest that the numbers of piscivorous birds (especially mergansers) are increasing in the upper river, perhaps in response to federal protection, improved reproductive conditions for waterfowl, and reduced effects of pesticides such as DDT.

Because their metabolism is much faster than that of a fish, piscivorous birds are theoretically capable of having a much larger impact on juvenile chinook than piscivorous fish. Actual studies of the impact of bird predation on salmon in the Columbia Basin are comparatively rare. However, Ruggerone (1986) demonstrated that gulls alone at a single mainstem dam can consume a significant proportion of migrating smolts. In the Yakima, large numbers of gulls congregate below the outfalls of smolt bypasses at irrigation dams, and in wide shallow reaches at low flows (Seiler 1992). Gulls have frequently been observed preying on smolts at the outfall of the Chandler smolt trap when riverflow is low (B. Watson, YIN, personal communication). Common mergansers have also been observed feeding below irrigation dams and in the free-flowing river, and salmonids have been found in their guts during winter (G. McMichael, WDFW, pers. comm.). In addition, cormorants are believed to be responsible for the large number of fish observed with "bird scars" (G. McMichael, pers. comm.)

Several other predator species, such as walleye, largemouth bass, bullhead, flathead catfish, crappie, bull trout, cutthroat trout, hooded merganser, belted kingfisher (White 1936) common bittern, osprey, mink and black bear occur in the Yakima basin. However, either because of their low abundance or inability to consume large numbers of spring chinook, interactions with these species will not be monitored closely.

However, their abundance will be indexed as part of other monitoring efforts.

Predation Indices (PI's) will be developed to gauge each predator/prey interaction monitored. Predators will be sampled during seasons and at times of the day when predation can be expected to occur at maximal rates. Separate indices will be developed for fish, birds, and mammals.

The terms of the PI for fish are predator density at a specified site or over a specified length of stream, water temperature ( $^{\circ}\text{C}$ ) (T), mean weight (g) of predator (W), mean number of spring chinook salmon in each predator's gut (S), and mean weight (g) of the gut contents (GW). These variables are used in the following equation (Ward et al. 1995) to estimate the fish PI:

Predation Index for fish = (Predator Density)(Consumption index),

and the consumption index (CI) is:

$$CI = 0.0209(T)^{1.60}(W)^{0.27}(S \cdot GW^{-0.61})$$

The predation index for birds and mammals are somewhat different. The bird PI (Ruggerone 1986) is:

Predation Index for birds = (PD)(FS)(FA)

where PD is predator density, FS is average foraging success, and FA is the number of foraging attempts per hour. Except for otters residing in the upper Yakima, we do not plan to monitor the impacts of mammalian predators because we have no evidence that mammalian impacts in the Yakima are great enough to warrant the effort. For otters, however, we will use the following expression for the Predation Index (Dolloff

1993):

Predation index for otters = (PD)(SO)

where PD is predator density and SO is half the average number of sagittal otoliths in scats.

Predators will be sampled at times of the day and season when predation is at a maximum. A brief description of the monitoring concepts for each life-stage is described below.

*Fry: fish predators* - sculpins and associated trout will be sampled immediately downstream of spring chinook salmon redds in index locations near acclimation ponds and the central hatchery facility. Fish will be collected from a minimum of six redd locations. Sampling will be conducted shortly after emergence (June-July) with a backpack electrofisher. Stomach contents will be obtained using gastric lavage.

*Parr: fish predators* - northern squawfish and trout will be sampled in five established index sites: LCYN, UCYN, EBURG, THORP, and CELUM during rainbow trout population estimates in September and October. Stomach contents will be obtained using gastric lavage.

*Parr: bird predators* - a census of bird predators will be conducted in five established index sites mentioned above. Birds will be counted during November by an observer in an inflatable raft drifting downstream or from a helicopter. Where possible, birds will be watched to determine their consumption rate. If necessary and permitted, a few birds will be sacrificed to verify visual observations.

*Parr mamma/ predators* - a visual census of the number of otter will be conducted



above Roza Dam. An average number of defecations per day will be determined and scats will be collected and examined for sagittal otoliths. Otoliths will be measured and used to determine the size of fish consumed.

*Fall migrant or spring smolt fish predators* - predators will be collected from Roza, Wapato, Prosser, and Horn Rapids (below the dams and fish bypasses) and in index reaches near the peak of spring and winter fish migration and toward the last 25% of the spring migration. During the winter, predators will not be collected at Horn Rapids. Predator density will be calculated using a multiple mark-recapture estimator.

*Fall migrant or spring smolt: bird predators* - a visual census of the predatory birds will be conducted at Roza, Wapato, Prosser, and Horn Rapids (below the dams and fish bypasses) and in index reaches. Where possible, birds will be watched to determine their consumption rate. Nonlethal gut content analysis will also be done when possible. If necessary and permitted, a few birds will be sacrificed to verify visual observations.

*Fall migrant to adult: mamma/ predators* - a visual census of the number of otter will be conducted above Roza Dam. An average number of defecations per day will be determined and scats will be collected and examined for sagittal otoliths. Otoliths will be measured and used to determine the size of fish consumed.

### *Pathogens*

Viruses, bacteria, fungi, and parasites are obviously capable of killing spring chinook (Bucke 1993). Like other salmonids, spring chinook are particularly vulnerable to infectious disease when physiological stress has compromised their immune system (Wedemeyer 1970, Pickering and Duston 1983, Pottinger and Pickering 1992). Because the process of smoltification itself constitutes a bioenergetic stress, smolts are particularly susceptible to environmental stressors, and disease outbreaks among smolts subjected to stressful conditions are common. Water quality in the lower

Yakima River frequently degenerates to acutely stressful levels for chinook smolts, particularly toward the end of the smolt outmigration in May and June. During their long pre-spawning fast, adult spring chinook channel most of their bioenergetic resources into gamete production and migration, and are also quite vulnerable to disease. Therefore, we will intensively sample the carcasses of spawned-out adults in the hatchery and on the spawning grounds for pathogens and evidence of infection. A sample of smolts will also be sacrificed for pathological examination both as they leave the acclimation raceways and as they pass through the Chandler trap on the lower Yakima. All spring chinook handled for any purpose at any life stage will also be visually examined for evidence of disease.

### *Competitors*

Rainbow trout/steelhead, mountain whitefish and, especially, redbase shiners are probably the most significant competitors for juvenile spring chinook in the Yakima Basin.

Competition monitoring will initially emphasize interactions between spring chinook and redbase shiners. Both species have very similar habitat preferences, and redsides have been shown to displace spring chinook from preferred habitat (Hillman 1989b) and to be competitively superior to chinook at temperatures above 18° C (Reeves et al. 1987). Upper Yakima spring chinook parr are frequently observed in close association with redbase shiners, and interspecific conflict between individuals in such associations is common (Pearsons et al. 1996).

The impact of competitive interactions with rainbow/steelhead and whitefish will also be examined. Rainbow/steelhead are commonly associated with spring chinook in the upper Yakima, particularly in side channels and during the late summer and early fall (Pearsons et al. 1998). Interactions are frequent in aggregations of rainbow and chinook and sometimes result in the displacement of spring chinook (Pearsons et al.

1996). The mountain whitefish is one of the most abundant fishes in the upper Yakima (Pearsons et al. 1996). Juvenile chinook and whitefish are, however, rarely found in association (Pearsons et al. 1996). Even so, whitefish may exploit food resources that spring chinook salmon also utilize, and may therefore be able to reduce food availability to the point that growth and survival of spring chinook are affected (Daily 1971). Comparisons of diets between the two species indicate that they eat a variety of aquatic invertebrates (Laakso 1951, Daily 1971, Healey 1991, Northcote and Ennis 1994).

The impact of competition on upper Yakima spring chinook will be assessed indirectly, by comparing inter-specific food and space utilization. We will estimate the pervasiveness of interspecific interactions by the frequency with which chinook salmon and competitor species are observed within 30 cm of each other. These observations will be made by snorkeling three well-studied reaches in the upper Yakima. We will gauge food availability and the outcome of interspecific food competition by comparing relative gut contents (gut weight divided by body weight or maximum stomach weight) between spring chinook and sympatric competitor species, and by comparing gut contents between spring chinook that were or were not collected from interspecific aggregations. Finally, we will attempt to quantify the impact of competition on spring chinook by comparing competitor densities with the length-weight relationship of spring chinook collected in sympatry.

It is frequently difficult to determine the significance of many kinds of observations that might logically indicate the occurrence of significant levels of competition. High resource overlap between sympatric species is a good indication of competition only if resources are relatively scarce and at least one of the species fares better in allopatry. Conversely, low resource overlap is a good indication that significant competition is *not* occurring only when it can be demonstrated that the lack of overlap is due to innate differences in preferences. Thus, without knowledge of resource availability and

innate species-specific preferences, resource overlaps are poor indices of competition. Accordingly, we will gauge the severity of competition by monitoring both resource availability and overlap, and interpreting such observations in the light of published reports of species preferences.

We will use the combinations of observed levels of overlap and abundance shown in Tables 3 and 4 to determine the probability of serious competitive impacts on spring chinook. This probability assessment will determine our response to a particular interaction. Controlled phase-2 experiments will be conducted whenever the probability of serious competitive interaction is high, and refined phase-I observations will be implemented when the probability is judged to be moderate. We will merely continue baseline phase-I monitoring for those interactions determined to have a low probability of significantly affecting growth of spring chinook.

Table 3, **Components of food competition index and relative certainty of competition.** Boundary between high and low stomach fullness is 0.5 and between high and low diet overlap is 0.25.

		Stomach Fullness	
		High	Low
Diet Overlap	High	Low	High
	Low	Low	Moderate

**Table 4. Components of space competition index and relative certainty of competition. Boundary between high and low competitor abundance is 0.5 and between high and low overlap is 0.25. Index assumes that when competitors are within 30 cm of each other they will behaviorally interact (Pearsons et al. 1996).**

		Abundance of competitor <sup>a</sup>	
		High	Low
Spatial Overlap <sup>b</sup>	High	High	Moderate
	Low	Moderate	Low

<sup>a</sup> competitor abundance will be expressed as the ratio of competitor abundance/spring chinook salmon abundance when fish are found within the same pod (within 1 foot of each other).

<sup>b</sup> expressed as the percent of spring chinook salmon pods that have at least one competitor included

Abundance of competitor example: of the rainbow trout (RBT) and spring chinook (SPC) found within the same pod,

Pod 1 3 RBT/6 SPC = 0.5

Pod 2 6 RBT/3 SPC = 2.0

Pod 3 1 RBT/10 SPC = 0.1

Average =  $\frac{2.613}{3} = 0.87$

### *Mutualists*

Beaver and riparian vegetation are probably the key mutualists for spring chinook in the

Yakima basin. Riparian vegetation is known to affect the densities of salmonids by providing cover from predators, instream structure, shading, and a foundation for the food chain (Platts and Nelson 1989, Li et al. 1994, Tait et al. 1994). Beaver construct dams which can increase nutrient retention and provide habitat structure for rearing salmonids (Naiman et al. 1988). Positive relationships between beaver density and salmonid abundance have been observed in small tributary streams (Gard 1961, Nickelson et al. 1992). Furthermore, high densities of juvenile spring chinook salmon have been observed in areas created by beavers (T. Pearsons, WDFW, unpublished data). Beaver appear to have been quite abundant in the Yakima basin historically but were trapped extensively before 1850 for their fur (Johnson and Chance 1974, Glauert and Kunz 1976). The abundance, type, and function of riparian vegetation have decreased dramatically throughout the Yakima basin as a result of resource uses such as logging, channelization, grazing, mining, water management, and housing development (Pearson 1985, Johnson 1994, Leland 1995). Furthermore the role of riparian vegetation as hydraulic, temperature, and predator cover has been reduced because of the way water is managed in the upper Yakima basin.

The distribution, abundance and size of hydraulic refuges provided by beavers and riparian vegetation will be enumerated by examination of aerial photographs and by floating sections of the upper Yakima River, Cle Elum River and the North Fork of the Teanaway River. Flights will be conducted during the winter. In addition, the distribution, abundance, and composition of riparian vegetation will be evaluated using aerial photographs and ground surveys.

### *Prey*

Chinook salmon rearing in streams prey primarily on larval and adult insects (Healey 1991). During the winter in the Fraser River basin, juvenile chinook salmon consume mainly Diptera, Trichoptera, and Plecoptera (Levings and Lauzier 1991). The diet of chinook salmon during downstream migration in the Snake River is dominated by

dipterans (Muir and Coley 1996).

Prey availability can have a strong influence on the abundance and growth of spring chinook salmon. A decrease in prey abundance can potentially increase intraspecific competition of spring chinook salmon. Alteration of stream flows, such as occurs in the Yakima basin, can significantly impact prey abundance. Stomach fullness of spring chinook salmon in the Yakima River has been shown to vary with location and time of year (B. Beckman, unpublished data, NMFS). Furthermore, decreases in the availability of salmon carcasses could decrease the food base for spring chinook salmon (Bilby et al. 1996). This could occur if carcasses from YFP broodstock are not released back into the Yakima basin in ways that simulate natural carcass distributions.

The availability of prey will be assessed by examining the stomach fullness of spring chinook salmon during the summer and fall in four areas: NELSN, CELUM, THORP, and NFT. Spring chinook salmon will be collected by electrofishing. Stomach fullness will be enumerated by dividing the dry weight of the stomach contents by the total body weight or other relevant denominator (Herbold 1986). Stomach contents will be acquired by lavage techniques.

### **Interactions between Hatchery and Wild Spring Chinook**

An extremely important class of interactions that can affect supplementation success is interactions between hatchery spring chinook and their wild **counterparts**<sup>39</sup>.

