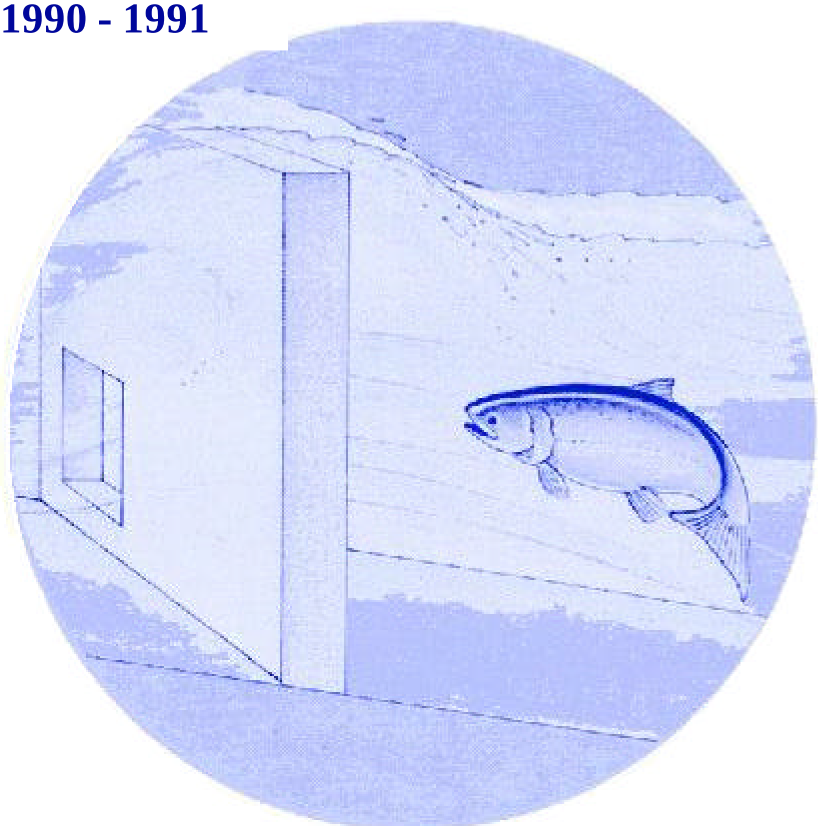
Regional Assessment of Supplementation Program (RASP)

Technical Report
1990 - 1991



DOE/BP-01830-11

October 1991

This Document should be cited as follows:

Mobrand, Lars, "Regional Assessment of Supplementation Program (RASP)", Project No. 1985-06200, 108 electronic pages, (BPA Report DOE/BP-01830-11)

Bonneville Power Administration
P.O. Box 3621
Portland, Oregon 97208

This report was funded by the Bonneville Power Administration (BPA), U.S. Department of Energy, as part of BPA's program to protect, mitigate, and enhance fish and wildlife affected by the development and operation of hydroelectric facilities on the Columbia River and its tributaries. The views in this report are the author's and do not necessarily represent the views of BPA.

REGIONAL ASSESSMENT OF SUPPLEMENTATION PROJECT

Status Report

Prepared for

Thomas S. Vogel and Thomas J. Clune, Project Managers
U.S. Department of Energy
Bonneville Power Administration
Division of Fish and Wildlife
P.O. Box 3621
Portland, OR 97208-3621

Project No. 85-62
Contract Number DE-AC06-76RL01830

October, 1991

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

Scientists with expertise and interest in supplementation have contributed to RASP, among them are: Tom Backman, Ed Bowles, Craig Busack, Rich Carmichael, Duane Fickeisen, Larry Lestelle, Jim Lichatowich, Rich Lincoln, Lars Mobrand, Willa Nehlsen, Rich Turner, Tom Vogel, Harry Wagner, and Bruce Watson. Over the course of a year, eight workshops were conducted.

The Scientific Review Group (SRG) provided numerous constructive and insightful comments. Some SRG comments are incorporated in this document; others identify needs and revisions that will be addressed in future reports.

Coordination and editing of this report was performed by Mobrand Biometrics, Inc.

0. EXECUTIVE SUMMARY

This progress report covers the first year of the Regional Assessment of Supplementation Program (RASP). It describes the work completed in seven specific subject areas: 1) the definition of supplementation, 2) guidelines for setting supplementation objectives, 3) a classification of proposed and ongoing projects, 4) a conceptual model of supplementation risks and benefits, 5) a spreadsheet model of supplementation risks and benefits, 6) identification of critical uncertainties regarding supplementation, and 7) the global design of supplementation research and monitoring.

RASP has defined supplementation as *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. This definition imposes a restriction on the development of supplementation objectives: steps must be taken to preserve the long term fitness of the target population. This implies maintenance of genetic and life history variability, and natural rates of genetic change.

The objectives of proposed supplementation programs should be framed in terms of four ecological dimensions: post-release survival, reproductive success, long term fitness, and ecological interactions. Managers are free to express tradeoffs among the dimensions, however, the resulting objectives must be framed with sufficient specificity to make evaluation and determination of risks and benefits possible.

A conceptual model of supplementation is the central core of the work accomplished last year by RASP (Figure 0.1). The other subject areas addressed by RASP either feed into and support the conceptual model or are dependent on the model for their development. The conceptual model is the basis for a spreadsheet model which the manager can use as one of the tools to examine risks and benefits of alternative supplementation strategies.

Flowing from the development and operation of the conceptual and spreadsheet models are critical uncertainties regarding supplementation (these uncertainties are in the spreadsheet model as assumptions), and a system for prioritizing uncertainties so a global research program can address them in an efficient manner. Those critical uncertainties that are not amendable to resolution through research or will not be resolved in the near future are the basis for the design of the risk containment monitoring.

If the processes and methods that RASP develops are to retain their value, RASP must be updated and reevaluated as new information and experience is gained (Figure 1.1). Updating is especially critical if the model is to remain an effective tool and if it is to