Interactions in the Yakima basin, Columbia River, and the estuary can occur at the juvenile or adult stage. There may also be interactions in the ocean. Several negative interactions that would result in decreased natural production are possible. Direct predation is one possibility. Sholes and Hallock (1979) found that yearling fall chinook released from a California hatchery preyed extensively on wild subyearlings. Increased

---

<sup>39</sup> Good reviews are found in Mamell (1986) and Steward and Bjorn (1990). White et al. (1995) present an extensive listing of papers dealing with interactions.

indirect predation pressure is another possibility. Consumption of juvenile salmonids may increase when hatchery fish are released (Collis et al. 1995). In addition, if wild fish are smaller than hatchery fish, they may be selectively targeted by predators when both types of juveniles are present (Shively et al. 1996). Hatchery fish may also cause premature migration of wild juveniles (Hillman and Mullan 1989) the so-called “pied piper” effect. They may also compete for space or food resources (Peery and Bjornn 1996). Hatchery-reared fish may be more piscivorous than their wild counterparts because they are generally larger and can consume larger prey items. In addition, larger hatchery fish may outcompete smaller wild fish for resources when they set up feeding stations during downstream migration or if residualism occurs. Disease transfer is another possibility. Although there apparently is no direct evidence for disease transfer in a native-stock supplementation effort, such efforts can easily include many factors that can enhance disease possibilities (review in Steward and Bjornn 1990). A final concern is nutrient mining due to removal without replacement of adults for hatchery broodstock. The importance of carcasses to the food web of a stream is just now becoming appreciated (e.g., Bilby et al. 1996).

However, positive interactions are also possible. The daily consumptive capacity of predators is limited (Vigg and Burley 1991). Hatchery releases could in theory satiate the predators, allowing *higher* survival of wild fish (Peterman and Gatto 1978, Peterman 1987). If hatchery returns result in a substantial increase in the number of carcasses in the stream relative to pre-hatchery conditions, the result will be nutrient enhancement (Bilby et al. 1996).

Interactions between hatchery and wild spawners are another possibility. Hatchery and wild fish may compete for spawning sites and mates (e.g., Fleming and Gross 1992, 1993). If hatchery-origin adults are poor spawners relative to wild fish (e.g., Chilcote et al. 1986, Leider et al. 1990), wild fish pairing with hatchery fish may be wasting some of their reproductive potential.



Although we have chosen to consider hatchery-wild interactions as a category of factors limiting supplementation success, as indeed they are, there is an equally good argument for approaching them from a risk-containment perspective. Thus, we can consider hatchery fish as strong interactors affecting supplementation success, or we can consider wild spring chinook a “target taxon of concern”. This is much more a philosophical issue than an operational one, as the monitoring measures remain the same no matter how the problem is viewed.

Since monitoring the condition of the wild component of the Upper Yakima spring chinook stock is a major component of Natural Production monitoring, there is a considerable overlap between Natural Production monitoring and monitoring ecological hatchery-wild interactions. These measures include, but are not limited to, abundance of smolts and adults; size structure of parr, smolts, and adults; and distribution of parr and spawning adults. Interactions indices will also be measured concurrently with other activities. Interactions will only be measured during four stages of the hatchery fish life cycle: smolt, residual, precocial, and anadromous adult. Relationships between interactions indices and the status of wild spring chinook salmon could trigger the following responses: 1) begin phase II research to determine cause and effect, 2) change management actions to minimize impacts, 3) evaluate effectiveness of change.

A great deal of information about hatchery-wild interactions will come directly from Natural Production monitoring, and Ecological Interactions monitoring already described. For example, pathogen sampling already described will cover the disease transmission aspect of hatchery-wild interactions. Similarly, interactions between wild and hatchery spawners will be noted during Natural Production reproductive success monitoring (measures under I.A.2). However, we propose several additional natural production measures that can serve as interaction indices of predation, competition, and altered migration behavior.

## Interactions between Spring Chinook and Fish from Other Inbasin Artificial Propagation Programs

Releases of non-YFP hatchery fish may adversely impact upper Yakima spring chinook, NTTOC, and the ability to monitor the YFP effectively. For instance, release of large numbers of hatchery who smolts might decrease the survival of spring chinook or NTTOC through competition, predation (direct or through predator attraction), or pathogenic interactions (WDFW 1995). For example, hatchery who salmon released in the Yakima River have the potential to consume chinook salmon that are as large as 45.3% of their own body length (T. Pearsons, WDFW, unpublished data). It is therefore imperative that all non-YFP releases of hatchery fish be coordinated with the YFP so that appropriate adjustments to monitoring protocols can be implemented<sup>40</sup>. In some cases, it may also be necessary to revise non-YFP release strategies (number, species, location, life-stage, condition, and timing) to minimize risk to upper Yakima spring chinook or NTTOC. Some coordination has already been achieved. In 1997, coho releases in the Yakima and Naches Rivers were delayed until May 15 to allow the age-0 chinook time to grow large enough to reduce the risk of predation by coho.

The potential impact of non-YFP releases on spring chinook monitoring warrants additional emphasis. Given the constraints of existing facilities and manpower, the release of large numbers of non-YFP fish can very easily become a major complication. For example, large numbers of who released above Prosser and subsequently entrained in Chandler Canal might decrease the accuracy (increased fish misidentification) and precision (lower subsampling of wild spring chinook salmon) of

---

<sup>40</sup>In most cases, these adjustments would consist of adding the non-YFP hatchery fish to the list of potential "strong interactor species", and then monitoring its interactions according to the presumptive guild – viz as a predator, competitor, disease vector, mutualist or prey. Except perhaps for location and timing, monitoring measures would be as described previously for resident strong interactor species.

To collect the required number of wild spring chinook for various monitoring purposes at Chandler Canal, a specified fraction of the smolts diverted into the canal must be routed into a live-box for examination. If hatchery coho outnumber wild spring chinook 20 to 1 (as may be the case for next few years), it will not be possible to route a sufficiently high fraction of fish (for spring chinook monitoring) into the livebox unless fish are worked up two or three times a day. Without this intensive effort, gross

passage estimates for wild upper Yakima spring chinook smolts. Releases of who parr might complicate competition studies by making it more difficult for snorkelers to discriminate spring chinook from coho in multispecies pods". It will also be more difficult to determine whether YFP spring chinook caused observed impacts to NTTOC if large numbers of non-YFP fish are present. Finally, the suitability of Naches and American River stocks as reference populations for the upper Yakima stock could be compromised if large numbers of smolts or parr of a potential strong interactor species are routinely released only in the Naches Basin, or if natural reproduction of such a species were reestablished only in the Naches. In such a case, the differences in community ecology between the upper Yakima and the Naches would be too great to permit the inference that relative differences in the performance between the upper Yakima and Naches/American stocks were attributable to the YFP.

Currently, species released by non-YFP programs include coho, fall chinook and rainbow trout. Except perhaps for monitoring, fall chinook releases are not expected to have a major impact on the spring chinook effort. Most coho are currently released in the lower river, where the only impacts on spring chinook are likely to consist of possible monitoring complications and indirect **predation**<sup>43</sup>. In recent years, however, coho parr and smolts have also been released in the Naches Basin. These releases may have a greater potential to affect spring chinook production as well as YFP monitoring. The impacts of hatchery-reared who on Naches spring chinook is currently being monitored by the YIN.

---

overcrowding and consequent high mortality in the livebox would occur.

<sup>42</sup> This will be only a potential complication so long as coho continue to be released only in the Naches and lower Yakima (and do not colonize the upper Yakima). No competition studies are currently planned for the Naches or lower Yakima.

<sup>43</sup> Coho smolk could either increase predatory losses of spring chinook (wild and/or hatchery) by increasing the feeding rates of resident predators (functional response) or attracting more predators (numerical response). Conversely, they could shield spring chinook from predation if they were more vulnerable to predators and especially if their numbers were so large as to 'swamp' the predators' consumption capacity.

Because the who program is in flux, and is being monitored outside the YFP, we have not developed monitoring measures for it with respect to spring chinook<sup>44</sup>. As the who program evolves and possibly is integrated with the YFP, specific monitoring measures will be developed.

Except for a small release in Wilson Creek, all stream releases of hatchery trout currently occur in the Naches Basin (Naches mainstem, Little Naches River and Bumping River). As mentioned previously, rainbow trout have the potential to interact with spring chinook as competitors, predators and disease vectors. There is therefore a clear potential for direct impacts on Naches/American spring chinook production as well as Naches NTTOC (particularly steelhead and resident rainbow). Currently no measures have been established to monitor the impacts of hatchery trout.

The preceding comments should not be misinterpreted as a criticism of ongoing efforts to supplement fall chinook, to reestablish who production, or to augment the rainbow trout sport fishery. Rather, they should be understood as a justification for the need for close coordination between the YFP and other fish enhancement programs to ensure success of monitoring efforts and to maximize compatibility of all production programs.

## **Interactions Affecting Stewardship And Utilization Taxa<sup>45</sup>**

Supplementation of upper Yakima spring chinook salmon will undoubtedly impact other taxa, and the number of taxa potentially impacted is vast. Potential impacts include exploitative or interference competition, direct or indirect predation, behavioral anomalies such as pied piper effects, and disease transfer. In many cases the effects may be negligible or may impact taxa deemed to have little ecological or social value.

---

<sup>44</sup> Monitoring coho releases for impacts on fall chinook is a YFP function, but these efforts, since they do not involve spring chinook, are not included here.

<sup>45</sup> Much of the material in this section is taken from WDFWs draft Objectives for Nontarget Taxa of Concern Relative to Supplementation of Upper Yakima Spring Chinook (Pearsons, in prep.).

However, others may affect important taxa significantly. This class of Nontarget Taxa of Concern (NTTOC) is called Stewardship and Utilization Taxa (SUT). An essential element of the YFP is to manage the program to keep impacts to SUT “within specified limits”. Accordingly, we must monitor the status of such taxa to detect impacts and the effects of compensatory actions.

In order to monitor success in attaining objectives, the objectives must first be defined. In developing objectives for SUT we first identified the species to consider and then determined allowable impacts (deviations from current status) for each species. The Co-managers of the project, the YIN and the WDFW, have not yet met to adopt an official list of SUT species and allowable impacts. When they do, their decision will be recorded in the Objectives for Nontarget Taxa of Concern *Relative of Supplementation of Upper Yakima Spring Chinook*, a document now in draft form (Pearsons et al., in preparation).

It is extremely important to begin baseline monitoring of prospective SUT taxa as soon as possible since little is known about their distribution, abundance, size structure or monitoring tractability. Without adequate baseline data it will be impossible to determine achievement of objectives, since objectives must be expressed in terms of deviations from current conditions. Therefore, informed by preliminary discussions with WDFW and YIN staff and local fishing clubs, MIPT has acted in advance of the official adoption of an NTTOC-SUT plan, and has developed a provisional plan to guide collection of baseline data.

The first critical decision made was to include only fish species as **SUT**<sup>46</sup>. Forty-eight fish species occur in the Yakima basin, 29 natives and 19 exotics (Patten et al. 1970,

---

<sup>46</sup> Many other non-fish nontarget taxa may also be impacted (e.g. bald eagle, sharp tailed snake) and may be considered in future analyses.

Mongillo and Faulconer 1980, McMichael 1991). Species were assigned to the NTTOC-SUT list based on perceived vulnerability to spring chinook supplementation and importance in terms of stewardship and utilization values. All native fish species are included on the basis of stewardship, and those that are **regionally**<sup>47</sup> or locally<sup>48</sup> (within the Yakima Basin) rare, are considered extraordinarily important in terms of stewardship. Species used for food or recreation are considered important on the basis of utilization value. Exotic species were not included as SUT because the targeted species – upper Yakima spring chinook – is native and therefore inherently more valuable. In other words, because the target species is native, we considered any negative impact to exotics acceptable.

Quantitative status objectives for NTTOC-SUT were framed in terms of the acceptable impact to a taxon's baseline status or health (before supplementation). Objectives were framed in terms of acceptable deviations (as a percentage) from baseline (pre-supplementation) *distribution, abundance and size structure*. Thus, failure to meet an objective for an SUT taxon would occur if an unacceptably large (and adverse) change in any of these three variables could be attributed to spring chinook supplementation. Attributing an impact to supplementation will probably be difficult because all other possible causes must be ruled out. Determining the cause of a change in SUT status will sometimes require small scale experiments within the treated area (Pearsons et al. 1993).

When objectives between SUT taxa conflict, the needs of the more important taxon will be considered first. Species that fit in more than one category were placed in the category of higher priority. For example, westslope cutthroat trout can be classed as a stewardship or utilization species. They were in fact classed as a stewardship species

---

<sup>47</sup> Listed as a category 1 or 2 species on the Federal Register.

<sup>48</sup> Few individuals having been collected during the last decade.

because they are regionally rare (a category 2 species on the Federal Register).

Acceptable impact levels were chosen using the following priorities in order of importance; stewardship over utilization, rare over common, native over nonnative, use is very important over important. Impact levels for stewardship taxa were influenced by the current status of the taxon. Similar to taxa that are listed as threatened or endangered, we consider *no* impact acceptable for species that are regionally rare. Native game or food fish were judged to be very important (as opposed to important) based upon perceived or actual use. About half the SUT finally identified (Tables 56 were in the utilization category and half in the stewardship category.

Monitoring measures for SUT were developed by considering the hypothesized spatial-temporal overlap with spring chinook, perceived risk of not achieving objectives, and monitoring opportunities and constraints (Table 6). The latter factor is extremely important, and sets this section of the monitoring plan apart from the others. As mentioned in the Introduction, this phase of the YFP monitoring plan is conceptual in most areas. Power, logistical difficulty, and cost have not yet been considered. It is unnecessary to restrict proposed monitoring measures for SUT to this level because we already have enough experience to make reasonable projections of monitoring feasibility and cost. Therefore, the monitoring ‘prescriptions’ listed in Table 6 and described in the outline reflect expected logistical difficulties and acceptable costs.

**Table 5. Nontarget taxa of concern of stewardship or utilization importance (SUT) that may be affected by YFP spring chinook supplementation. Acceptable impacts refer to changes in one or more of distribution, abundance, or size structure.**

<b>Stewardship Taxa</b>	
Rare- species, stock, or regionally	No impact
Bull trout	
Weslope cutthroat trout	
Pacific lamprey	
Rare- in basin	Impact < 5%
Marion Drain fall chinook	
Upper Yakima steelhead	
Mountain sucker	
Leopard dace	
Sandroller	
Common- other native species	Species must be kept at sustainable levels
<b>Utilization Taxa</b>	
Highly valued native game or food fish	Impact < 10%
Rainbow (redband) <sup>49</sup> trout in the mainstem Yakima	
Naches steelhead	
Satus steelhead	
Toppenish steelhead	
Naches spring chinook	
American River spring chinook	
Valued native game or food fish	Impact < 40%
Mountain whitefish	
Rainbow (redband) trout in tributaries	

<sup>49</sup> All native Yakima rainbow trout and steelhead are considered redband trout (*Oncorhynchus mykiss gairdneri*) (Behnke 1992) although in the text for the sake of clarity, we will continue to call them rainbow trout and steelhead.



**Table 6. Perceived overlap with spring chinook, preliminary ecological risk assessment of non-attainment of objectives, and monitoring prescription for Stewardship and Utilization Taxa (SUT). Prescriptions are described in the outline of monitoring measures below. For overlap and risk L=low, M=med H=high.**

	Overlap	Risk	Prescription
<b>Stewardship Taxa</b>			
Rare- species, stock, or regionally			
Bull trout	L	L	A
Wesloche cutthroat trout	L	L	A
Pacific lamprey	H	H	B
Rare- in basin			
Marion Drain fall chinook	L	L	C
Upper Yakima steelhead	H	H	D,
Mountain sucker	H	L	E
Leopard dace	H	L	E
Sandroller	L	L	E
<b>Common- other native species</b>	L-H	L	G
<b>Utilization Taxa</b>			
Highly valued native game or food fish			
Rainbow (redband) trout in the mainstem Yakima	H	M	E
Naches steelhead	L	L	D2
Satus steelhead	L	L	D3
Toppenish steelhead	L	L	D3
Naches spring chinook	M	M	F
American River spring chinook	M	M	F
Valued native game or food fish			
Mountain whitefish	H	L	E
Rainbow (redband) trout in the tributaries	M	L	E

For some SUT, the deficiency of baseline data, small sample sizes, or high natural variation will preclude the detection of impacts as small as those specified in Table 3. In such cases, the ability to detect and contain ecological risks will be low, and the merit of the project must be weighed against the risk of failing to meet the NTTOC objective. For example, the objective for pacific lamprey is no impact, but impacts may not be statistically detectable until they reach 75%. This should not result in a relaxation of the objective (e.g., changing acceptable impact levels to 75%) but rather an acknowledgment that monitoring will not allow the detection of impacts until more than the “acceptable” level of damage has already occurred.

## Outline of Monitoring Measures for Ecological Interactions

### I. Interactions affecting Supplementation Success

#### A. Interactions with “Strong Interactor” <sup>50</sup> Taxa

1. Predators- a predation consumption index will be developed that applies to the fry, Parr, winter migrant, and smolt life stages.

##### a. *Interactions with fry*

- (1) *Fish predators (sculpin and rainbow trout <sup>51</sup>) at index locations near redds*

---

<sup>50</sup> List of potential strong interactors is in Table 2 above.

<sup>51</sup> Cutthroat trout, bull trout, crappie, walleye, etc., are potential spring chinook predators, but are expected to be too uncommon to be included in predation index, with the possible exception of cutthroat in the extreme upper basin.

b. *Interactions with pan*

- (1) *Fish predators (squawfish and rainbow trout) at index sites*
- (2) *Bird predators (mergansers, herons) at index sites (same sites used for fish predators)*
- (3) *Mammal predators (otter) at index sites*

c. *Interactions with winter migrants and spring smolts*

- (1) *Fish predators (squawfish, bass, catfish, trout) below dams (Roza, Wapato, Presser), at bypasses, and in index reaches at peak winter migration time for spring chinook*
- (2) *Bird predators (mergansers, herons, gulls, terns, cormorants) below dams (Roza, Wapato, Presser), at bypasses, and in index reaches at peak winter migration time for spring chinook*
- (3) *Fish predators (squawfish, bass, catfish, trout) below dams (Roza, Wapato, Prosser, Horn Rapids), at bypasses, and in index reaches at peak spring migration time for spring chinook*

- (4) ***Bird predators (mergansers, herons, gulls, terns, cormorants, loons, grebes)below dams (Roza, Wapato, Prosser, Horn Rapids), at bypasses, and in index reaches at peak spring migration time for spring chinook***
- (5) ***Fish predators (squawfish, bass, catfish, trout)below dams (Roza, Wapato, Prosser, Horn Rapids), at bypasses, and in index reaches during last quartile of spring smolt migration for spring chinook***
- (6) ***Bird predators (mergansers, herons, gulls, terns, cormorants, loons, grebes)below dams (Roza, Wapato, Prosser, Horn Rapids), at bypasses, and in index reaches during last quartile of spring smolt migration for spring chinook***
- (7) ***Mammal predators (otter) in index reaches at peak migration time (winter, spring) for spring chinook***

d. ***Interactions with adults***

- (1) ***Mammal predators (otter) at index sites***

2. Pathogens (viruses, bacteria, fungi, parasites)

- a. ***Occurrence and infection levels (determined by pathological examination) in adult broodstock at Roza<sup>52</sup>***
  - b. ***Occurrence and infection levels (determined by pathological examination) in spring smolts migrating past Prosser through migration period*** (utilizing fish collected at Chandler for substock identification work)
  - c. ***Occurrence and infection levels (determined by pathological examination) in hatchery smolts exiting acclimation raceways<sup>4</sup>***
  - d. ***Occurrence of and infection levels by external pathogens (determined by routine visual inspection) of all spring chinook collected for other monitoring purposes***
3. Competitors (rainbow trout/steelhead, redbreast shiners, mountain whitefish)
- a. Indirect measures
    - (1) ***Occurrence of spring chinook within 30 cm of a competitor and relative abundance of competitors in index areas*** (determined by snorkeling observations)

---

<sup>52</sup> This measure is also listed in the Facility control

section (Section 3).

- (2) ***Relationship of gut fullness and diet overlap to competitors in index areas*** (utilizing fish collected expressly for this purpose or primarily for other purposes)
    - (3) ***Relationship of length-weight relationship to relative abundance of competitors*** (utilizing fish collected during rainbow trout population surveys)
  - b. Direct measurement of competition
    - (1) ***Growth in small scale experimental arenas with varying abundance of competitors***
- 4. Mutualists (beaver, riparian vegetation)
  - a. ***Distribution, size, and abundance of hydraulic refuges in Yakima basin created by beaver and riparian vegetation, and composition of riparian vegetation***  
(determined by winter aerial photographs and 'ground-truthed" by floating sections of the Upper Yakima, Cle Elum River, and North Fork Teanaway)
- 5. Prey (ephemeroptera, plecoptera, trichoptera, diptera, coleoptera)
  - a. ***Gut fullness of juvenile spring chinook salmon collected in summer in four index areas (Nelson, Cle Elum, Thorp, North Fork Teanaway)***



- a. ***Comparison of migration timing (fry and presmolts/smolts) with and without hatchery fish present at Chandler and/or Roza to determine if a spike in wild spring chinook migration occurs concurrent with hatchery releases***
  - b. ***Snorkel observations to determine if wild spring chinook are “pulled” from feeding stations by migrating hatchery fish***
- C. Interactions between spring chinook and fish released from other inbasin artificial propagation programs

***No specific measures proposed at this time.***

## II. Interactions affecting Stewardship and Utilization Taxa (SUT)

### A. Interactions affecting Stewardship Taxa

- 1. Bull trout and cutthroat trout: monitoring prescription A
  - a. ***Abundance and size structure in index areas***
  - b. ***Abundance, size structure, and distribution of fluvial life-history forms*** (probably very few, but collected as collateral information from other monitoring activities)



- c. ***Distribution and spatial overlap with Upper Yakima spring chinook***
  - d. ***Conduct small-scale competition experiments to determine effect on growth rate, if overlap in range with spring chinook in a stream is > 5%***
- 2. Pacific lamprey: prescription B
  - a. ***Index of abundance and size structure of juveniles and adults at Roza and Prosser dams***
  - b. ***Distribution of adults and juveniles in index areas***
- 3. Marion Drain fall chinook: monitoring prescription C,
  - a. ***Number and distribution of redds***
  - b. ***Size at age of adults (carcass recoveries)***
- 4. Upper Yakima steelhead: prescription D,
  - a. ***Number and size of adults at Roza***
  - b. ***Size at age of adults at Roza*** (collected incidentally during spring chinook trapping operations)
  - c. ***Size at age of smolts passing downstream past Roza***

5. Mountain sucker, leopard dace, and sandroller: monitoring prescription E
  - a. ***Density, distribution, and size structure in index areas***
  - b. ***Relative abundance of fish moving downstream past Prosser***
6. Other non-utilization native fish taxa: prescription G
  - a. ***Relative abundance of fish moving downstream past Prosser***
  - b. ***Distribution and relative abundance*** (collected as collateral information during other sampling activities)

B. Interactions affecting Utilization Taxa

1. Rainbow (redband) trout in the mainstem Yakima: prescription E
  - a. ***Density, distribution, and size structure in index areas***
  - b. ***Relative abundance of fish moving downstream past Prosser***
2. Naches Steelhead: monitoring prescription **D<sub>2</sub>**

- a. ***Number of adults*** (determined by subtracting counts from other areas from Prosser count)
3. Satus Creek and Toppenish Creek steelhead: prescription **D<sub>3</sub>**
  - a. ***Number of adults on spawning grounds***
  - b. ***Number and distribution of redds***
4. Naches and American River spring chinook: monitoring prescription F
  - a. ***Smolts/ female spawner***
  - b. ***Spawning timing and distribution***
  - c. ***Size at age of adults***
  - d. ***Migration timing of smolts relative to Upper Yakima hatchery smolts***
  - e. ***Stray rate of Upper Yakima spring chinook onto Naches and American River spawning grounds***
5. Rainbow (redband) trout in tributaries and mountain whitefish: prescription E
  - a. ***Density, distribution, and size structure in index areas***

- b. **Relative abundance of fish moving downstream past  
*Prosser***

## Section 2. OCT/SNT Comparisons

The second experimental tier of the YFP spring chinook supplementation effort is a rigorous test of the effects of different acclimation “treatments” on the survival and reproductive success of hatchery fish. This will be accomplished by replicated releases of treatment groups reared in eighteen identical (except for treatment-specific modifications) raceways. The groups of fish will then be acclimated and released from eighteen raceways (again, identical except for treatment-specific modifications) at three sites, with six raceways located at each of the sites: Clarke Flat (near Thorp), Jack Creek (on the north fork of the Teanaway), and Easton (near Easton Dam). From a monitoring perspective, this experimental layout possesses two important features:

- 1) The number and size of OCT and SNT replicates should allow detection of significant differences in survival from a single release. Specifically, if a smolt-adult survival of 0.2% can be achieved for fish subjected to the poorer of the two treatments, and if 810,000 fish can be released, a 50% difference in survival rate between fish subjected to the two treatments can be detected with 90% power from a single year’s release (Hoffmann et al. 1994).<sup>53</sup> If survival rates are less than expected, or if release numbers are below 810,000, specified power will be achievable only by pooling data over years. As mentioned in the Introduction, these power specifications are a marked difference between this experimental tier and the first , for which statistical power has yet to be determined for nearly all response variables.
- 2) Although the project was designed to achieve specified power in evaluating two specific rearing treatments, the layout is not treatment-specific. It is a general

---

<sup>53</sup> There are some additional assumptions about sampling rate, sunhal rate variance, the magnitude and distribution of environmental variance, and the probability of type I error. See Hoffmann et al. (1994) for details.

design for testing treatments by replicated releases of treatment groups. Now and for the foreseeable future, the plan is to test the so called Optimal Conventional Treatment (OCT) against the Semi-Natural Treatment (SNT). The same layout could be used in the future to compare other treatments (e.g., diet or prophylactic treatments), possibly more than two at a time.

Under the current plan, OCT fish will be released from three acclimation raceways at each of the three sites and SNT fish from the other three. The OCT treatment is “conventional” because, for the most part, standard Columbia Basin spring chinook hatchery practices will be followed. Differences between YFP OCT fish and fish produced by other spring chinook hatcheries will be relatively minor, consisting primarily of the use of ‘state-of-the-art’ cultural **techniques**<sup>54</sup> and a greater emphasis on quality control in the OCT treatment. Thus, qualified by cultural differences between the OCT treatment and procedures at individual hatcheries, YFP results can be extrapolated to other conventional hatcheries, at least on a relative SNT/OCT basis.

In contrast, the SNT treatment is a more natural rearing regime (Maynard et al. 1995) quite unlike the typical hatchery environment. As currently planned, the SNT treatment will combine the following: cover, in-water structure, rugose substrate, and undewater feeding (Steve Schroder and Curt Knudsen, WDFW, pers. comm.), and possibly predator-avoidance training. Exact treatment specifications will not be determined until small scale test releases in western Washington have been evaluated.

From a monitoring perspective, the exact differences between OCT and SNT treatments are unimportant. What is important is that the treatments are expected to produce smolts that differ in coloration, behavior, and physiology.

---

<sup>54</sup> The OCT treatment was modeled after the Eastbank Hatchery.

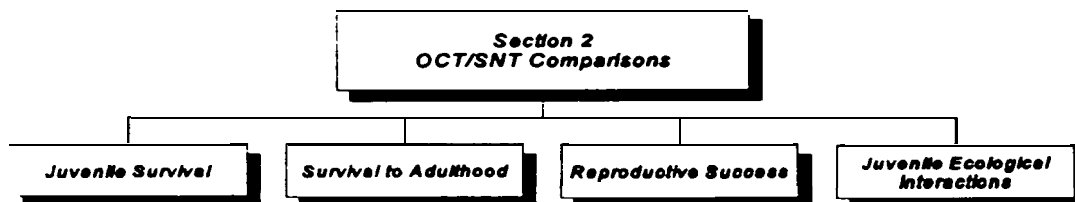


Fig. 8. Organization of Section 2 of YFP spring chinook monitoring plan.

We anticipate large differences in early post-release survival, and traits associated with survival, between OCT- and SNT-reared fish. Specifically, we anticipate large differences in survival between the acclimation sites and Chandler trap, as well as from Chandler and the acclimation sites to smolt monitoring facilities at McNary Dam<sup>55</sup>. Thus, the first of the four monitoring measures described below targets early smolt survival. Because fish from the two treatment groups will be tagged with benignly and unambiguously readable VIJ marks, all juvenile survival measures should be feasible. Power has yet to be determined, but since the numbers of fish will be so high at this life

---

<sup>55</sup> Equally large or larger differences would be expected between acclimation ponds/Chandler and smolt monitoring facilities at John Day and Bonneville Dams. But estimating such differences at John Day and Bonneville is completely dependent upon the installation and/or refinement of passive interrogated transponder (PIT)-tag detectors. Because large scale detectors either have not yet been installed (John Day) or require considerable refinement for optimal performance (Bonneville), we do not now emphasize estimating relative smolt survival to these mainstem facilities. However, we intend to exploit to the fullest the monitoring opportunities PIT-tag detectors at these sites offer.

stage and at these facilities, and since so few of the measures require lethal sampling (only I.E and I.K), adequate power should not be a problem. The procedures we propose to estimate early smolt survival are identical to those proposed for hatchery/wild comparisons (Natural Production, Section 1 A), but sample sizes will differ because of power considerations specific to OCT/SNT comparisons.