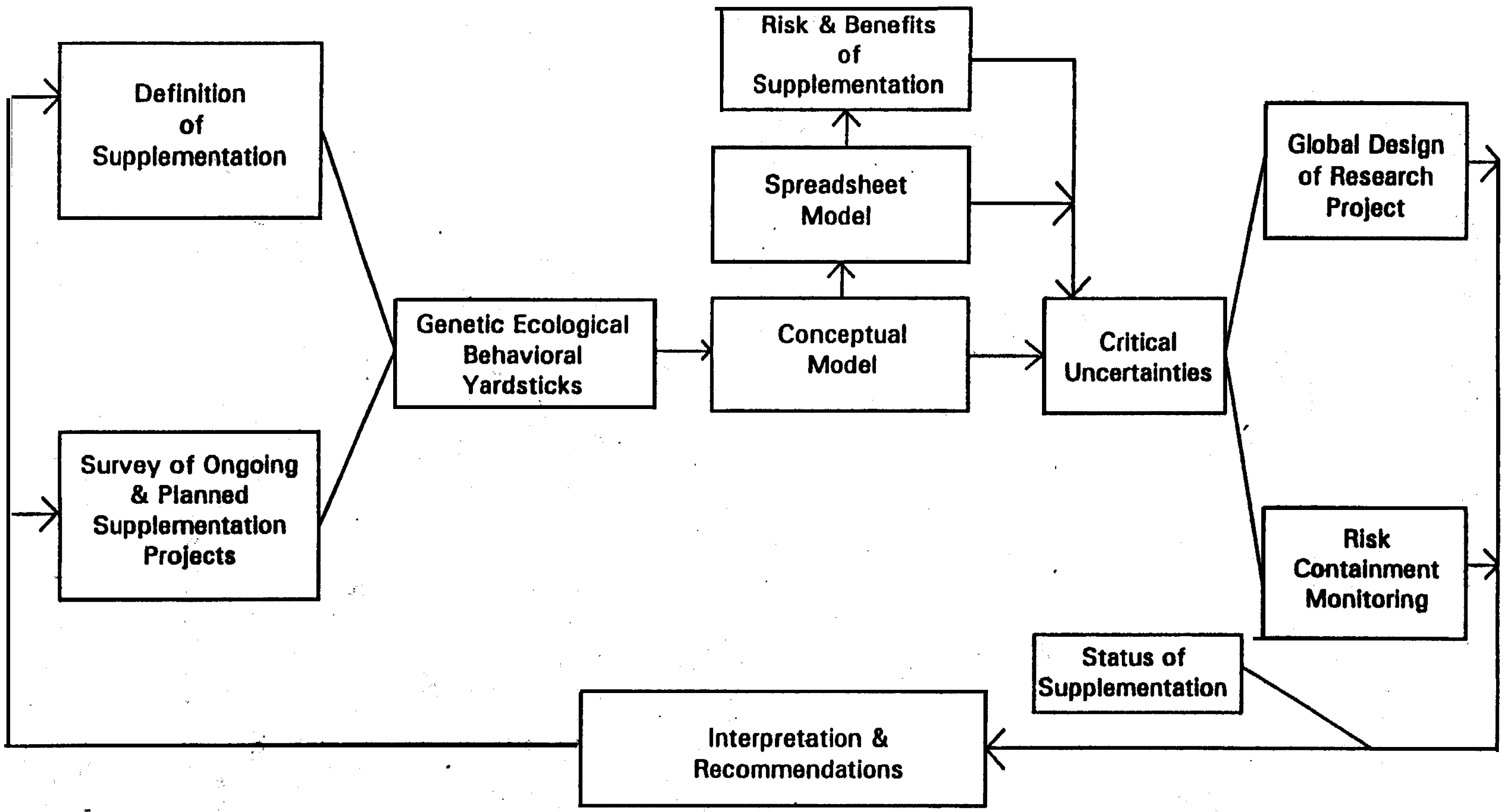


Figure 0.1 **Diagrammatic representation of RASP's tasks during the first year.**

reflect our improved understanding of supplementation. Perhaps the Central Information System is a vehicle that might be used to retrieve and store new information on supplementation so updating can be done routinely in an efficient and timely manner.

As uncertainties are resolved through the global research program and through experience gained from careful monitoring of supplementation projects, the precision of the spreadsheet model can be improved. However, there are too many unpredictable factors in the freshwater and marine environments to expect to ever use the model as a precise forecasting tool. The model does have an important role in supplementation planning today and in the future. The model must be thought of as a scratch pad, a means to work out and test new ideas, and a way to sort out alternative strategies. When used properly, the model can help set the sideboards on the range of possible risks and benefits and it can be used to test assumptions regarding supplementation. The model won't make decisions, but it can be an important tool for the manager struggling with a decision.

FUTURE DIRECTION

RASP has addressed all the objectives in the work plan, however, the value of this work in supplementation planning will be enhanced if developed further. For example, the model, as presently implemented, does not include stochastic variation, or life history complexity (multiple smolt ages so it can handle steelhead). Updated genetic and behavioral yardsticks and more options for the genetic scenarios would be helpful.

The uncertainties need documentation with literature citations, and they should be assembled in a format suitable for future updating. The global research design and risk containment monitoring needs greater detail and literature documentation.

In the coming months, RASP will complete four additional work products:

- Update of the supplementation and M&E survey to include all planned and ongoing projects. This will complete the classification and overview of supplementation in the region.

- Enhance several features of the conceptual and spreadsheet models. Review the theoretical concepts that influence the choice of strategies and potential success of supplementation. Concepts and theories applied in the model will be expanded, and the potential role of supplementation will be discussed.

- **Document the critical uncertainties and develop a user friendly data base covering the literature ielevant to those uncertainties.**
- **Design a global research and monitoring program for supplementation.**

1. INTRODUCTION

The Fish and Wildlife Program of the Northwest Power Planning Council (NPPC) prescribes several approaches to achieve its goal of doubling the salmon and steelhead runs of the Columbia River. Among those approaches are habitat restoration, improvements in adult and juvenile passage at dams and artificial propagation. Supplementation will be a major part of the new hatchery programs. The purpose of the Regional Assessment of Supplementation Project (RASP) is to provide an overview of ongoing and planned supplementation activities, to construct a conceptual framework and model for evaluating the potential benefits and risks of supplementation and to develop a plan for better regional coordination of research and monitoring and evaluation of supplementation. RASP has completed its first year of work. Progress toward meeting the first year's objectives and recommendations for future tasks are contained in this report.

BACKGROUND OF RASP

In January 1990, the Columbia Basin Fish and Wildlife Authority (Authority), citing the number of activities being conducted under different programs and differentparts of the Fish and Wildlife Program, asked the Supplementation Technical Work Group (STWG) to coordinate, prioritize and review all ongoing and planned supplementation studies in the Columbia River Basin. This request was supported by the Pacific Northwest Utilities Conference Committee, which has been concerned about the number of supplementation activities being conducted, the high cost and long-term nature of supplementation studies, and the need to coordinate them to prevent unnecessary duplication of effort. STWG provided the Authority with a plan to accomplish the coordination and review needs.

In August 1990, the NPPC gave conditional approval to proceed with the final design of the Yakima Production Project. The Council called on the Bonneville Power Administration (BPA) to 'fund immediately a supplementation assessment to reevaluate, prioritize and coordinate all existing and planned supplementation monitoring and evaluation activities in the basin... Provid[ing] for the participation of the fishery agencies and tribes and others having expertise in this area."

RASP was created in response to the Council's request and to address long-standing concerns about the need to coordinate supplementation research and monitoring and evaluation. RASP encompasses the activities proposed by STWG.

HISTORICAL PERSPECTIVE

RASP is- clearly the product of recent initiatives, however, it is also embedded in a larger historical context. RASP was established to help facilitate, in the specific area of supplementation, implementation of a changing management paradigm for rebuilding the salmon and steelhead populations of the Columbia River Basin. The new paradigm elevates concern over the conservation of genetic resources to the level of a basin-wide policy (Columbia Basin Fish and Wildlife Authority (CBFWA) 1991). This new policy emphasis reflects the results of a Council sponsored workshop on genetic conservation and production quality. The workshop concluded that salmon production goals for the basin can only be achieved and sustained if the genetic resources of the basin's remaining salmon stocks are maintained (Riggs 1990). Developing and implementing production initiatives consistent with genetic conservation clearly calls for new thinking, new approaches and new performance measures in the basin's salmon and steelhead restoration programs.

Salmonids have been artificially propagated in the Columbia Basin for over 100 years. Throughout that period hatcheries have been the major tool of managers who used them to meet the utilitarian goals of supplying the fishing industry with commodity and replacing production lost through habitat destruction. Prior to the 1940s and 50s, with little scientific advice, the hatchery program, which released primarily fry and sac fry, made small to negligible net contribution to the fishery. Following 1940, research on hatchery practices and evaluation of the hatchery program lead to progressively better culture techniques and healthier smolts that survived better after their release. However, nearly all the early research focused on nutritional requirements of salmonids, developing treatment and diagnosis of disease, designing better physical facilities, selecting the best time and size to release juveniles from the hatchery, and other in-hatchery practices. The impact of hatchery programs on naturally reproducing fishes and factors determining survival of the hatchery fish after release received little attention.

Supplementation – the attempt to increase natural production through the use of artificially propagated fish – has focused attention on the behavioral, ecological, and genetic influences on the success and sustainability of salmonid restoration. If natural production is to be increased through the use of artificially propagated fish, then behavioral, genetic and ecological considerations become as important or more important than the standard hatchery practices. Recent studies have demonstrated the importance of genetic and ecological factors in the successful use of artificial propagation to supplement natural production (Reisenbichler and McIntyre 1977, Chilcote et al. 1986, Nickelson et al. 1986, and Oregon Department of Fish and Wildlife 1986).

The recent emphasis on supplementation to'revitalize natural production in the basin (Table 5.1), the precarious status of several stocks of salmon and steelhead (Nehlsen et al. 1991), and the commitment to double dwindling total production in the basin (Northwest Power Planning Council 1987), has reaffirmed the importance of hatcheries in the Columbia's salmon production system (Table 1 .1). Hatcheries will remain important in some of their traditional roles and they will assume additional roles in supplementation. The roles and responsibilities of hatcheries are changing. The relationship between artificially propagated and wild fish is receiving more attention and so are the accountability and the criteria by which hatcheries are evaluated. For examples of these changes, see the supplementation section of the Integrated System Plan (CBFWA 1991); Oregon's Natural Production and Wild Fish Management Rules (Oregon Administrative Rules 635-07-501 through 529 and 635-07-800 through 815) and Idaho's Draft Anadromous Fishery Management Plan 1991 - 1996 (Personal communication Ed Bowles, September 17, 1991).

Table 1.1 Percent of projected production attributable to supplementation in System Planning. Computed from System Planning Model output (Duane Anderson, NPPC, personal communication).

SPECIES/STOCK	COLUMBIA RIVER REGION				
	LOWER	MID	SNAKE	UPPER	ALL
LATE COHO	97.7%	-	-	-	97.7%
EARLY COHO	100.0%	1~00.0%	-	-	100.0%
FALL CHINOOK	0.0%	37.4%	51.2%	0.0%	8.6%
SPRING CHINOOK	88.4%	64.0%	74.3%	34.7%	65.4%
SUMMER CHINOOK	-	6.3%	66.9%	38.4%	43.5%
SUMMER STEELHEAD A	100.0%	25.6%	95.5%	73.9%	71.8%
SUMMER STEELHEAD - B		-	72.0%	-	72.0%
WINTER STEELHEAD	48.0%	100.0%	-	-	60.2%
ALL	45.4%	47.5%	78.2%	34.5%	52.4%

Throughout most of their 100 year history in the Columbia Basin, hatcheries' were evaluated by a narrow set of market, production, and efficiency criteria. For example, hatchery performance measures included the economic value of hatchery contributions to the catch, pounds of fish. released, contribution to the fisheries and feed conversion ratios. These criteria will remain important but ecological, life history and genetic performance measures will be added to them. Hatcheries will be evaluated in terms of genetic risk (Busack 1990), status of natural production, productivity and life history patterns (particularly where-an increase of natural production is the goal), and overall fitness of the target stock.

Changing management strategies, especially fundamental changes, are not easy to accommodate. Managers are faced with major new challenges while at the same time the conventional wisdoms they relied on in the past are weakened or removed. The hatchery program is facing a challenge greater than any it has had to face since the 1940s when it became generally accepted procedure to rear salmon to full term smolts to achieve highest survival. The transition from fry or sac fry releases to full term smolts presented huge physical and technical problems. For example, many of the early hatcheries were designed for fry release and did not have year-round water supplies (Oregon Fish Commission 1955). Holding fish for extended periods required better understanding of nutritional requirements of salmon and of disease control, prevention, and treatment. Those were not small obstacles that had to be overcome.

Hatcheries today are facing an equivalent challenge: to integrate the artificial and natural salmon production systems in the Columbia Basin to produce a net doubling of the total production. However, the increase in production has to be done in a way that makes it sustainable. This will call for new ideas in the physical design and operation of hatcheries as well as a better technical understanding 'of genetics, behavior, competition and predation – fields that were not strongly emphasized in the domain of artificial propagation until recently. RASP was established to help develop processes and methods to ensure that the transition is completed in a rational and efficient way.

However; RASP is not the only entity contributing to the transition. In the next section, selected reports by others that are relevant to the objectives and tasks of RASP are briefly reviewed.

RELATIONSHIP TO OTHER WORK

The recent emphasis on restoration of' natural production and concern about the erosion of genetic resources in the Columbia Basin has produced several recent publications containing information relevant to RASP. Following% a brief description of selected published reports and work in progress on the topic of supplementation in the Columbia Basin.

Current Work

Smith, E.M., B.A. Miller, J.D. Rodgers and M.A. Buckman. 1985. Outplanting anadromous salmonids -- a literature survey. U.S. Department of Energy, Bonneville Power Administration Project No. 85-68.

Smith et al. (1985) reviewed 200 references on topics dealing with offstation releases of hatchery fish for the purpose of supplementing or reestablishing natural rearing. Their conclusions were divided into three categories: streams managed exclusively for wild production, streams managed for a mixture of hatchery and wild production, and streams managed exclusively for hatchery production. They concluded that streams managed exclusively for wild fish should only be enhanced through habitat protection and harvest control. Streams managed for a mixture of hatchery and wild production present technical, biological, and political problems that may make increasing production without impacting the wild stock impractical. Smith et al. (1985), however, provides a set of guidelines to minimize wild-hatchery interactions recognizing that the effectiveness of many of the recommendations has not been proven. The primary consideration in streams managed exclusively for'hatchery fish is to plant fish at a time when environmental bottlenecks can be avoided. Smolts may be released if a rapid build up of adults is desired.

One purpose of RASP is to clearly define the technical uncertainties that Smith et al. (1985) thought would limit the success of supplementation in the mixed hatchery-wild streams, use a life history model to determine the sensitivity of risks and benefits of supplementation to changes in the uncertainties, and devise a global research plan to efficiently reduce those uncertainties.

Miller, W.H., T.C. Coley, H.L. Burge and T.T. Kisanuki. 1990. Analysis of salmon and steelhead supplementation: emphasis on unpublished reports and present programs. U.S. Department of Energy Bonneville Power Administration project No. 88-l 00.

Miller et al. (1990) reviewed 316 past and present supplementation projects, however, only 26 of the projects actually fit Miller's definition of supplementation (Table 1.2). Twenty-five of the projects were considered a success by the project leaders, however, only eighteen of those were the subject of quantitative evaluation. Even though the project leaders considered all but one of the supplementation projects a success, Miller et al. (1990) concluded that none of the evaluated projects had rebuilt natural runs to self-sustaining levels. They did not state whether the failure to show self-sustaining populations was the result of an inadequate experimental design or a true failure in supplementation.

Miller et al. (1990) compiled a useful data base containing the 316 projects. The report's narrative provides useful information on a wide variety of supplementation projects. However, the criteria by which projects were evaluated were not clearly defined. Miller et al. (1990) and the project leaders were obviously using different criteria to determine success of the supplementation projects. The lack of clear evaluative criteria, has led readers with differing perspectives to draw different conclusions regarding the success of supplementation.

It's questionable whether any of the projects considered supplementation by Miller et al. (1990) would have fit the definition proposed by RASP (Table 1.2). A review of the Miller report using the more restrictive criteria of RASP could lead one to the conclusion that supplementation has not been attempted or evaluated.

Table 1.2 Examples of definitions of supplementation. used in recent publications The definition used by RASP is highlighted for comparison.

***"Supplementation is the use of artificial propagation in the 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)**
"The release of fish from hatcheries at locations away from the hatchery to increase natural production in streams determined to be seeded or used at less than 'optimal levels'." (Smith et al. 1985)
"Planting all life stages of hatchery fish to enhance wild/natural stocks of anadromous salmonids." (Miller et al. 1,996)
"The stocking of fish into the natural habitat to increase the abundance of naturally reproducing fish populations." (Cuenco 1991)
"Supplementation is usually undertaken to provide harvestable surpluses of fish from stocks that may not otherwise naturally produce sufficient fish to meet the demand from fishermen. Management opportunities range from rebuilding threatened or endangered wild stocks to bolstering already self sufficient natural runs. Hatchery fish used to supplement wild stocks of salmonids are stocked at egg, fry fingerling, smolt and adult life stages." (Steward and Bjornn 1990)

Cuenco, Michael L. 1991. Examples where supplementation has successfully resulted in increasing natural reproducing fish populations. Manuscript Columbia River Inter-Tribal Fish Commission. Portland, OR.