An increase in early smolt survival is meaningless to project success if it does not translate into increased numbers of returning adults. Accordingly, the second monitoring measure targets adults on the spawning grounds or in the harvest. As mentioned in the Introduction, we are still uncertain how readable VIJ marks will be in returning adults. Therefore we are keeping the option open of ad-clipping and coded-wire-tagging hatchery smolts to guarantee treatment groups will be recognizable on the spawning grounds and in various fisheries. As with measuring early smolt survival, the procedures we will use to estimate smolt-to-adult survival are identical to those proposed for hatchery/wild comparisons (Natural Production, Section 1 A). In light of the fact the project was scaled and laid out expressly to estimate OCT and SNT return rates with adequate power, we anticipate no problems in this area so long as a suitable mark is available.

Although differential reproductive performance is logically an important consideration, we do not in fact expect to see such differences between OCT and SNT adults. Even if such differences do occur, they will probably be very small, requiring large sample sizes to detect with reasonable power. We have proposed a third category of monitoring measures to address inter-group reproductive differences, but in fact all these measures are identical to those proposed in the Natural Production Section (Section 1A). Thus, estimating the relative reproductive success of OCT and SNT fish will be entirely collateral to hatchery/wild observations, involving no more than a rearrangement of the same data set.



The fourth category of OCT/SNT measures, ecological interactions, differs from the other three in that it is not an OCT/SNT partitioning of hatchery/wild data from measures proposed in the Natural Production section. In this case, the measures consist of directed studies of behavioral interactions between hatchery smolts and Nontarget Taxa of Concern (NTTOC). The differences between the treatments may result in differences in agonistic behavior toward wild fish, and these will be very important to detect. Fish of both treatments will be abundant at this point, so adequate power should be readily achievable.

## Outline of Monitoring Measures for OCT/SNT Comparisons

- I. Performance of OCT- and SNT-conditioned fish, relative to each other and to wild fish, in juvenile survival and traits strongly linked with survival
  - A. ***Smolt&pawner as fish leave acclimation raceways***
  - B. ***Smolt-smolt survival rates from Roza to Chandler and McNary*** (and if possible, points further downstream in Columbia basin such as John Day and Bonneville)
  - C. ***Developmental profile from beginning of treatment through smoltification (e.g., growth rates, temperature units to reach specified developmental stages)***
  - D. ***Smolt morphology (e.g., length, weight, truss measurements, coloration)***
  - E. ***Smolt physiology (e.g., lipid, ATPase, thyroxine, cortisol, sodium, and glucose levels)***

- F. Smolt behavior -gloss /eve/ (e.g., migration rate and timing)
- G. ***Smolt behavioral profile change over time evaluated in test aquaria***  
(e.g. agonistic behavior, predator avoidance, feeding)
- H. ***Residualism rates***
- I. ***Precocialism rates***
- J. ***Smolt loss due to predation in basin below Chandler by squawfish, smallmouth bass, channel catfish and piscivorous birds***
- K. ***Occurrence of pathogens (determined by histological examination) in smolts migrating past Prosser***
- II. Performance of OCT- and SNT-conditioned fish, relative to each other and to wild fish, in adult survival to the fishery and spawning grounds
  - A. ***Smolt-adult survival rates from Chandler to Prosser*** (extrapolating to upper basin if possible)
  - B. ***Contribution to fisheries, determined by CWT recoveries***
    - 1. ***Ocean fisheries***
    - 2. ***Columbia River Fisheries***
      - a. ***Lower Columbia gill-net fishery***

b. **Zone 6 fishery**

3. **Yakima basin fisheries**

III. Performance of OCT- and SNT-conditioned fish, relative to each other and to wild fish, in reproductive success and traits strongly linked to reproductive success <sup>56</sup>.

- A. **Comparison of gamete quality measured in hatchery test crosses (*hxh,wxw,hxw,wxh*) (e.g., fertilization rates, viability, temperature units to hatch, fry size/egg size)**
- B. **Comparative performance of adults for the following demographic and life history characteristics: age, size at age, sex ratio, fecundity at age, migration timing, spawning timing (both in hatchery and on spawning grounds), spawning distribution/habitat utilization, and straying**
- C. **Comparative performance of adults in semi-natural test arena for reproductive behavior (e.g., spawning site competition, redd construction, mate selection)**

---

<sup>56</sup> All OCT/SNT data collected will be collateral data from Natural Production monitoring; no attempt will be made to equalize OCT and SNT sample sizes to increase statistical power.

- D. ***Comparative performance of juveniles in semi-natural test arena for parentally determined life history traits (e.g., distribution, size, emergence timing, migration timing, growth)***
  - E. ***Direct reproductive success comparisons measured as fish produced by individuals or individual pairs in natural or semi-natural test arenas***
    - 1. ***MACRO level- measure production (as returning adults) by individual pairs for entire upper Yakima population*** (will require complete DNA profile of population)
    - 2. ***MESO level- measure production (as outmigrating juveniles) by individual pairs in a restricted-entry natural stream reach*** (will require complete DNA profile of spawners in stream reach)
    - 3. ***MICRO level- measure production (as outmigrating juveniles) by individual pairs in a semi-natural stream arena*** (will require DNA profile of all spawners tested)
- IV. Differential performance of OCT- and SNT-conditioned juveniles in ecological interactions with naturally produced spring chinook and Nontarget Taxa of Concern
- A. ***Agonistic behavior (aggressiveness and dominance) of recently released smolts toward naturally produced spring chinook, evaluated in controlled test arenas.***

- B. ***Agonistic behavior (aggressiveness and dominance) of recently released smolts toward rainbow trout, evaluated in controlled test arenas***

## Section 3. Facility and Field Monitoring Activity

### Quality Control

Proper operation of facilities is obviously vitally important to the success of the project, but choosing monitoring measures for facility operations was one of the more challenging aspects of monitoring plan development. Because there are so many layers to facility operations, it was difficult to decide which aspects of facility operations should be considered subjects for monitoring and which should not. The logical trap MIPT tried to avoid was thinking that since all aspects of facility operations are related at some incremental level to the success of the project, that measures for every aspect of facility operations need to be included in the plan. We decided for this iteration of the monitoring plan that measures would be proposed only for aspects of facility operations that pose a serious *risk to monitoring effectiveness or to stock health*. A threat to stock health in this sense includes anything with the potential *to degrade genetic condition, demographic status, and maintenance of life history variation, or to cause increases in infection or injury*. Thus, determining if the Roza adult trap is causing a displacement of spawners from above Roza to below is appropriate, but checking to see if fish ascend the fish ladder rapidly or hesitantly during trap operation would be inappropriate unless short-term ladder passage rates can be shown to be very important to stock health. Another way of looking at this is that an aspect of facility operations must have ‘scientific’ (as opposed to ‘operational’) interest to be included in the plan. Even so, some measures are phrased in such general terms that they could include tasks like checking ladder passage rates at Roza, or checking incubation temperatures at the Cle Elum rearing facility. Rearing protocols in fact merit special mention in this context. A rearing protocol consists of a vast number of potentially monitorable steps, and a decision will have to be made as to which will be included in the monitoring plan.

A related problem that arose in developing monitoring measures for facilities was the realization that many candidate measures are ‘metamonitoring’; i.e., monitoring of monitoring. For example, for all four permanent monitoring facilities we have included the measure “compliance with monitoring protocols’. Including it was logical because success of the monitoring plan requires that the protocols be carried out as specified, but it really is more an operational than a scientific matter. We see this metamonitoring and the operational monitoring already discussed as being more appropriately dealt with by a facilities certification process. At present no such process exists. We urge that one be developed as soon as possible (see also the Introduction section of the plan). Once a certification process exists, a clearer understanding can be developed of the boundary between certification and scientific monitoring.

Although this section of the plan may change considerably as we discuss it with hatchery operations personnel and the certification process develops, it should not be thought of as preliminary. It is a comprehensive statement of the scientific and stock health concerns we have about the hatchery and monitoring facilities. In some cases we are confident that the facility can be operated correctly, and are merely stressing the importance of doing so. In other cases, such as the Chandler facility, considerable uncertainties exist about how well the facility can perform, so we do not know at this point what to expect in terms of ‘correct’ operation. Finally, in some cases, problems exist that may have serious consequences if they are not solved. The Roza adult trap is perhaps the best example of this kind of concern.

Monitoring measures for facilities are presented in four sections: hatchery, acclimation raceways, permanent monitoring facilities, and field monitoring ‘facilities’. The hatchery and acclimation raceways are related in the sense that they are both part of rearing operations, but the monitoring concerns for each are quite different because in the acclimation raceways there are additional concerns about the performance of the volitional release system.

The Roza adult trap is a permanent monitoring facility, but since it is also the broodstock collection facility, it is also an integral part of the hatchery rearing operations. For the sake of simplicity we have listed measures for all Roza adult trap functions in the permanent monitoring facilities section. The field monitoring activities section is a catchall for all monitoring activities not conducted at permanent facilities. The overall organization of this section of the plan is shown in Fig. 9.

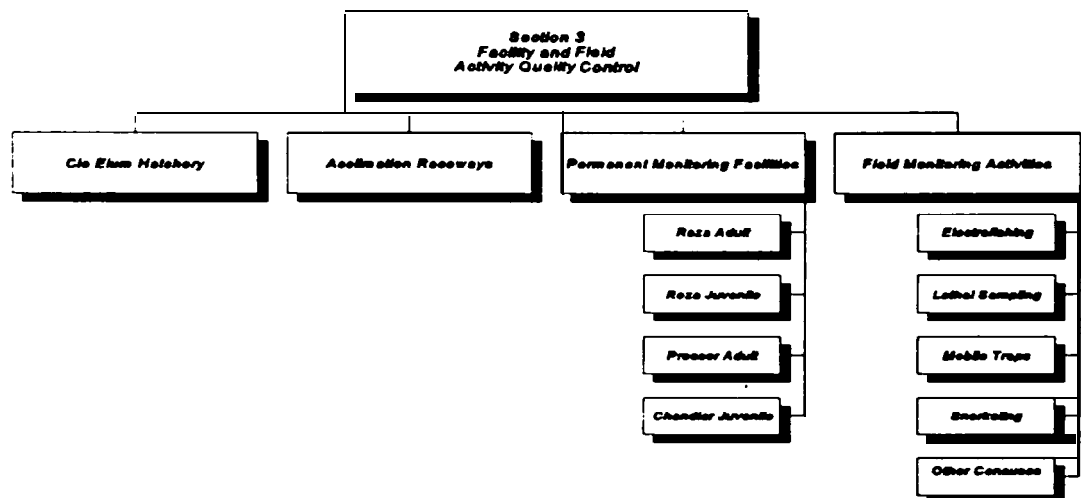


Fig. 9. Organization of Section 3 of the YFP spring chinook monitoring plan.

### **Cle Elum Hatchery**

Measures in this section focus on mortality rates and patterns, and compliance with protocols. Underlying scientific concerns include relative hatchery/wild egg-smolt survival; genetic, behavioral, physiological, and morphological impacts on hatchery fish; and ecological impacts on the wild population. Mortality rates are critical to the success of the project. Hatchery fish are expected to have substantially poorer smolt-adult survival than wild fish. The hatchery benefit all comes in the egg-smolt phase, so



keeping mortality to a minimum can translate to big dividends later. The pattern of mortality in terms of deviation from randomness is important for assessing potential genetic impacts. If, for example, prespawning mortality occurs disproportionately among early returnees, hatchery operations could shift the run timing to later returnees. Genetic concerns are also prominent among the reasons for monitoring compliance with rearing **protocols**<sup>57</sup>. This is especially true of the spawning protocol, which can have a large impact on the effective population size of the stock.

Rearing protocols must also be monitored for their impact on the morphology, physiological status and behavior of OCT and SNT fish, particularly during the later phases of rearing and acclimation. Carcass distribution protocols (plans for returning carcasses to natural spawning areas) must be monitored for their impact on the trophic dynamics of spawning and early rearing areas. There is growing evidence that not returning carcasses to the “donor stream” depresses primary and secondary productivity in affected reaches. Accordingly, we recommend that as many broodstock carcasses be returned to natural spawning areas as possible (see Introduction section).

## **Acclimation Raceways**

Measures for the acclimation raceways include compliance with OCT and SNT rearing protocols, for obvious reasons. Other concerns include volitional release protocols (time and date of initiation and egress rate), the methods used to estimate the actual number of fish entering the river, and ambient environmental conditions during the release period. The temporal pattern of release must be known because of its impact on the timing of monitoring operations downriver. Initial release number must be known because of its obvious impact on the accuracy of all subsequent survival estimates. Finally, environmental conditions during release (e.g., river discharge, water

---

<sup>57</sup> The rationale for many hatchery monitoring protocols will be developed in the Genetic Culture Guidelines document.

temperature, turbidity, etc.) must be tracked because of the large impact they can have on post-release survival.

## **Permanent Monitoring Facilities**

Most of this section is devoted to permanent monitoring facilities. The Yakima basin contains four of them: Roza adult, Roza juvenile, Prosser adult, and Chandler juvenile. Only Roza adult was designed specifically for upper Yakima spring chinook enhancement as currently envisioned. The others were designed primarily for efforts on other stocks not currently targeted for enhancement, or for an earlier and superseded spring chinook program.

It was unclear at the outset of MIPT deliberations whether Roza juvenile, Prosser adult and Chandler juvenile were essential elements of a monitoring plan for upper Yakima spring chinook supplementation. Accordingly, we first determined what sorts of observations were needed and where they were needed, and then examined the adequacy of existing facilities. In other words, we fit the facilities to the monitoring plan, not vice versa. After considerable discussion of alternatives, we decided that all existing facilities were needed, but that all had problems with regard to their specific monitoring mission.

A description of monitoring roles, issues and actual or potential problems for each of the four facilities follows. The description of monitoring facilities is organized differently from other measures described in this document. Although some facility monitoring measures are described in the standard way, most are presented in tables as “concerns” with associated priorities (1 =high, 2=medium, 3=low, ?=unknown but possibly important). The tabular format was chosen because it clearly depicts the number and diversity of monitoring concerns at these facilities for both target and nontarget species.

**Roza Adult Facility** (ladder and viewing window, trap)

This facility is the intended broodstock trapping site for the project, so it has to have the capability of collecting broodstock as specified by protocol. The facility will also be used to sample a substantial proportion of returning adults intrusively. The viewing window/videotape system will be used to enumerate spring chinook and certain nontarget taxa of concern (steelhead and lamprey). Most concerns about this facility (Table 3.1) are trap-related. We are concerned about the possibility of inadequate sampling access. It may be desirable to sample all or a large percentage of fish, and it is unclear whether this will be possible. The trap may also cause fallback and reascension, which would complicate fish counting and probably displace spawning to areas below the dam.

**Roza Juvenile Facility** (trap)

This facility intercepts juveniles that have been entrained in Roza canal (which originates on the right bank of the Yakima River at Roza Dam) and are being returned by a screened bypass system to the river. We plan two major target stock roles for this trap: collecting fish for OCT/SNT and hatchery/wild comparisons, and collecting fish for tagging to estimate relative survival rates downstream. We also plan to use the facility for monitoring juvenile steelhead and lamprey. Proper operation of this facility is critical to many aspects of monitoring. The Roza juvenile facility currently suffers from several serious problems. Sampling efficiency is probably too low to collect adequate numbers of hatchery and wild fish for a series of four or five paired releases per season, especially during low run years. We are therefore considering the installation of fish guidance equipment to boost collection efficiency when needed. MIPT has proposed that fish guidance equipment be tested at Roza in 1998. A proposal to test infrasound and strobe light guidance systems is now being developed. The facility may also be a biased sampler, although existing data are equivocal on this point. Other major problems include excessive passage time, winter operations, and operator safety. The trap was built by the Bureau of Reclamation to test the efficiency of the fish

screening system, and was never intended to be used routinely for fish sampling. It is inoperable during the winter whenever screen maintenance or ice formation requires the pool to be lowered, precluding the sampling of winter migrants. It is also extremely hazardous: the work-up area lies at the bottom of a 20-ft deep concrete pit which is reached only by ladder and is prone to sudden flooding and ice formation. This facility will probably have to be modified substantially to fulfill its monitoring role.

### **Prosser Adult Facility** (ladders and viewing windows)

This facility consists of three ladders (right bank, left bank, and center) and viewing/videotape systems. There is also a trap at the right bank ladder, but we do not anticipate using the trap for spring chinook monitoring. The intended target stock monitoring role for this facility is to estimate total return to the basin. All three spring chinook stocks are commingled at this point, and total wild and hatchery counts at Prosser, along with Roza counts, redd counts, and harvest information, can be used to estimate total adult return and inbasin adult mortality. It is also essential for monitoring adult fall chinook, steelhead (all stocks) and lamprey.

We have fewer concerns about this facility than the other three. The only high priority wncems are associated with nontarget taxa monitoring: unobserved passage of fall chinook (primarily jacks) and lamprey, and confusion of fall chinook jacks and who. The unobserved passage problem is caused by spaces between crowding bars wide enough to allow fall chinook jacks and adult lamprey to go up the ladders without being seen at the window.

### **Chandler Juvenile Facility** (trap)

This facility intercepts juveniles that have been entrained in the Chandler canal (which originates on the left bank of the Yakima River at Prosser Dam) and are being returned by a screened bypass system to the river. The intended role for this facility is estimation of juvenile production (by estimating passage by the facility), survival rate

estimation (by PIT- and VIJ- tag interrogation), and sampling for other hatchery/wild and OCT/SNT comparisons. It is also to be used to estimate juvenile production by nontarget salmonid taxa and, by index, of Pacific lamprey. This is a very important facility: many project evaluations depend on it providing precise and unbiased estimates of juvenile passage.

Chandler is, however, the most problematic of the four facilities. Many wncems exist about its correct operation (MIPT 1996). Some wncems are very old. Despite considerable efforts over several years (Fast et al. 1991, Neeley 1992, Sandford and Ruehle 1996) the facility has never been satisfactorily 'calibrated' – that is to say, the relationship between canal diversion and smolt entrainment rates has never been described with desired precision. Because the essence of passage estimation at Chandler involves dividing raw daily catches by the estimated daily entrainment fraction, uncertainties about the existing diversion/entrainment relationship must be resolved. It is also unclear whether or not the facility samples fish without bias (e.g., size-, handling-, mark- or tag- and prior-experience-bias). As can be seen from Table 10, a variety of other wncems also exist for target stock monitoring, but bias and precision are the most serious. There are also serious stock health wncems for nontarget taxa. Mortality in the canal before fish enter the facility, mortality in the facility, and mortality in the bypass outfall may be a serious problem for fall chinook and, at least occasionally, for spring chinook as well. MIPT spent a great deal of time exploring Chandler problems in 1996 and has developed a proposal, now in procurement, for a three-year research plan to clear up many of these uncertainties (MIPT 1996).

## **Field Monitoring Activities**

Field monitoring activities share many quality control characteristics with facilities, so including them in this section seemed reasonable. One major distinction between field

monitoring activities and facilities, however, is that no aspect of field activities can be considered purely “operational”, with monitoring of them relegated to operations manuals. Every aspect of these activities relates directly either to data quality or to resource health, so all our concerns about these activities need to be reflected in the monitoring plan. Field monitoring activities fall into six major categories: 1) electrofishing, 2) lethal sampling, 3) mobile traps, 4) snorkeling, 5) redd surveys, and 6) other visual censuses (such as mainstem fish assemblage counts, bird surveys, and observations of bird predation). Lethal sampling clearly is quite different from the others. It is not an activity in itself, but rather a type of disposition of specimens collected by these activities. Lethal sampling can impose a substantial load on the population under study, so in some cases our ability to obtain information by lethal sampling is limited. It thus becomes a monitoring concern. Note also that although we deal with it explicitly only in this section of the monitoring plan, many monitoring activities associated with facilities may also involve lethal sampling. The lethal sampling load will have to be evaluated for these monitoring measures as well.

Field techniques that will be used in monitoring were assessed for potential problems in data quality control and risk to the resource or sampler. Where applicable, each technique was evaluated with respect to three types of concern: sampler error, sampling impacts, and application. Sampler error includes misidentification of species, origin (hatchery or wild), treatment (OCT or SNT), gut contents, and behavior; or incorrect measurement of lengths or weights. Sampling impacts are injuries or mortalities incurred by target and nontarget taxa as a result of sampling. These impacts were considered at as many as three levels: individuals, individuals within a monitoring index site, or an entire population. Application is our ability to safely and reliably use a field technique under a variety of ecological conditions, such as flow extremes, high turbidity, temperature extremes, and heavy large debris load.

Concern levels are tabulated in Tables 1 I-16 according to the following scheme:

#### Sampler error

- 1 =high chance for error
- 2=moderate chance for error
- 3=low chance for error

#### Sampling impacts

- 1=high chance for injuries and/or mortalities
- 2=moderate chance for injuries and/or mortalities
- 3=low chance for injuries and/or mortalities

#### Application

- 1= low chance of being able to achieve sampling
- 2=moderate chance of being able to achieve sampling
- 3=high chance of being able to achieve sampling

Rankings reflect levels of concern for the monitoring effort during an average year. Rankings would differ in years of low population abundances such as in 1996.

The main wncems about field sampling for the YFP monitoring plan are as follows: sampler error due to snorkeling, injuries/mortalities due to electrofishing and lethal sampling, and application of monitoring plan using mobile traps and snorkeling. These wncems can be reduced through adequate training of field personnel, quality control monitoring, electrofishing guidelines to minimize injuries, and minimizing the number of fish that are euthanized.

## Outline of Monitoring Measures for Facilities and Field Operations

- I. Cle Elum Hatchery
  - A. ***Adult transportation (Roza trap to C/e Elm hatchery) mortality rates and patterns***
  - B. ***Prespawning mortality rates and patterns at hatchery***
  - C. ***Compliance with spawning protocol***
  - D. ***Compliance with carcass distribution protocol (if applicable)***
  - E. ***Compliance within randomization protocols for distributing fish to raceways***
  - F. ***Compliance with OCT/SNT rearing protocols***
  - G. ***Incubation mortality rates***
  - H. ***Ponding mortality rates***
  - I. ***Rearing mortality rates***
  - J. ***Juvenile transportation (C/e Elum hatchery to acclimation sites) mortality rates***



## II. Acclimation Raceways

- A. ***Compliance with OCT/SNT rearing protocols***
- B. ***Acclimation mortality rates***
- C. ***Pathogen occurrence and infection levels (determined by pathological examination) in hatchery smolts exiting acclimation raceways)<sup>58</sup>***
- D. ***Enumeration accuracy (precision and bias) during release***
- E. ***Performance of volitional release system***
- F. ***Abiotic variation in release environments between sites and years***

## III. Permanent Monitoring Facilities

---

<sup>58</sup> Measure is also listed in Ecological Interactions section (Section 1D).

A. Roza Adult Facility

1. ***Pathogen occurrence and infection levels of fish sampled, especially those collected for broodstock***
2. ***Compliance with broodstock collection protocol***
3. ***Compliance with monitoring protocols***
4. ***Monitoring addressing the facility-specific concerns in Table 7***

**Table 7. Facility-specific quality control concerns requiring monitoring at the Roza adult facility. Numbers indicate priority levels for monitoring.**

	Upper Yakima Spring Chinook		NTTOC	
Concern	Wild Adults	Hatchery Adults	Steelhead	Pacific Lamprey
Unobserved passage	3	3	1	1
Fallback/reascension	2	2	2	2
Spawning ground displacement	2	2	2	?
Injuries/ mortalities	2	2	2	2
Misidentification	3	3	3	
Passage delay	2	2	2	?
Adequate sampling access	1	1		

## B. Roza Juvenile Facility

1. *Compliance with monitoring protocols*
2. *Monitoring addressing the facility-specific concerns in Table 8*

<b>Table 8. Facility-specific quality control concerns requiring monitoring at the Roza Juvenile facility. Numbers indicate priority levels for monitoring.</b>					
	Upper Yakima Spring Chinook			NTTOC	
Concern	Hatchery Smolts	Wild Smolts	Winter Migrants	Steelhead	Pacific Lamprey
Sampling bias	?	?	?		
Sampling efficiency	1	1	1		
Facility/ handling mortality	2	2	2	2	?
Winter down time			1		?
Passage delay	1	1	?	1	?

### C. Prosser Adult Facility

#### 1. *Compliance with monitoring protocols*

#### 2. *Monitoring addressing the facility-specific concerns in Table 9*

<b>Table 9. Facility-specific quality control concerns requiring monitoring at the Prosser adult facility. Numbers indicate priority levels for monitoring</b>						
	Upper Yakima Spring Chinook		NTTOC			
Concern	Wild Adults	Hatchery Adults	American/ Naches Spring Chinook Adults	Steelhead	Marion Drain Fall Chinook	Pacific Lamprey
Unobserved passage	2	2	2	3	1	1
Fallback/ reascension	3	3	3	3	2	2
Displacement					1	3
Injuries/ mortalities	3	3	3	3	3	3
Misidentification	2	2	2	3	1	
Passage delay	3	3	3	3	3	?

## IV. Field Monitoring Activities

### A. Electrofishing

1. *Compliance with monitoring protocols*
2. *Monitoring addressing the activity-specific concerns in Table 11*

**Table 11. Activity-specific quality control concerns associated with electrofishing. Numbers indicate levels of concern (1=high, 2=moderate, 3=low). SUT = stewardship and utilization taxa, and SIT = strong interactor taxa (see Ecological Interactions, Section 1D).**

Concern	Spring Chinook						NTTOC	
	Hatchery Smolts	Wild Eggs	Wild Fry	Wild Parr	Wild Smolts	Wild Adults	SUT	SIT
Sampler Error	2		3	3	2	3	2	3
Sampling Impacts- Individual	2	↓	2	2	2	↓	↓	2
Sampling Impacts- Monitoring Site	2	↓	2	2	2	↓	↓	2
Sampling Impacts- Population	3	↓	3	3	3	2	2	3
Application	2		2	3	2		3	?

## B. Lethal sampling

1. *Compliance with monitoring protocols*
2. *Monitoring addressing the activity-specific concerns in Table 12*

**Table 12. Activity-specific quality control concerns associated with lethal sampling. Numbers indicate levels of concern (1=high, 2=moderate, 3=low). SUT = stewardship and utilization taxa, and SIT = strong interactor taxa (see Ecological Interactions, Section 1D).**

	Spring Chinook						NTTOC	
Concern	Hatchery Smolts	Wild Eggs	Wild Fry	Wild Parr	Wild Smolts	Wild Adults	SUT	SIT
Sampler Error	3		3	3	3	3	3	3
Sampling Impacts- Individual	1		1	1	1	1	1	1
Sampling Impacts- Monitoring Site	3		3	3	2	2	3	3
Sampling Impacts- Population	3		3	3	3	3	3	3
Application	3		2	2	3		3	?