Cuenco (1991) described several successful supplementation projects, however, the report, like Miller et al. (1990), failed to clearly state the criteria used to determine success. Success may have been measured by questionable criteria. In example 3, a hatchery program for chinook salmon begun in 1984 in Horse Linto Creek, a tributary to the Trinity River, was deemed a success in 1989 when 70 spawning pairs were observed. Five years from the first hatchery plant is not enough time to complete a cycle of naturally produced fish and determine if the program had produced a self-sustaining population.

Cuenco (1991) did show that under some circumstances supplementation produces self-sustaining populations. Whether or not those successes were achieved without adverse genetic or ecological impacts on the target and nontarget populations cannot be determined from the information supplied.

Scientific Review Group. 1991. Review of fisheries supplementation in the context of activities related to the Columbia River Basin Fish and Wildlife Plan. Memorandum to Wally Steucke, IPP Coordinator. 7pp. Portland, Or,

The Scientific Review Group (SRG) reviewed the Supplementation Work Plan and reports by Miller et al. (1990), Steward and Bjornn (1990) and Bjornn and Steward (19901. Principal investigators dealing with supplementation were interviewed by the SRG. Rather than focus on specific plans or reports, the SRG developed a general overview of supplementation. The SRG's overview has provided RASP with guidance over the past several months. There is a general correspondence between the objectives of RASP and the subjects discussed in the SRG report. For example, a definition of supplementation, setting supplementation objectives, classification, identifying critical unknowns and research design are common to the RASP and SRG reports. The concerns, discussed by SRG and their recommendations will continue to guide RASP through the development of a final report.

Steward, C.R. and T.C. Bjornn. 1990. Supplementation of salmon and' steelhead stocks with hatchery fish:. A synthesis of published literature. U.S. Department of Energy, Bonneville Power Administration Project 88-100.

Steward and Bjornn (1990) greatly expanded the review of Smith et al. (1985). RASP will use the information base contained in Steward and Bjornn (1990) to document the critical uncertainties discussed later in this report.

Bjornn, T.C. and C.R. Steward. 1990. Concepts for a model to evaluate supplementation of natural salmon and steelhead stocks with hatchery fish. U.S. Department of Energy, Bonneville Power Administration Project 88-l 00.

See The Supplementation Model - Conceptual Framework in this report for a discussion of the paper referenced above.

Lee, D.C. and J.B. Hyman. 1991. Stochastic life-cycle model (SLCM): A tool for simulating the population dynamics of anadromous salmonids. Resources for the Future, Washington, D.C. 22 pages.

See Supplementation Model- Conceptual Framework for a discussion of this paper.

Riggs, L. 1990. Principals for genetic conservation and production quality. Northwest Power Planning Council Contract C 90-005.

This report was the product of a workshop – the first of a series of three – on production principals sponsored by the Northwest Power Planning Council (NPPC). The report develops genetic conservation guidelines for all forms of production and, therefore, has broader application than supplementation as' defined by RASP. However, the principles and guidelines are applicable to RASP.

Riggs (1990) introduces the subject of gene conservation with the unequivocal statement: 'Sustainable increases in salmon and steelhead productivity in the Columbia River Basin can only be achieved if the genetic resources required for all forms of production, present and future, are maintained in perpetuity." This statement symbolizes the changing management paradigm in the Columbia River Basin. The report gives six guiding principles, six management opportunities, and seven implementation guidelines. RASP has used Riggs (1990) as the general context within which it carries out its work.

Work in Progress

The NPPC has completed a second workshop which addressed sustainability of anadromous fish resources. The subject of sustainability was divided into three general areas: genetic diversity and conservation, population viability and supplementation, and hatcheries. Draft technical reports on each of the subject areas are being revised. While all the reports will be relevant to RASP, 'the report on supplementation and hatcheries (with a draft title of Genetic Conservation Guidelines for Salmon and Steelhead Supplementation) will have obvious application to the RASP process. Two members of RASP have helped prepare the report.

The technical reports mentioned here, including those that are in draft form such as the Sustainability Workshop reports and the Monitoring and Evaluation Group's (MEG) report (Guide to Genetic Impact Monitoring) offer a wealth of useful information to the manager contemplating a supplementation project. However, because of the magnitude of the printed material and some overlap and inconsistencies in the presentation of similar ideas, the prudent manager may find it difficult to interpret and reduce the mass of information to a consistent set of ideas and guidelines from which to develop his or her program. In the next year RASP will attempt to integrate the new information into the framework presented in this report in such a way that the manager will have a useful planning, evaluation and decision making tool.

2. APPROACH

Supplementation is one of many tools embedded in the complex scientific, social, and economic matrix of fisheries management in the Columbia Basin. It is difficult at best to extract one of those tools from the management matrix, examine and evaluate it, describe its risks and benefits, uncover the technical uncertainties that limit success, and recommend an adaptive research and management course.

An assessment of supplementation offers special challenges because of the variety of implementation strategies available to the manager and the diversity of management' objectives consistent with supplementation. For example, a target stream may be supplemented with adults, eggs, fry or smolts. Broodstock may be drawn from the local population, from adjacent or distant stocks if the local stock has been extirpated, or from a combination of local and distant stocks in a special breeding program. Objectives may include the recovery of an endangered stock, the conservation of a unique genetic trait, or the attainment of full production potential in a subbasin.

Supplementation encompasses enough diversity that internal consistency among the various objectives of RASP could not be left to chance. RASP developed several unifying themes. The central themes used by RASP and incorporated into this report are: changing management paradigm, definition of supplementation, currency of supplementation objectives, 'classification, and ecological dimensions.

CHANGING MANAGEMENT PARADIGM

Supplementation is controversial. Managers disagree as to what supplementation -is, whether it has been successful in the past,'and whether it can be implemented in the present without inflicting further damage to depleted natural production in the basin. To a large degree, RASP is a product of this controversy.

We believe the disagreements over supplementation reflect the tensions of a shifting management paradigm in the Columbia Basin. The shift is, in part,, a recognition of the impact of traditional hatchery practices on natural production 'and the growing appreciation for the value of the genetic resources of the extant salmon populations in the basin.

We believe much of the controversy surrounding supplementation could be resolved if the broader management context were understood and if energy expended in conflict were directed toward the huge technical challenges presented by the shifting management paradigm.

Past practices have failed to produce the desired results and have, instead, created unanticipated problems. The challenge of finding effective ways to meet objectives is big. Clearly RASP has an educational, as well as a technical, role in the supplementation issue. Our approach has been to address the technical issues while acknowledging their context in a changing management framework in the Columbia River Basin.

DEFINITION OF SUPPLEMENTATION

The need for a clear definition of supplementation was recognized early in the development of RASP, and a definition was assigned as one of the, first objectives of RASP. Historically, supplementation has been defined in vague terms which has, in part, led to different interpretations of the past record as discussed in the Introduction. Several different definitions of supplementation are in use today (see Table 1.2).

All definitions recognize the goal of increasing or rebuilding wild/natural production through the use of artificially propagated fish. However, those definitions, framed in narrow production terms, fail to recognize that supplementation attempts the more complex task of integrating natural and artificial production systems.

The definition developed by RASP recognizes the broader management context of supplementation, specifically an increase in natural production, the. maintenance of long-term fitness of the supplemented stock, and a limitation on the impacts on nontarget stocks. These concepts are discussed in Chapter 3 and are incorporated into the model.

CURRENCY OF SUPPLEMENTATION OBJECTIVES

Historically, objectives for target populations were expressed in terms of the number of fish returning to the subbasin or contributing to the fishery. To be consistent with the changing management framework described.above, those historical measures of success or evaluation currency must be expanded to include indices of the genetic composition and performance of the returning fish.

An important feature of the conceptual model is the identification of four types. or classes of fish which are subsequently used in the spreadsheet model'to track the genetic composition and relative fitness of a stock: first generation hatchery fish (T_3), a fish with two hatchery parents (T,), a fjsh with one hatchery and one wild parent (T,), and a wild fish or a fish whose fitness is equated to a wild fish (T_0) . These types, their notations and their definitions are used throughout this report to set objectives, to track benefits and risks in the supplementation model and in the description of uncertainties.

CLASSIFICATION

The 63 ongoing and currently proposed supplementation projects (see Table 5.1) in the basin are classified by three features: target stock characteristics, receiving stream characteristics, and supplementation strategy.

RASP has used the patient/treatment analogy to explain the relevance of these classification strata.

The stock and stream characteristics describe the condition of the patient needing help through supplementation. Supplementation strategies are the possible treatments available to the manager to effect a cure. Since the purpose of supplementation is to integrate natural and artificial production systems, the status of the target stock and the condition of its habitat (condition of the patient) are crucial to the selection of appropriate strategies. Related questions are: When is supplementation the right prescription? For ESA conditions? What is the appropriate supplementation treatment and dosage?

Classification enables RASP to identify clusters of projects sharing similar patient/treatment characteristics. The clusters of similar projects will be used to evaluate output from the supplementation model. For example, in developing the global research design it is important to know if projects falling together in the classification scheme respond in a similar manner to similar supplementation strategies.

Classification, combined with the supplementation model, will be used to rank critical uncertainties and set priorities in the global research design. Uncertainties associated with a large cluster of similar supplementation projects may receive a higher research priority than uncertainties associated with a single project.

ECOLOGICAL DIMENSIONS

In order to deal effectively with the biological reality of past extinctions and present stock depletions, and the conflict generated when artificial and natural production systems are proposed for integration, supplementation planning must be based on an analysis of the relationship between the propagated fish and the targeted population and its habitat. Whatever form this analysis takes – conceptual model, computer simulation, or simple strategic plan -- the resulting supplementation objectives must consider all the major ecological dimensions within which the program must operate.

RASP has identified four dimensions important to supplementation: post-release survival, reproductive success, long term fitness, and ecological interactions (see Chapter 4). Managers are free to establish their specific objectives and express tradeoffs among the dimensions as value judgments. However, the objectives of each supplementation program must incorporate all the ecological dimensions with sufficient detail and specificity to permit meaningful evaluation and determination of risks and benefits.

3. DEFINITION OF SUPPLEMENTATION

RASP recognized the need for a clear working definition of supplementation to guide its work. This chapter presents that definition and discusses its implications.

The definition limits supplementation to the explicit intention of maintaining or increasing natural production by means of artificial propagation. It is also clear, however, that *inadvertent* supplementation – the unplanned addition of hatchery-reared individuals to naturally reproducing populations – occurs every time surplus adults from a hatchery program survive to spawn in the wild. This type of 'incidental supplementation", which comprises the bulk of the examples cited in the Miller report (Miller, 1990), has almost certainly been more frequent than the "planned supplementation" which is the focus of this report. While inadvertent supplementation is not addressed directly, the proposed framework for setting and evaluating objectives and the model described in a later section could be adapted to all forms of artificial enhancement.

DEFINITION

> *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.

Supplementation Is.. .

Supplementation refers to strategies for increasing natural production by taking fish into a protected artificial environment and then releasing them, or their progeny; into streams where they are later expected to reproduce naturally.

The four goals shared by all supplementation programs are as follows:

- use of artificial spawning and/or rearing conditions to bypass "survival bottlenecks" and increase survival above expected natural rates
- increasing natural production or maintaining production in the face of anticipated declines
- long term preservation of the fitness and fundamental genetic integrity of target populations
- limitation of ecological and genetic impacts on both target and non-target populations

None of these elements is unique to supplementation. For example, traditional hatchery production for harvest augmentation may employ similar artificial means, and habitat improvement is usually intended to improve natural production. The unique feature of supplementation is the assumption that artificial propagation can be used to improve the production of naturally-spawning populations without adverse genetic or ecological effects.

Ecological and genetic impacts on natural populations resulting from supplementation are explicit concerns. At a minimum, supplementation programs are designed to conserve the genetic identity and variability of the target population and to hold the competitive and predatory impacts on other populations within prescribed limits. A genetic monitoring program and contingency plans for dealing with genetic problems are also highly recommended.

As defined here, supplementation encompasses a wide range of manggement objectives -the supplementation continuum – ranging from reestablishment of natural production in vacant habitat to generation of various levels of surplus production for harvest and other uses.

Supplementation may employ one or more of many different strategies. For example, fish may be removed from and subsequently returned to the natural environment at different times and lifestages; programs may be temporary or' long term; and implementation may be constant (annual) or intermittent. The optimal combination of supplementation strategies depends upon production and utilization. objectives, constraints and opportunities of recipient streams and target populations, and the risks and uncertainties entailed by limited'knowledge.

Supplementation Is Not.. .

Supplementation is most clearly differentiated from conventional hatchery programs by the respective goals each sets for using adult production. The typical goal of the conventional hatchery is to maximize adult production for harvest while assuring the collection of adequate broodstock. The minimization of adverse impacts of surplus hatchery spawners on natural production is at most a condition on the primary mission.

The ideal conventional hatchery would be located in an area devoid of natural production; surplus spawners could, in this instance, be regarded simply "economically," as a reduction of net benefits to be corrected by adjustments in harvest or production programming. The complications of genetic and ecological interactions between hatchery and natural fish would be precluded, and the manager could safely implement a hatchery-oriented breeding program to select for traits most suited to hatchery survival and fisheries contribution.

Most Columbia Basin hatcheries are, however, located in areas with natural production; and most have, intentionally or unintentionally, imposed selective pressures on hatchery and natural populations. The relatively recent recognition that the ecological and genetic consequences of hatchery fish spawning with natural fish might include a depression of natural production has raised concerns over the unintended effects and has lead to a number of measures intended to produce hatchery-reared fish as similar as possible to natural fish and/or to isolate the hatchery genetically. The difficulty of ensuring hatchery/natural genetic compatibility in traditional production programs and the absolute priority placed on harvest augmentation most distinguish conventional hatcheries from supplementation programs.

Supplementation is differentiated from other artificial attempts to increase natural production by the required elements of artificial spawning or rearing. We have defined "artificial" as "the substitution of human activity occurring in a man-made environment for voluntary behavior by fish in a natural stream." Accordingly, neither riparian restoration nor installation of instream structures intended to improve habitat would be considered supplementation because neither involves artificial spawning or rearing. Similarly, construction of spawning channels is not supplementation so long as fish spawn there *voluntarily*; a spawning channel *would,* however, represent supplementation when fish are transported to the channel for spawning. The 'outplanting" of artificially fertilized eggs in low-tech egg boxes or man-made 'redds" would, for example, also fit the RASP definition of supplementation.

4. OBJECTIVES AND EVALUATION

Supplementation, as a means of implementing the new paradigm of sustainable natural production, is a relatively new and untested mode of operation. It requires ongoing evaluation to identify and correct problems in its application. This chapter identifies broad objectives of supplementation, general strategies for accomplishing them, and a proposed method of evaluation based on specific goals.

In order to deal effectively with the biological and legal reality of past and threatened extinctions, and the conflicts between hatchery practices and the preservation of natural production, supplementation planning must be based on an analysis of all dimensions of the relationship between the targeted population and its physical and biological environment. In the final analysis, planning and implementation must become more sophisticated because simpler approaches have failed to provide expected benefits even as they caused unanticipated problems.

OBJECTIVES

Four objectives of supplementation programs were identified by the Scientific Review Group (letter from SRG to IPP Coordinator, November 13, 1990):

- conservation
- introduction/restoration
- rearing augmentation
- harvest augmentation

The latter, harvest augmentation, would not be considered supplementation within the RASP definition because it does not necessarily include an increase in natural production. However, when an increase in or maintenance of natural production is a concurrent requirement for success, the project would be considered supplementation. As defined by Miller (1990), harvest augmentation is, 'the stocking of anadromous fish where the *primary* purpose is to return adults 'for sport, commercial, or tribal harvest," and is thus fundamentally an option for conventional hatcheries/'

Conservation may be defined as the use'bf artificially propagated fish to increase the abundance of a wild/natural population depressed to critical levels by overharvest, habitat degradation, or other factors. Artificially propagated fish are released, in an attempt to "push" the population above minimum viable levels, and to maintain or increase genetic variability in order to promote -long term fitness (Fisher, 1958).