### C. Mobile traps

1. ***Compliance with monitoring protocols***
2. ***Monitoring addressing the activity-specific concerns in Table 13 below***

Table 13. Activity-specific quality control concerns associated with mobile traps. Numbers indicate levels of concern (1=high, 2=moderate, 3=low). SUT = stewardship and utilization taxa, and SIT = strong interactor taxa (see Ecological Interactions, Section 1D).								
	Spring Chinook						NTTOC	
Concern	Hatchery Smolts	Wild Eggs	Wild Fry	Wild Parr	Wild Smolts	Wild Adults	SUT	SIT
Sampler Error	3		3	3	3	3	3	3
Sampling Impacts- Individual	2		2	2	2	2	2	2
Sampling Impacts- Monitoring Site	3		3	3	3	3	3	3
Sampling Impacts- Population	3		3	3	3	3	3	3
Application	I		I	2	I		2	

## D. Snorkeling

1. *Compliance with monitoring protocols*
2. *Monitoring addressing the activity-specific concerns in Table 14*

**Table 14. Activity-specific quality control concerns associated with snorkeling. Numbers indicate levels of concern (1=high, 2=moderate, 3=low). SUT = stewardship and utilization taxa, and SIT = strong interactor taxa (see Ecological Interactions, Section 1D).**

	Spring Chinook						NTTC	
Concern	Hatchery Smolts	Wild Eggs	Wild Fry	Wild Parr	Wild Smolts	Wild Adults	SUT	SIT
Sampler Error	1		2	2	1	3	2	
Sampling Impacts	3	3	3	3	3	3	3	3
Application	1		1	2	1	3	3	



## E. Redd surveys

1. *Compliance with monitoring protocols*
2. *Monitoring addressing the activity-specific concerns in Table 15*

**Table 15. Activity-specific quality control concerns associated with redd surveys. Numbers indicate levels of concern (1=high, 2=moderate, 3=low). SUT = stewardship and utilization taxa, and SIT = strong interactor taxa (see Ecological Interactions, Section 1D).**

	Spring Chinook						NTTOC	
Concern	Hatchery Smolts	Wild Eggs	Wild Fry	Wild Parr	Wild Smolts	Wild Adults	SUT	SIT
Sampler Error						2		
Sampling Impacts	3	3	3	3	3	3	3	3
Application						3		

F. Other censuses, such as mainstem fish assemblage counts, bird surveys, observations of predation by birds, etc.

1. *Compliance with monitoring protocols*
2. *Monitoring addressing the activity-specific concerns in Table 16 below*

**Table 16. Activity-specific quality control concerns associated with other censuses. Numbers indicate levels of concern (1=high, 2=moderate, 3=low). SUT = stewardship and utilization taxa, and SIT = strong interactor taxa (see Ecological Interactions, Section 1D).**

	Spring Chinook						NTTOC	
Concern	Hatchery Smolts	Wild Eggs	Wild Fry	Wild Parr	Wild Smolts	Wild Adults	SUT	SIT
Sampler Error	2		2	2	2	2	2	2
Sampling Impacts	3	3	3	3	3	3	3	3
Application	3		3	3	3	3	3	3

## Literature Cited

- Akcakaya, **H.R.**, and S. Ferson. 1990. RAMAS/space users manual: Spatially structured population models for conservation biology. Exeter Software, Setauket, NY.
- Alexander, G. R. 1979. Predators of fish in coldwater streams. Pages 153-170, *in* R. H. Stroud and H. E. Clepper, eds., *Predator-Prey Systems in Fisheries Management*. editors. Sport Fishing Institute, Washington, D.C.
- Allee, W.C., A.E. Emerson, O. Park, KP. Schmidt. 1949. *Principles of Animal Ecology*. Saunders, Philadelphia, PA.
- Allendorf, F.W., and S.R. Phelps. 1980. Loss of genetic variation in a hatchery stock of cutthroat trout. *Transactions of the American Fisheries Society* 109: 537-543.
- Anonymous. 1990. Yakima/Klickitat Production Project preliminary design report. Report, DOE/BP-O0245 Bonneville Power Administration, Portland, OR.
- Bagenal, T.B. 1969. Relationship between egg size and survival in brown trout *Salmo trutta* L. *Journal of Fish Biology* 1:349-353
- Bartley,D., M.Mangel, G. Gall, and B.Bentley. 1992. Use of linkage disequilibrium data to estimate effective size of hatchery and natural fish populations. *Conservation Biology* 6:365-375.
- Beauchamp, D. A. 1995. Riverine predation on sockeye salmon fry migrating to Lake Washington. *North American Journal of Fisheries Management* 15:358-365.
- Behnke, R.J. 1992. Native trout of western North America. American Fisheries Society Monograph 6. Bethesda, MD.
- Berejikian, B. A. 1995. The effects of hatchery and wild ancestry and experience on the relative ability of steelhead trout fry (*Oncorhynchus mykiss*) to avoid a benthic predator. *Canadian Journal of Fisheries and Aquatic Sciences* 52:2476-2482.
- Bemier, N. J., D. D. Heath, D. J. Randall and G. K Iwama. 1993. Repeat sexual maturation of precocious male chinook salmon (*Oncorhynchus tshawytscha*) transferred to seawater. *Canadian Journal of Zoology* 71:683-688
- Beyer, J. M., G. Lucchetti, and G. Gray. ~~1988~~ Digestive tract evacuation in northern

- squawfish (*Ptychocheilus oregonensis*). Canadian Journal of Fisheries and Aquatic Sciences 45:548-553.
- Bilby, R. E., B. K. Fransen, and P. A. Bisson. 1998. Incorporation of nitrogen and carbon from spawning coho salmon into the trophic system of small streams: Evidence from stable isotopes. Canadian Journal of Fisheries and Aquatic Sciences 53: 164-173.
- Bjornn, T.C. and D.W. Reiser. 1991. Habitat requirements of salmonids in streams. American Fisheries Society Special Publication 19: 83-138.
- Brown, L. R., and P. B. Moyle. 1981. The impact of squawfish on salmonid populations: A review. North American Journal of Fisheries Management 1: 104-111.
- Bucke, D. 1993. The significance of diseases and anomalies in wild salmonids. Fisheries Research 17:209-217.
- Burgman, M.A., S. Ferson, and H.R. Akcakaya. 1993. Risk Assessment in Conservation Biology. Chapman and Hall, NY.
- Busack, C. 1990. Yakima/Klickitat Production Project genetic risk assessment. *in* Yakima/Klickitat Production Project preliminary design report, Appendix A. Report, DOE/BP-00245-2. Bonneville Power Administration, Portland, OR.
- Busack, C., and A. Marshall. 1991. Genetic analysis of YFP chinook salmon stocks. Pages 2-45 *in* C. Busack, C. Knudsen, A. Marshall, S. Phelps, and D. Seiler. Yakima Hatchery Experimental Design. Progress Report, DOE/BP-001 02. Bonneville Power Administration, Portland, OR.
- Busack, C.A., and G.A.E. Gall. 1980. Ancestry of artificially propagated California rainbow trout strains. California Fish and Game 66: 17-24.
- Busack, C.A., and K.P. Currens. 1995. Genetic risks and hazards in hatchery operations: Fundamental concepts and issues. American Fisheries Society Symposium 15: 71-80.
- Cada, G.F., M.D. Deacon, S.V. Mitz and M.S. Bevelheimer. 1994. Review of information pertaining to the effect of water velocity on the survival of juvenile salmon and steelhead in the Columbia River Basin. Prepared for the Northwest Power Planning Council by Oak Ridge National Laboratory, Contract DE-Ac05849R21400 to the US Department of Energy, Portland, OR.

- Chapman, D., C. Peven, A. Giorgi, T. Hillman, and F. Utter. 1995. Status of spring chinook salmon in the mid-Columbia region. Don Chapman Consultants, Inc., Boise, ID.
- 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.
- Colbume, J.K., B.D. Neff, J.M. Wright, and M.R. Gross. 1996. DNA fingerprinting of bluegill sunfish (*Lepomis macrochirus*) using (GT)<sub>n</sub> microsatellites and its potential for assessment of mating success. Canadian Journal of Fisheries and Aquatic Sciences 53: 342-349.
- Collis, K., R.E. Beaty, and B.R. Crain. 1995. Changes in catch rate and diet of northern squawfish associated with the release of hatchery-reared juvenile salmonids in a Columbia River reservoir. North American Journal of Fisheries Management 15: 346-357.
- Cuenca, M.L. 1994. A model of an internally supplemented population. Transactions of the American Fisheries Society 123: 277-288.
- Currens, K.P. 1993. Genetic vulnerability of the Yakima/Klickitat Fisheries Project: a risk assessment. Unpublished report.
- Daily, M. K. 1971. The mountain whitefish: a literature review. Forest, Wildlife and Range Experiment Station, University of Idaho - Station Paper 8. Moscow, Idaho.
- Dolloff, C. A. 1993. Predation by river otters (*Lutra canadensis*) on juvenile coho salmon (*Oncorhynchus kisutch*) and dolly varden (*Salvelinus malinus*) in southeast Alaska. Canadian Journal of Fisheries and Aquatic Sciences 50:312-315.
- Doyle, R.W. 1983. An approach to the quantitative analysis of domestication in aquaculture. Aquaculture 33: 167-185.
- Falconer, D.S. 1981. Introduction to Quantitative Genetics. Longman, New York, NY.
- Fast, D.E., J. Hubble, M. Kohn, and B. Watson. 1991. Yakima River spring chinook enhancement study. Final report, DOE/BP-39461 -9. Bonneville Power Administration, Portland, OR.

- Fish Passage Center. 1997. Draft Fish Passage Center Annual Report, 1996. Fish Passage Center, Portland, OR.
- Flain, M. 1970. Precocious male quinnat salmon *Oncorhynchus tshawytscha* (Walbaum) in New Zealand. New Zealand Journal of Marine and Freshwater Research 4:217-222.
- Fleming, I. A. 1996. Reproductive Strategies in Atlantic salmon: ecology and evolution. Reviews in Fish Biology and Fisheries. 6:379-416.
- Fleming, I.A. and M.R. Gross. 1990. Latitudinal clines: A trade-off between egg number and size in Pacific salmon. Ecology 71: 1-11.
- Fleming, I.A., and M.R. Gross. 1992. Reproductive behavior of hatchery and wild coho salmon (*Oncorhynchus kisutch*): Does it differ? Aquaculture 103:101-121.
- Fleming, I.A., and M.R. Gross. 1993. Breeding success of hatchery and wild coho salmon (*Oncorhynchus kisutch*) in competition. Ecological Applications 3:230-245.
- Foerester, R. E. , and A.L. Prichard. 1941. Observations on the relation of egg content to total length and weight in the sockeye salmon (*Oncorhynchus nerka*) and the pink salmon (*Oncorhynchus gorbuscha*). Transactions of the Royal Society of Canada 35:51-60.
- Frankham, R., H. Hemmer, O.A. Ryder, E.G. Cothran, M.E. Soule, N.D. Murray, and M. Snyder. 1986. Selection in captive populations. Zoo Biology 5: 127-138.
- Gard, R. 1961. Effects of beaver on trout in Sagehen Creek, California. The Journal of Wildlife Management 25:221-241.
- Gebhards, S. V. 1960. Biological notes on precocious male chinook salmon parr in the Salmon River drainage, Idaho. The Progressive Fish-Culturist 22: 121-123.
- Gharett, A.J., and S.M. Shirley. 1985. A genetic examination of spawning methodology in a salmon hatchery. Aquaculture 47: 245-256.
- Gharett, A-J., and W.W. Smoker. 1991. Two generations of hybrids between even- and odd-year pink salmon (*Oncorhynchus gorbuscha*): a test for outbreeding depression? Canadian Journal of Fisheries and Aquatic Sciences 48: 1744-1749.

- Gilpin, M.E. 1987. Spatial structure and population vulnerability. Pages 87-124 *in* M.E. Soule, ed., *Viable Populations for Conservation*, Cambridge U. Press, New York.
- Gilpin, M.E., and M.E. Soule. 1986. Minimum viable populations: the processes of species extinctions. Pages 13-34 *in* M.E. Soule, ed., *Conservation Biology: The Science of Scarcity and Diversity*. Sinauer Associates, Sunderland, MA.
- Glauert, E. T., and M. H. Kunz. 1976. Kittitas Frontiersmen. Ellensburg Public Library, Ellensburg, Washington.
- Gordon, H., and M. Gordon. 1957. Maintenance of polymorphism by potentially injurious genes in eight natural populations of the platy fish, *Xiphophorus maculatus*. *Journal of Genetics* 55: 1-44.
- Grant, W.S. (ed.) 1997. Genetic effects of straying of non-native hatchery fish into natural populations. NOAA Technical Memorandum NMFS-NWFSC-30.
- Hard, J.J. 1995. Genetic monitoring of life-history characters in salmon supplementation: Problems and opportunities. *American Fisheries Society Symposium* 15: 212-225.
- Healey, M. C. 1991. Life history of chinook salmon (*Oncorhynchus tshawytscha*). Pages 312- 393 *in* C. Groot and L. Margolis, eds., *Pacific Salmon Life Histories*. UBC Press, Vancouver, British Columbia.
- Hedrick, P.W. 1983. *Genetics of Populations*. Science Books International, Boston, MA.
- Herbold, B. 1986. An alternative to the fullness index. Pages 319-320 *in* Contemporary studies on fish feeding: the proceedings of Gutshop "84.
- Hilbom, R. and C. J. Walters. 1992. Quantitative fisheries stock assessment: choice, dynamics and uncertainty. Chapman and Hall, New York, NY.
- Hill, W.G. 1981. Estimation of effective population size from data on linkage disequilibrium. *Genetical Research* 38:209-216.
- Hillman, T. W. 1989a. Nocturnal predation by sculpins on juvenile chinook salmon and steelhead. Pages 248-264 *in* Don Chapman Consultants Inc., Summer and winter ecology of juvenile chinook salmon and steelhead trout in the Wenatchee River, Washington. Final report submitted to Chelan County Public Utility District, Washington.

- Hillman, T.W. 1989b. Spatial interaction of juvenile chinook salmon and the redbside shiner. Pages 209-247 *in* Don Chapman Consultants Inc., Summer and winter ecology of juvenile chinook salmon and steelhead trout in the Wenatchee River, Washington. Final report submitted to Chelan County Public Utility District, Washington.
- Hillman, T. W. and J. W. Mullan. 1989. Effect of hatchery releases on the abundance and behavior of wild juvenile salmonids. Pages 265-285 in Don Chapman Consultants Inc., Summer and winter ecology of juvenile chinook salmon and steelhead trout in the Wenatchee River, Washington. Final report submitted to Chelan County Public Utility District, Washington.
- Hindar, K., N. Ryman, and F. Utter. 1991. Genetic effects of cultured fish on natural fish populations. *Canadian Journal of Fisheries and Aquatic Sciences* 48:945-957.
- Hoffmann, A., C. Busack, and C. Knudsen. 1994. Experimental designs for testing differences in survival among salmonid populations. Report, **DOE/BP-00029-3**. Bonneville Power Administration, Portland OR.
- Howell, P., K. Jones, D. Scarnecchia, L. LaVoy, W. Kendra, and D. Ortmann. 1985. Stock Assessment of Columbia River Salmonids, Vol.1 and 2. Report, DOE/BP-12737. Bonneville Power Administration, Portland, OR.
- Hunter, J. G. 1959. Survival and production of pink and chum salmon in a coastal stream. *Journal of the Fisheries Research Board of Canada* 16:835-886.
- Johnson, D. R., and D. H. Chance. 1974. Presettlement overharvest of upper Columbia River beaver populations. *Canadian Journal of Zoology* 52:1519-1521.
- Johnson, W. H. 1994. The Yakima River corridor: habitat potential and land use. Masters thesis, Central Washington University, Ellensburg, Washington.
- Johnsson, J.L., and M.V. Abrahams. 1991. Interbreeding with domestic strain increases foraging under threat of predation in juvenile steelhead trout (*Oncorhynchus mykiss*): an experimental study. *Canadian Journal of Fisheries and Aquatic Sciences* 48: 243-247.
- Kapuscinski, A.R., and L.M. Miller. 1993. Genetic hatchery guidelines for the Yakima/Klickitat fisheries project. Public review draft. Unpublished report.