Introduction/restoration is the-use of artificially propagated fish to establish a stock in an area where that species was not native (introduction) or to re-establish a species in an area from which it has been extirpated (restoration). The purpose of both introduction and restoration is to achieve naturally-spawning populations which maintain themselves above minimum viable levels. Genetic character *per se* is irrelevant so long as the populations become self-sustaining and retian adequate genetic variability.

Rearing augmentation attempts to increase natural production in existing wild/natural populations by planting artificially propagated fish in rearing habitat that is chronically underutilized.

These qualitative objectives are useful in discriminating projects at a gross level. They do not, however, provide measurable benchmarks for evaluation of individual projects. Each qualitatively distinct type of supplementation program must be analyzed as rigorously and comprehensively as possible, and specific, quantitative objectlves must be established for all population responses of concern.

POPULATION RESPONSES

RASP has identified four population responses or "dimensions" whereby supplementation objectives should be stated and evaluated. For each of these measurable response variables must be identified in order evaluate success:

- post release survival
- reproductive success
- long-term fitness
- ecological interactions

Post-release Survival

Post release survival focuses on the absolute and relative survival of hatchery-reared fish from the time of release to the time adults return to the subbasin or are harvested in a fishery. All environmental conditions and experimental treatments that impact survival are considered. Survival rates preceding the outmigrant smolt stage are also included in the case of supplementation programs utilizing eggs, fry, parr, or pre-smolts.

Post-release survival objectives may be affected by:

- survival of hatchery-reared fish

- relative survival of different treatment groups of hatchery-reared fish;
- temporal/spatial distribution of mortality.

Where significant effects of supplementation on post-release survival are hypothesized, intermediate response variables should be defined. These intermediate survival rates should be defined over observable intervals and should have a clear relationship to the critical uncertainties and experimental hypotheses of an individual project. Such measures should be defined to provide information on the actual mechanisms of a particular strategy as well as indications of performance.

Examples of such variables are in-basin ("smolt to smolt") survival or smolt survival between monitoring locations in the subbasin and mainstem Columbia River.

Peoroductive Success

Reproductive success focuses on how well supplementation fish reproduce in the natural environment. Reproductive success spans only a single generation, whereas long-term fitness measures stock productivity over multiple generations. Broadly defined as the number of offspring produced per spawner, reproductive success may be measured at several life history stages, and considers ail events and behavior that impact parent/progeny ratios. Comparisons of reproductive success between hatchery and natural fish (during pre-spawning and spawning) and among offspring of their subsequent matings (during incubation, juvenile rearing, and smolt-to-adult) allow inferences to be made regarding critical periods and influences experienced by supplementation fish. These comparisons also aid determination of what influence genetic factors may have on reproductive success.

Reproductive success may be affected by supplementation. treatments in several ways. Potential effects include changes in:

- fecundity resulting from differential maturation rates acting through sex, age, and size composition
- pre-spawning mortality resulting from effects of adult run size on holding and pre-spawning densities
- spawning distribution and effectiveness including homing and distribution, mate acquisition and redd digging capability, spawning timing, and egg retention

- offspring survival and production including survival rates (egg-to-fry, fry-to-presmolt and presmoit-to-smolt and recruit per spawner ratios for hatchery-reared and natural fish of various hatchery/wild pedigrees.

Where supplementation strategies are expected to affect reproductive strategies, specific hypotheses and response variables should be identified to permit evaluation of the effects.

Lona Term Fitness

Long term fitness is defined as 'the adaptive capability of a population to persist in the face of environmental variability while undergoing natural genetic change". Ultimately, long-term fitness is demonstrated by the simple fact that a population has maintained itself over a long period of time.

In the context of a supplementation program, long-term fitness must be addressed through genetic considerations. These include:

- identification of genetically distinct subgroups within the targeted population, and the determination of the status or "seeding" of substocks

- assessment of genetic risks, at the substock level

- definition of fitness in terms of morphology, behavior and physiology, and specification of impacts of supplementation on fitness components

- development of procedures to monitor and evaluate variability and change of genetic frequencies within substocks

- development of supplementation strategies and artificial production protocols to ensure that genetic safeguards are adequately addressed (e.g., broodstock collection procedures, mating strategies, etc.).

Strategies should be developed to protect long-term fitness, and related hypotheses should be defined to detect genetic effects.

Ecoloqical Interaction3

Ecological interactions refer to effects. of supplementation on both target and non-target populations and on the environment. The focus is on the targeted subbasin.

Optimal design of supplementation strategies should consider the physical habitat's spawning, summer rearing, and over wintering capacity. Seasonal movement patterns within the subbasin are also important in identifying optimal release times and locations.

One of the most important biotic effects is the impact of a successful supplementation program on non-target species or races. Although it is a generally accepted ecological principle that total production of a number of species produced sympatricaliy will be greater than the ailopatric production of any single species, it is also true that a dramatic increase in one, formerly depressed, component of a community will be associated with some decrease in the other components (Ricklefs, 1973).

The inter- and intra-specific trade-offs implicit in any supplementation program must be made explicit, and strategies should be developed to meet defined objectives for protection of non-target species.

The RASP spreadsheet model can be adapted to estimate impacts on nontarget species. Based on assumed multi-species carrying capacity and an estimate of niche overlap, an estimate of non-competitive impacts on the survival of the nontarget species by life stage and, in some cases, an estimate of gene flow into the nontarget population and resultant decreases in fitness, the spreadsheet could be modified to assess equilibrium population numbers for the nontarget species.

Another important biotic issue focuses on adverse predatory and competitive impacts on the targeted population. Supplementation programs should incorporate release sites, times and practices designed to circumvent adverse competitive and predatory impacts. Perhaps an even larger issue is whether or not the targeted population currently exists within a "lower stability region" or 'predator trap," and if so, whether contemplated releases will be large enough to move the population into a higher stability region. Peterman (1977) suggested that depensatory mortality could lead to the establishment of two separate equilibrium populations: a small population within a lower stability region demarcated on its upper end by depensatory mortality in excess of density-dependant mortality; and a larger population in an upper stability region in which abundance causes depensatory mortality to be much smaller than density-dependant mortality.

Planners are well advised to examine historical escapement records for evidence of multiple stability regions. If the evidence indicates the population is so depressed that depensatory mortality might be "trapping" it in a lower stability region, planners should consider either making the program large enough to "swamp" competitors and predators, or providing for reduced predation and competition.

Species issues related to physical habitat include:

- factors limiting production, including identification of critical or unique seasonal patterns of habitat use by specific life history stages

- species-specific carrying capacities in mainstem reaches and tributaries

- changes in habitat parameters including: fish passage at facilities, screening, flows, water quality, and logging operations and plans

Issues related to impacts on nontarget species include:

- competitive and genetic interactions between resident (pre-existing) and anadromous trout (supplemented)

- interactions between pre-existing resident trout and other anadromous species

- interactions among anadromous salmonids themselves (supplemented and natural), e.g., competition, predation, '"pied-piper" effects,. and residualism.

Issues related to impacts of other species on target species include:

- specific times and places associated with large losses of outplanted fish and development of compensatory release strategies

- multiple stability regions caused by depensatory mortality and development of plans intended to move the population into the higher stability region.

Strategies should be developed to meet specific management objectives defined for environmental interactions.

EVALUATION

Evaluation of supplementation is necessary to test hypotheses and develop successful strategies and protocols. It is also necessary to detect unintended results of supplementation.

To quote Danny Lee (Lee, 1991), "In contrast to planning, program evaluationfocuses on determining the impact that a single management strategy has had on a fish population. The primary analytical challenge here is to separate the effect of the implemented strategy from the effect of random environmental variations." Given the magnitude of environmental variation, this "primary challenge" is formidable: determining whether objectives expressed wholly in terms of adult returns are achievable by a particular strategy can take many years. This fact highlights the importance of designing studies in which environmental variability is tightly controlled to increase experimental power (Section 8 discusses this issue in detail). It also suggests that experimental designs should include sub-hypotheses expressed in terms of "intermediary response variables," or "surrogate variables," which can be tested more easily.

The potential benefits and risks associated with a particular project are dependent on the objectives of the project. Thus the same hypothetical outcome would be evaluated as a success for one project and a failure for another.

Currency of Supplementation

Objectives for target populations can be expressed in terms of the number of fish returning to the subbasin or the fishery over time and the "type" (in the special sense defined in Section 2) of these fish. The relative number of fish of different types and the total number of fish of all types, as well as time trends and fluctuations in type-specific and total returns, represent the currency for assessing supplementation at the target population level.

To reiterate the definition presented in in Section 2, "type" refers to the rearing history and ancestry (wild or hatchery) of an individual fish in the supplemented population. In this context, "wild" (Type 0) denotes either a fish having no hatchery-reared ancestors, or one in which hatchery parents have been succeeded by a sufficient number of natural generations to have become equivalent to aboriginal wild fish in fitness.

Genetic success is demonstrated by the observation of an increase in total production of fish of all types which is maintained indefinitely (over a large number of generations). Except for introduction or restoration projects, all successful supplementation projects will also be identified by the persistence of a significant proportion of "wild" types in the equilibrium population.

To facilitate discussion of goals and evaluation, it will be useful to review several terms representing four fundamental types:

- wild fish, in the special sense described above (denoted as T_0)
- first generation hatchery-reared fish (denoted T_3)

- fish with one or two hatchery parents (denoted T, and N,, respectively).

The use of just these four types, when combined with variable "genetic recovery rates" – the number of natural generations required for the progeny of a T, fish to become T_0 – allows for a considerable degree of sophistication and genetic realism.

Settina Goals

Prescriptions, rules, or norms do not apply to the setting of objectives for supplementation programs, with the exception that steps must be taken to preserve the long-term fitness of the target population.

Trade-offs implied by a desired set of outcomes in the areas of post release survival, ecological interactions and, to a degree, reproductive success,, represent value judgments. Conditioned by existing State and Federal laws (such as the Endangered Species Act), objectives are set at the discretion of local managers and their constituents. However, an effective supplementation program could conceivably represent a large scale ecological change. Such large scale changes in an ecosystem always have side effects, both on target and nontarget populations. The long-term, ecological perspective needed in a system as intricately interconnected as the Columbia Basin requires that side effects and trade-offs be explicitly considered in the design, implementation and evaluation of supplementation programs.

The requirement to preserve long-term fitness generally implies maintenance of genetic identity, variability, and pre-supplementation rates of genetic change. The most basic aspect of preserving long-term fitness is that the population not go extinct. Unfortunately, all too many populations in the Columbia Basin are so numerically depressed and/or genetically compromised that preserving the population may entail counter-intuitive actions. It may, for instance, be necessary implement an *outbreeding* program (with a stock from a similar type of habitat) to increase genetic variability in a critically depressed stock which might otherwise be eliminated by one or two atypical seasons. But, however justified and implemented, supplementation programs must attempt to ensure the long term fitness of the targeted population.

The following hypothetical program is discussed to illustrate setting goals. For heuristic reasons, the goals are described in terms of types (the $T_0,...,T_3$ "currency" described above). While recognizing that it may *current/y* be impossible to monitor all types in all areas, there is nevertheless considerable value using the concept in planning and, especially, in modeling. By assigning all pedigrees "below" T_0 fractional relative decrements in fitness (T_0 has a dimentionless fitness of 1 .O by definition), and varying the rate (and the possibility) of regaining T_0 status, considerable realism and flexibility can be injected into the planning process.

Consider an upper basin summer steelhead population which is essentially wild (has never been supplemented) and is currently depressed. Some of the conditions that caused the initial depression have been eliminated (e.g., a tributary dam has been removed), and improvements in others (passage at mainstem dams) can be anticipated. Spawning and rearing habitat in the subbasin is excellent in quality and currently is utilized primarily by a large population of rainbow trout which supports a fishery of some intensity.

In good years, abundance is maintained, but managers fear that three or four bad years in succession could result in critical depression or extinction. The managers' fundamental objective is to use supplementation to increase the abundance of the population rapidly and substantially, and to preserve as much as possible of the native gene pool. Secondarily, the managers would like to re-establish a terminal steelhead fishery, which has been closed for a number of years. The managers determine to accomplish these general objectives by sustained smolt supplementation utilizing local broodstock. Within this context, they might set the following specific goals:

Post release survival. The managers wish to double spawning escapement by the third generation of supplementation:

$$(\sum N_i)_{after\ 2\ generations} = 2N_{0_{now}}$$

They also have set the objective that this escapement will be maintained in the face of a terminal fishery that harvests anaverage of 20% of the returns; therefore, they have set the objective that escapement *to the subbasin* should be 2.5 times the current average. Through modeling, it has been estimated that, given the number of smolts that can be produced, this can only be accomplished if the smolt-to-adult survival of supplementation fish is at least 50% of the wild rate.

Reproductive success. Model runs indicate that targeted production increases cannot be maintained unless egg-to-smolt survival of T_2 and T, fish is, respectively, 80 and 90 percent of the wild rate:

$$S_{egg/smolt,T_2} = .8S_{egg/smolt,T_0}$$

$$S_{egg/smolt,T_1} = .9S_{egg/smolt,T_0}$$

Equally necessary, on the basis of model runs, is the preservation of the pre-supplemented age distribution and mean fecundity in T_3 fish:

$$Fec_{T_3} = Fec_{T_0}$$

An additional management objective is that the "homing fidelity" of T_3 fish be at least 90% of the T_0 rate, and that T_2's and T_1's home at rates 'equivalent to wild fish.

Long term fitness. Managers have determined that the probability of the population becoming extinct in the next 100 years should be less than 5 percent. In addition, the number of hatchery fish (N_3) should never exceed the sum of N_2's, N_1's, and N_0's. It is assumed that after two natural generations, T, fish become equally fit as wild fish (T_0's).

Ecological interactions. Managers decide to accept a 50% reduction in abundance of rainbow trout by the third generation, if necessary, but determine to implement acclimation and release strategies that might reduce this impact.

Strategy Selection

The use of some type of model is essential to determining the optimal strategy to accomplish a set of goals for a particular stock and stream – for a particular "system". "Model," as used here, does not necessarily mean an integrated life cycle computer simulation, or the specific spreadsheet model developed by RASP. Rather, a model is an interrelated set of quantitative relationships and parameters that summarizes the best existing understanding of production for a specific system. It is the task of the planner to use the most appropriate model for the system of interest to determine which combination of actions – which strategy – has the greatest probability of producing the desired results:

$$Pr\{ Obj_i, \ldots, Obj_k \mid Stock_x, Stream_y, Strategy_z \}$$

This represents the *conditional* probability of meeting objectives i through k given stock x, stream y, and strategy z. We cast supplementation planning in this light to emphasize that the outcome of a particular strategy depends on the system. This dependency, in turn, emphasizes the need for an integrated, empirically based model.

5. CLASSIFICATION OF STOCKS, STREAMS, AND STRATEGIES

Classification of supplementation projects is being undertaken to identify similar projects. This is expected to result in the clustering of related projects so that inferences about strategies and responses can be made across clusters. It wilt also help identify where additional monitoring and evaluation is needed and where unnecessary duplication can be avoided.

NATURE AND PURPOSE OF CLASSIFICATION

Initially, the most important way to classify projects is in terms of similarities among their various critical uncertainties. As is evident from the schematic representation of the RASP process in Fig. 1.1, the identification of *critical uncertainties* Is pivotal In the development a global design for supplementation research. Therefore, all project-specific critical uncertainties must first be established. Then, it can be anticipated that one or more techniques of cluster analysis will be employed to identify groups of projects related by all of their major testable assumptions.