- Knudsen, C. 1991. Scale pattern and age/length analysis of 1989 and 1990 Yakima River adult spring chinook. Pages 101-121 in C. Busack, C. Knudsen, A. Marshall, S. Phelps, and D. Seiler. Yakima Hatchery Experimental Design. Progress Report, DOE/BP-O01-02. Bonneville Power Administration, Portland, OR.
- Kohane, M. J., and P.A. Parsons. 1988. Domestication: evolutionary change under stress. *Evolutionary Biology* 23:31-48.
- Krebs, J. R. 1974. Colonial nesting and social feeding as strategies for exploiting food resources in the Great Blue Heron (*Ardea herodias*). *Behavior* 51:99-151.
- Kreeger, K.E. and W.J. McNeil. 1993. Summary and estimation of historic run-sizes of anadromous salmonids in the Columbia and Yakima Rivers. Unpublished report prepared for the Yakima River Basin Coalition.
- Laakso, M. 1951. Food habits of the Yellowstone whitefish *Prosopium williamsoni cismontanum* (Jordan). *Transactions of the American Fisheries Society* 80:99-109.
- Leary, R.F., F.W. Allendorf, and K.L. Knudsen. 1985. Developmental instability as an indicator of reduced genetic variation in hatchery trout. *Transactions of the American Fisheries Society* 114: 230-235.
- Leafy, R.F., F.W. Allendorf, and K.L. Knudsen. 1986. Genetic differences among rainbow trout spawned on different days within a single season. *The Progressive Fish-Culturist* 51: 10-19.
- Leberg, P.L. 1990. Influence of genetic variability on population growth: implications for conservation. *Journal of Fish Biology* 1990 (Supplement A): 193-195.
- Leider, S.A., P.L. Hulett, J.J. Loch, and M.W. Chilcote. 1990. Electrophoretic comparison of the reproductive success of naturally spawning transplanted and wild steelhead trout through the returning adult stage. *Aquaculture* 88: 239-252.
- Leland, H. V. 1995. Distribution of phytobenthos in the Yakima River basin, Washington, in relation to geology, land use, and other environmental factors. *Canadian Journal of Fisheries and Aquatic Sciences* 52: 1108-1129.
- Lestelle, L.C., J.A. Lichatowich, L.E. Mobrand, and V.I. Cullinan. 1994. Ecosystem diagnosis and treatment planning model as applied to supplementation. Model description, user guide and theoretical documentation for the model introduced

in the summary report series on supplementation in the Columbia Basin. Report, DOE/BP-251 05-1 Bonneville Power Administration, Portland, OR.

- Lestelle, L.C., L.E. Mobrand, J.A. Lichatowich, and T.S. Vogel. 1996. Applied ecosystem analysis – a primer. Report, DOE/BP-33243-2. Bonneville Power Administration, Portland, OR.
- Levings, C. D., and Lauzier, R. B. 1991. Extensive use of the Fraser River basin as winter habitat by juvenile chinook salmon (*Oncorhynchus tshawytscha*). Canadian Journal of Zoology 69:1759-1 767.
- Li, H. W., G. A. Lamberti, T. N. Pearsons, C. K. Tait, J. L. Li, and J. C. Buckhouse. 1994. Cumulative effects of riparian disturbances along high desert trout streams of the John Day Basin, Oregon. Transactions of the American Fisheries Society 123:627-640.
- Lichatowich, J.A., and S.P. Cramer. 1979. Parameter selection and sample sizes in studies of anadromous salmonids. Oregon Department of Fish and Wildlife Information Report Series, Fisheries, No. 80-I.
- Long, J.C. 1991. The genetic structure of admixed populations. Genetics 127: 417-427.
- Lynch, M. 1991. The genetic interpretation of inbreeding depression and outbreeding depression. Evolution 45: 622-629.
- Marnell, L.F. 1986. Impacts of hatchery stocks on wild fish populations. Pages 339-347 in R.H. Stroud, ed., Fish Culture in Fisheries Management. Proceedings of a Symposium on the Role of Fish Culture in Fisheries Management. American Fisheries Society, Bethesda, MD.
- Marshall, A.R., M. Miller, C. Busack, and S.R. Phelps. 1991. Genetic stock identification analysis of three 1990 Washington ocean and Strait of Juan de Fuca chinook salmon fisheries. GSI Summary Report 91-1, Washington Department of Fisheries, Olympia.
- Maynard, D.J., T.A. Flagg, and C.V.W. Mahnken. 1995. A review of seminatural culture strategies for enhancing the postrelease survival of anadromous salmonids. American Fisheries Society Symposium 15: 307-316.
- McIntyre, J.D., R.R. Reisenbichler, J. Emlen, R.L. Wilmot, and J.E. Finn. 1988. Predation of Karluk River sockeye salmon by coho salmon and char. Fishery Bulletin 86:611-616.

- McMichael, G. A. 1991. Summary memo of species distribution. Washington Department of Fish and Wildlife, Ellensburg. Unpublished report.
- Mendel, G., J. Bumgamer, K. Petersen, R. Bugert, L. Ross, D. Milks, J. Dedloff, J.B. Shaklee, and C. Knudsen. 1993. Tucannon River spring chinook salmon hatchery evaluation program. Annual report, AFF **1/LSR-93-06**. Lower Snake Compensation Plan, Boise, ID.
- Mesa, M. G. 1994. Effects of multiple acute stressors on the predator avoidance ability and physiology of juvenile chinook salmon. *Transactions of the American Fisheries Society* 123:786-793.
- MIPT (Monitoring Implementation Planning Team). 1996. Chandler smolt trap certification appendix: context, justification, and technical details.
- Modde, T., A. F. Wasowicz, and D. K. Hepworth. 1996. Cormorant and grebe predation on rainbow trout stocked in a southern Utah reservoir. *North American Journal of Fisheries Management* 16:388-394.
- Mongillo, P and L. Faulconer. 1980. Yakima fisheries enhancement study final report. Washington Department of Game, Applied Wildlife Ecology. Water and Power Resources Service contract 7-07-S0038.
- Mousalli, E. and M. Hillborn. 1986. Optimal stock size and harvest rate in multistage life history models. *Canadian Journal of Fisheries and Aquatic Sciences* 43: 135-141.
- Muir, W. D., and T. C. Coley. 1996. Diet of yearling chinook salmon and feeding success during downstream migration in the Snake and Columbia rivers. *Northwest Science* 70:298-305.
- Mullan, J. W., A. Rockhold, and C. R. Chrisman. 1992. Life histories and precocity of chinook salmon in the mid-Columbia River. *The Progressive Fish-Culturist* 54:25-28.
- Mundy, P.R., and B.D. Watson. Migratory behavior of yearling juvenile chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (*O. mykiss*) in relation to water movement in the Yakima River, Washington. (in preparation).
- Naiman, R. J., C. A. Johnston, and J. C. Kelley. 1988. Alteration of North American streams by beaver. *Bioscience* 38:753-762.

- Neeley, D. 1992. Compiled analyses of 1991-92 entrainment/survival studies at Chandler smolt trap. Unpublished reports to the Post Release Survival Task Team of the Yakima Fisheries Project.
- Neitzel, D.A. and G.E. Johnson. 1996. Study plan for evaluating carrying capacity: Measure 7.1A of the Northwest Power Planning Council's 1994 Fish and Wildlife Program. Final Report. Report prepared by Pacific Northwest National Laboratory, Richland, WA, for Bonneville Power Administration, Environment Fish and Wildlife Division, Portland, OR. May, 1996. DOE/BP-6261 I-7.
- Newman, D., and D. Pilson. 1997. Increased probability of extinction due to decreased genetic effective population size: experimental populations of *Clarkia pulchella*. *Evolution* 51: 354-362.
- Nickelson, T. E., J. D. Rodgers, S. L. Johnson, and M. F. Solazzi. 1992. Seasonal changes in habitat use by juvenile coho salmon (*Oncorhynchus Kisutch*) in Oregon coastal streams. *Canadian Journal of Fisheries and Aquatic Sciences* 49:783-789.
- Nickelson, T.E., M.F. Solazzi, and S.L. Johnson. 1986. Use of hatchery who salmon (*Oncorhynchus Kisutch*) presmolts to rebuild wild populations in Oregon coastal streams. *Canadian Journal of Fisheries and Aquatic Sciences* 43:2443-2449.
- Northcote, T. G., and G. L. Ennis. 1994. Mountain whitefish biology and habitat use in relation to compensation and improvement possibilities. *Reviews in Fisheries Science* 2:347-371.
- NPPC (Northwest Power Planning Council). 1990. Letter to Joe Blum, director of the Washington Department of Fisheries, August 9, 1990.
- Ojanguren, A.F., F.G. Reyes-Gavilan, and F. Brana. 1996. Effects of egg size on offspring development and fitness in brown trout, *Salmo trutta* L. *Aquaculture* 147:9-20.
- Olsen, J.B., J.K. Wenburg, and P. Bentzen. 1996. Semiautomated multilocus genotyping of Pacific salmon (*Oncorhynchus* spp.) using microsatellites. *Molecular Marine Biology and Biotechnology* 5: 259-272.
- Patten, B. G. 1975. Comparative vulnerability of fry of Pacific salmon and steelhead trout to predation by torrent sculpin in stream aquaria. *Fishery Bulletin* 73:931-934.

- Patten, B. H., R. B. Thompson, and W. D. Gronlund. 1970. Distribution and abundance of fish in the Yakima River, Washington, April 1957 to May 1958. U.S. Dept. Int. Fish Wildl. Serv. Fish Bulletin No. 603.
- Pearson, H. E. 1985. Hydrology of the upper Yakima River basin, Washington. Water-Supply Bulletin 52, DOE/USGS.
- Pearsons, T.N., G.A. McMichael, E.L. Bartrand, A. Fritts, and K. D. Ham (in prep.) Objectives for nontarget taxa of concern relative to supplementation of Upper Yakima spring chinook salmon.
- Pearsons, T. N., G. A. McMichael, E. L. Bartrand, M. Fischer, J. T. Monahan, and S. A. Leider. 1993. Yakima Species Interactions Study. Annual Report, DOE/BP-01483-3. Bonneville Power Administration, Portland, OR.
- Pearsons, T. N., G. A. McMichael, S. W. Martin, E. L. Bartrand, J. A. Long, and S. A. Leider. 1996. Yakima River Species Interactions Studies. Annual Report, DOE/BP-99852-3. Bonneville Power Administration, Portland, OR.
- Peery, C. A., and T. C. Bjorn. 1996. Small-scale investigations into chinook salmon supplementation strategies and techniques: 1992-I 994. Idaho Cooperative Fish and Wildlife Unit, Technical Report 96-3.
- Peterman, R.M. 1981. Form of random variation in salmon smolt-to-adult relations and its influence on production estimates. Canadian Journal of Fisheries and Aquatic Sciences 38: 1113-I 119.
- Peterman, R.M. 1987. Review of the components of recruitment of Pacific salmon. Pages 417429 in M.J. Dadswell, R.J. Klauda, C.M. Moffitt, R.L. Saunders, R.A. Rulifson and J.E. Cooper, eds. Common strategies of anadromous and catadromous fishes. American Fisheries Society Symposium 1: 417429.
- Peterman, R.M., and M. Gatto. 1978. Estimation of functional responses of predators on juvenile salmon. Journal of the Fisheries Research Board of Canada 35: 797-808.
- Philipp, D. P., J.M. Epifanio, and M. J. Jennings. 1993. Point/Counterpoint: conservation genetics and current stocking practices- are they compatible? Fisheries 18(12): 14-16.
- Pickering, A. D., and J. Duston. 1983. Administration of cortisol to brown trout, *Salmo trutta* L., and its effects on the susceptibility to *Sprolegnia* infection and furunculosis. Journal of Fish Biology 23: 163-I 75.

- Platts, W. S., and R. L. Nelson. 1989. Stream canopy and its relationship to salmonid biomass in the intermountain west. *North American Journal of Fisheries Management* 9:446-457.
- Poe, T. P., H. C. Hansel, S. Vigg, D. E. Palmer, and L. A. Prendergast. 1991. Feeding of predaceous fishes on out-migrating juvenile salmonids in John Day Reservoir, Columbia River. *Transactions of the American Fisheries Society* 120:405-420.
- Pottinger, T. G., and A. D. Pickering. 1992. The influence of social interaction on the acclimation of rainbow trout, *Oncorhynchus mykiss* (Walbaum) to chronic stress. *Journal of Fish Biology* 41:435-447.
- Reeves, G. H., F. H. Everest, and J. D. Hall. 1987. Interactions between the redbelt shiner (*Richardsonius balteatus*) and the steelhead trout (*Salmo gairdneri*) in western Oregon: the influence of water temperature. *Canadian Journal of Fisheries and Aquatic Sciences* 44: 1603-1613.
- Regional Assessment of Supplementation Planning (RASP). 1992. Supplementation in the Columbia River Basin, Parts I-5. Report, Bonneville Power Administration.
- Reid, D. G., T. E. Code, A. C. H. Reid, and S. M. Herrero. 1994. Food habits of the river otter in a boreal ecosystem. *Canadian Journal of Zoology* 72: 1306-1313.
- Reisenbichler, R.R.. 1997. Genetic factors contributing to declines of anadromous salmonids in the Pacific Northwest. Pages 223-244 *in* D.J. Stouder, P.A. Bisson, and R.J. Naiman, eds. *Pacific Salmon & Their Ecosystems: Status and Future Options*. Chapman and Hall, New York, NY.
- Reisenbichler, R.R., and J.D. McIntyre. 1977. Genetic differences in growth and survival of hatchery and wild steelhead trout (*Salmo gairdneri*) *Journal of the Fisheries Research Board of Canada* 34: 123-128.
- Ricker, W. E. 1941. The consumption of young sockeye salmon by predaceous fish. *Journal of the Fisheries Research Board of Canada* 5:293-313.
- Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Bulletin 191. Department of the Environment, Fisheries and Marine Service, Ottawa, Canada.
- Rieman, B. E., R. C. Beamesderfer, S. Vigg, and T. P. Poe. 1991. Estimated loss of juvenile salmonids to predation by northern squawfish, walleyes, and smallmouth bass in John Day Reservoir, Columbia River. *Transactions of the American Fisheries Society* 120:448-458.

- Robertson, O. H. 1957. Survival of precociously mature king salmon male parr (*Oncorhynchus tshawytscha* juv.) after spawning. California Fish and Game 43: 119-130.
- Ruggerone, G. T. 1986. Consumption of migrating juvenile salmonids by gulls foraging below a Columbia River dam. Transactions of the American Fisheries Society 115:736-742.
- Ryman, N. 1991. Conservation genetics considerations in fishery management. Journal of Fish Biology 39, Supplement A: 211-224.
- Ryman, N., and G. Stahl. 1980. Genetic changes in hatchery stocks of brown trout (*Salmo trutta*). Canadian Journal of Fisheries and Aquatic Sciences 37: 82-87.
- Ryman, N., and L. Laikre. 1991. Effects of supportive breeding on the genetically effective population size. Conservation Biology 5: 325-329.
- Ryman, N., P.E. Jorde, and L. Laikre. 1994. Supportive breeding and variance effective population size. Conservation Biology 9: 1619-1628.
- Sandford, B.P., and T.E. Ruehle. 1996. Juvenile salmonid PIT-tag studies at Prosser dam and Chandler canal fish collection facility, Yakima River, 1991 and 1992. Final Report. DOE/BP-07099-2. Bonneville Power Administration, Portland, OR.
- Seiler, D. 1992. Yakima River fall chinook monitoring, 1992. Unpublished WDFW report.
- Shaffer, M.L. 1981. Minimum viable population sizes for species conservation. Bioscience 31: 131-134.
- Shaklee, J.B., C.A. Busack, and C.W. Hopley. 1993. Conservation genetics programs for Pacific salmon at the Washington Department of Fisheries: Living with and learning from the past, looking to the future. Pages 110-141 in K.L. Main and B.Reynolds, eds., Selective Breeding of Fishes in Asia and the United States. The Oceanic Institute, Honolulu, HI.
- Shields, W.M. 1982. Philopatry, Inbreeding, and the Evolution of Sex. State University of New York Press, Albany, NY.
- Shively, R.S., P.P. Poe, and S.T. Sauter. 1996. Feeding response by northern squawfish to a hatchery release of juvenile salmonids in the Cleawater River, Idaho. Transactions of the American Fisheries Society 125: 230-236.

- Sholes, W.H., and R.J. Hallock. 1979. An evaluation of rearing fall-run chinook salmon, *Oncorhynchus tshawytscha*, to yearlings at Feather River Hatchery, with a comparison of returns from hatchery and downstream releases. *California Fish and Game* 64: 239-255.
- Simon, R.C. 1991. Management techniques to minimize the loss of genetic variability in hatchery fish populations. *American Fisheries Society Symposium* 10: 487-494.
- Simon, R.C., J.D. McIntyre, and A.R. Hemmingsen. 1986. Family size and effective population size in a hatchery stock of who salmon (*Oncorhynchus kisutch*). *Canadian Journal of Fisheries and Aquatic Sciences* 43: 2434-2442.
- Smith, R.W. and J.S. Griffith. 1994. Survival of rainbow trout during their first winter in the Henry's Fork of the Snake River, Idaho. *Transactions of the American Fisheries Society* 123: 747-756.
- Snieszko, S. 1974. The effects of environmental stress on outbreaks of infectious diseases of fishes. *Journal of Fish Biology* 6: 197-208.
- Steedman, R. J. 1991. Occurrence and environmental correlates of black spot disease in stream fishes near Toronto, Ontario. *Transactions of the American Fisheries Society* 120:494-499.
- Steward, C.R. and T.C. Bjorn. 1990. Supplementation of salmon and steelhead stocks with hatchery supplementation: A synthesis of published literature. U.S. Department of Energy, Bonneville Power Administration, Project 88-I 00. Portland, OR.
- Swain, D.P., and B.E. Riddell. 1990. Variation in agonistic behavior between newly emerged juveniles from hatchery and wild populations of who salmon, *Oncorhynchus kisutch*. *Canadian Journal of Fisheries and Aquatic Sciences* 47: 566-571.
- Tabor, R. A., R. S. Shively, and T. P. Poe. 1993. Predation on juvenile salmonids by smallmouth bass and northern squawfish in the Columbia River near Richland, Washington. *North American Journal of Fisheries Management* 13:831-838.
- Tait, C. K., J. L. Li, G. A. Lamberti, T. N. Pearsons, and H. W. Li. 1994. Relationships between riparian cover and the community structure of high desert streams. *Journal of the North American Benthological Society* 13:45-56.



- Tajima, F. 1992. Statistical method for estimating the effective population size in Pacific salmon. *Journal of Heredity* 83: 309-311.
- Tave, D. 1993. *Genetics for Fish Hatchery Managers*, second ed. AVI, Westport, CT.
- Taylor, E. B. 1989. Precocial male maturation in laboratory-reared populations of chinook salmon, *Oncorhynchus tshawytscha* *Canadian Journal of Zoology* 67: 1665-1669.
- Taylor, E.B. 1993. A review of local adaptation in Salmonidae, with particular reference to Pacific and Atlantic salmon. *Aquaculture* 98: 185-207.
- Templeton, A.R. 1986. Coadaptation, local adaptation, and outbreeding depression. Pages 105-116 in M.E. Soulé, ed., *Principles of Conservation Biology: The Science of Scarcity and Diversity*. Sinauer Associates, Sunderland, MA.
- Vigg, S. And C. C. Burley. 1991. Temperature-dependent maximum daily consumption of juvenile salmonids by northern squawfish (*Ptychocheilus oregonensis*) from the Columbia River. *Canadian Journal of Fisheries and Aquatic Sciences* 48: 2491-2498.
- Vigg, S., T. P. Poe, L. A. Prendergast, and H. C. Hansel. 1991. Rates of consumption of juvenile salmonids and alternative prey fish by northern squawfish, walleyes, smallmouth bass, and channel catfish in John Day Reservoir, Columbia River. *Transactions of the American Fisheries Society* 120:421-438.
- van den Berghe, E.P. and M.R. Gross. 1984. Female size and nest depth in who salmon (*Oncorhynchus kisutch*). *Canadian Journal of Fisheries and Aquatic Sciences* 41:204-206.
- Waldman, B., and J.S. McKinnon. Inbreeding and outbreeding in fishes, amphibians, and reptiles. Pages 250-282 in N.W. Thomhill, ed., *The Natural History of Inbreeding and Outbreeding*. University of Chicago Press, Chicago, IL.
- Waples, R.S. 1989. A generalized approach for estimating effective population size from temporal changes in allele frequency. *Genetics* 121:379-391.
- Waples, R.S. 1990. Conservation genetics of Pacific salmon. III. Estimating effective population size. *Journal of Heredity* 81: 277-289.
- Waples, R.S. 1991 a. Genetic interactions of hatchery and wild salmonids: lessons from the Pacific Northwest. *Canadian Journal of Fisheries and Aquatic Sciences* 48( Supplement 1): 124-133.

- Waples, R.S. 1991 b. Genetic methods for estimating the effective size of cetacean populations. Report of the International Whaling Commission, Special Issue 13: 279-300.
- Waples, R.S., and D.J. Teel. 1990. Conservation genetics of Pacific salmon. I. Temporal changes in allele frequency. *Conservation Biology* 4:144-156.
- Waples, R.S., and P.E. Smouse. 1990. Gametic disequilibrium analysis as a means of identifying mixtures of salmon populations. *American Fisheries Society Symposium* 7: 439-458.
- Waples, R.S., G.A. Winans, F.M. Utter, and C. Mahnken. 1990. Genetic monitoring of Pacific salmon hatcheries. NOAA Technical Report NMFS 92.
- Waples, R.S., O.W. Johnson, P.B. Aebbersold, C.K. Shiflett, D.M. Van Doornik, D.J. Teel, and A.E. Cook. 1993. A genetic monitoring and evaluation program for supplemented populations of salmon and steelhead in the Snake River Basin. Annual report, Bonneville Power Administration, Portland, OR.
- Ward, D. L., J. H. Petersen, and J. J. Loch. 1995. Index of predation on juvenile salmonids by northern squawfish in the lower and middle Columbia River and in the lower Snake River. *Transactions of the American Fisheries Society* 124:321-334.
- Washington Department of Fish and Wildlife. 1995. Ecological risk assessment - stocking hatchery wild salmon in the mid- and upper Columbia River basin. Olympia, Washington.
- Watson, B.D. 1993. Proposed natural production objectives for upper Yakima spring chinook under the Yakima/Klickitat Fisheries Project. Internal YFP report.
- Wedemeyer, G. A. 1970. The role of stress in the disease resistance of fishes. *American Fisheries Society Special Publication* 5:30-35.
- Weir, B.S., and W.G. Hill. 1980. Effect of mating structure on variation in linkage disequilibrium. *Genetics* 95: 477-488.
- White, H. C. 1939. Bird control to increase the Margaree River salmon. *Bulletin of the Fisheries Research Board of Canada* 58:1-30.
- White, R.J., J.R. Karr, and W. Nehlsen. 1995. Better roles for fish stocking in aquatic resource management. *American Fisheries Society Symposium* 15: 527-550.

- Withler, R.E. 1988. Genetic consequences of fertilizing chinook salmon (*Oncorhynchus tshawytscha*) eggs with pooled milt. *Aquaculture* 68: 15-25.
- Wood, C. C. 1987a. Predation of juvenile Pacific salmon by the common merganser (*Mergus merganser*) on eastern Vancouver Island. I: Predation during the seaward migration. *Canadian Journal of Fisheries and Aquatic Sciences* 44:941-949.
- Wood, C. C. 1987b. Predation of juvenile Pacific salmon by the common merganser (*Mergus merganser*) on eastern Vancouver Island. II: Predation of stream-resident juvenile salmon by merganser broods. *Canadian Journal of Fisheries and Aquatic Sciences* 44:950-959.

## Appendix

### Derivation of Expression for Estimating Density-Independent Component of Empirical Survival

In the discussion of productivity monitoring in Section 1A, the following equation was presented:

$$S_{d,j} = \text{survival}_j \left( 1 + \frac{S_j s_0}{K} \right) \quad (1)$$

where  $S_{d,j}$  is the density-independent component of egg-to-smolt survival through life stage  $j$ ,  $\text{survival}_j$  is an empirical estimate of egg-to-smolt survival for brood year  $j$ ,  $S_j$  is the estimated egg deposition for brood year  $j$ , and  $K$  and  $s_0$  are estimates of the carrying capacity and maximum possible egg-to-smolt survival, respectively. This equation, and one for survival from any arbitrarily chosen life stage to another, can be derived as follows. Survival through any life stage or series of life stages is the product of density-independent and density-dependent elements. Assume density-dependent survival is described by a Beverton-Holt (B-H) relationship. Then composite survival across a series of density-dependent and density-independent life stages will also be B-H (Mousalli and Hillborn 1986). In other words, survival from any arbitrarily chosen life stage to another can be described in the familiar form of a Beverton-Holt (or Ricker) stock-recruit relationship.

Let  $R_i$  be the number of recruits to the next life stage in the life history and  $S_i$  be the “stock” generating the recruitment. Then  $R_i/S_i$  is the survival or recruitment rate to the next life stage. Thus, where  $R_{ij}$  = the “recruits” (survivors) from life stage  $i$  in brood year  $j$ ,  $S_{ij}$  = the “stock”, the number of fish alive at the beginning of life stage  $i$  in brood

year  $j$ , and  $S_{dd,ij}$  and  $S_{di,ij}$  are, respectively, density-dependent and density-independent survival rates:

$$SURVIVAL \text{ LIFESTAGE } i \text{ YEAR } j = \frac{R_{ij}}{S_{ij}} = S_{dd,ij} * S_{di,ij} \quad (2)$$

and

$$S_{di,ij} = \frac{survival_{ij}}{S_{dd,ij}} \quad (3)$$

The B-H production function, in the form most often useful to YFP monitoring, is:

$$R = \frac{s_0 S}{1 + \left( \frac{s_0}{K} \right) S} \quad (4)$$

where  $S$  = stock,  $R$  = recruits,  $s_0$  = the maximum recruitment rate as stock numbers approach zero, and  $K$  = the maximum number of recruits (carrying capacity).

The original form of the B-H equation (Ricker 1975) is:

$$R = \frac{S}{\alpha S + \beta} \quad (5)$$

By dividing both numerator and denominator by  $\beta$ , eq. 5 is transformed into a form identical to eq. 4:

$$R = \frac{\frac{1}{\beta} S}{1 + \frac{\alpha}{\beta} S} \quad (6)$$

From eq. 6 it is evident that  $a = 1/K$ , and  $\beta = 1/s_0$ . If, for example, we are considering the "smolts per spawner" production function,  $R$  = smolts,  $S$  = parental spawners,  $1/\beta$  is the theoretical maximum number of smolts per spawner, and  $1/\alpha$  is the theoretical smolt carrying capacity.

Ricker (1975) gives the instantaneous rate of density-dependent mortality ( $Z_{dd}$ ) for a B-H production function as:

$$Z_{dd} = \ln\left(1 + \frac{\alpha S}{\beta}\right) = \ln\left(1 + \frac{S s_0}{K}\right) \quad (7)$$

If  $Z_{dd}$  is density-dependent mortality, then densitydependent survival is  $e^{-Z_{dd}}$ . Eq. 3 can therefore be rewritten as:

$$S_{d,ij} = \frac{\text{survival}_{ij}}{e^{-\ln(1 + \frac{S s_0}{K})}} = \text{survival}_{ij} \left(1 + \frac{S s_0}{K}\right) \quad (8)$$