Although the general technique of extracting the critical uncertainties implicit in any project have been developed in a general way (see Section 7), the technique has not yet been refined, nor has all of the required information been collected and collated. In particular, information on specific objectives, (expressed in' terms of the four ecological dimensions previously discussed) and monitoring and evaluation programs is needed for all projects. Definitive classification will not begin until all pertinent data is in hand.

Note that this "primary" classification scheme is based on the relationship between the "system" (the targeted stock and stream), the specific objectives of the project, and the strategies chosen to accomplish the objectives. The ad hoc classification therefore reflects social values through objectives and scientific judgement through the strategy. It is necessary to determine clusters of projects related in this way if the existing "universe" of supplementation is to be described and an efficient global design developed. However, to show affinities between groups of stocks and streams in the universe of potential supplementation projects -- the universe containing all possible combinations of objectives and strategies -- a very different classification scheme is required. With one important caveat, this scheme must focus on the critical attributes of the system alone. These attributes will be "critical" in the sense that they determine the response of the system to supplementation strategies. Importantly, these attributes must also be conditioned on a' particular strategy. This must be so because the attributes of systems interact with strategies; for example, the attributes that determine the response to a program based on smolt releases will almost certainly differ from the attributes that determine the response to a program based on fry. Strategy-specific classification of systems might be based on systematic spread-sheet modeling of combinations of systems and "standard" strategies. Clusters of systems that respond in similar ways to all combinations of strategies could then be grouped together as "functional equivelents". Implementation of this scheme awaits refinement of the spread-sheet model and the definition of standard treatments.

ONGOING AND PLANNED SUPPLEMENTATION PROJECTS

Ongoing and planned supplementation projects in Washington, Idaho and Oregon are summarized in Table 5.1. All of these projects, to a greater or lesser degree, fit the definition of supplementation proposed earlier. It is important to note that a number of ongoing outplanting programs were excluded from the list because they are intended *primarily* to augment harvest, not natural production. Many of these harvest augmentation programs are to be replaced with "true" supplementation projects; in such instances, only the planned project was analyzed.

The distribution by species among the 63 projects in the tri-state area is as follows:

- spring chinook - 42
- summer steelhead - 7
- summer chinook - 7
- fall chinook - 4
- sockeye - 2
- winter steelhead - 1

At this time we have incomplete data on 21 of the projects[1], but we expect to complete them soon.

[1] All eight of the Rock Island, the four Douglas Co. PUD projects, spring chinook projects on Asotin Creek and the Tucannon River, and the Snake River fall chinook program.

Table 5.1. Ongoing and planned supplementation projects.

	River	Species/Race	Project	Status	In RASP Database
1	Alturas Lk. Cr. Salmon R., ID	Spring Chinook	ISS-First Generation	Planned	Yes
2	Alturas Lk. Cr. Salmon R., ID	Spring Chinook	ISS-Second Generation	Planned	Yes
3	East Fork Salmon R., ID	Spring Chinook	ISS-First Generation	Planned	Yes
4	East Fork Salmon R., ID	Spring Chinook	ISS-Second Generation	Planned	Yes
5	Upper South Fork Salmon R., ID	Spring Chinook	ISS-First Generation	Planned	Yes
6	Upper South Fork Salmon R., ID	Spring Chinook	ISS-Second Generation	Planned	Yes
7	W.Fork Yankee Fork Salmon R., ID	Spring Chinook	ISS-First Generation	Planned	Yes
8	W.Fork Yankee Fork Salmon R., ID	Spring Chinook	ISS-Second Generation	Planned	Yes
9	Pahsimeroi R. Salmon R., ID	Summer Chinook	ISS-First Generation	Planned	Yes
10	Pahsimeroi R. Salmon R., ID	Summer Chinook	ISS-Second Generation	Planned	Yes
11	Clear Cr. MF Clearwater,ID	Spring Chinook	ISS	Planned	Yes
12	Red R. SF Clearwater, ID	Spring Chinook	ISS-First Generation	Planned	Yes
13	Red R. SF Clearwater, ID	Spring Chinook	ISS-Second Generation	Planned	Yes
14	American R. SF Clearwater, ID	Spring Chinook	ISS	Planned	Yes
15	Crooked R. SF Clearwater, ID	Spring Chinook	ISS	Planned	Yes
16	Papoose Cr. Lochsa R., ID	Spring Chinook	ISS	Planned	Yes
17	Pete King Cr. Lochsa R., ID	Spring Chinook	ISS	Planned	Yes
18	Squaw Cr. Lochsa R., ID	Spring Chinook	ISS	Planned	Yes
19	White Sand Cr. Lochsa R., ID	Spring Chinook	ISS	Planned	Yes
20	Big Flat Cr. Lochsa R., ID	Spring Chinook	ISS	Planned	Yes
21	Crooked Fork Lochsa R., ID	Spring Chinook	ISS	Planned	Yes
22	Lemhi R. Salmon R., ID	Spring Chinook	ISS-Smolt Program	Planned	Yes
23	Lemhi R. Salmon R., ID	Spring Chinook	ISS-Parr Program	Planned	Yes
24	Lemhi R. Salmon R., ID	Spring Chinook	ISS-Smolt/Parr Program	Planned	Yes
25	Slate Cr. Clearwater R., ID	Spring Chinook	Nez Perce Tribal Program	Planned	No
26	Eldorado Cr. Clearwater R., ID	Spring Chinook	Nez Perce Tribal Program	Planned	No
27	Lolo Cr. Clearwater R., ID	Spring Chinook	Nez Perce Tribal Program	Planned	No
28	Yoosa Cr. Clearwater R.,ID	Spring Chinook	Nez Perce Tribal Program	Planned	No
29	Newsome Cr. Clearwater R., ID	Spring Chinook	Nez Perce Tribal Program	Planned	No
30	Meadow Cr. Clearwater R., ID	Spring Chinook	Nez Perce Tribal Program	Planned	No
31	Mill Cr. Clearwater R., ID	Spring Chinook	Nez Perce Tribal Program	Planned	No
32	Clearwater R., ID	Fall Chinook	Nez Perce Tribal Program	Planned	No
33	Imnaha R., OR	Spring Chinook	ODFW	Ongoing	Yes
34	Hood R., OR	Winter Steelhead	ODFW	Planned	Yes
35	Hood R., OR	Spring Chinook	ODFW	Ongoing	Yes
36	Hood R., OR	Summer Steelhead A-run	ODFW	Ongoing	Yes
37	Umatilla R., OR	Summer Steelhead A-run	ODFW/Umatilla Tribe	Ongoing	Yes
38	Umatilla R., OR	Spring Chinook	ODFW/Umatilla Tribe	Ongoing	Yes
39	Umatilla R., OR	Fall Chinook	ODFW/Umatilla Tribe	Ongoing	Yes
40	Catherine Cr. Gr.Ronde R., OR	Spring Chinook	ODFW	Planned	Yes
41	Lookingglass Cr. Gr.Ronde R., OR	Spring Chinook	ODFW	Planned	Yes
42	Lostine R. Gr.Ronde R., OR	Spring Chinook	ODFW	Planned	Yes
43	Little Sheep Cr. Imnaha R., OR	Summer Steelhead A-run	ODFW	Ongoing	Yes
44	Upper Yakima R., WA	Spring Chinook	Yakima Project (YKFP)	Planned	Yes
45	Naches R. Yakima R., WA	Spring Chinook	YKFP	Planned	Yes
46	Upper Yakima R., WA	Summer Steelhead A-run	YKFP	Planned	Yes
47	Naches/lower Yakima Yak.R., WA	Summer Steelhead A-run	YKFP	Planned	Yes
48	Lower Yakima R., WA	Fall Chinook	YKFP	Planned	Yes
49	Klickitat R., WA	Spring Chinook	YKFP	Planned	Yes
50	Klickitat R., WA	Summer Steelhead A-run	YKFP	Planned	Yes
51	Tucannon R., WA	Spring Chinook	WDF	Planned	No
52	Asotin Cr. Snake R., WA	Spring Chinook	WDF	Planned	No
53	Snake R., WA	Fall Chinook	WDF	Planned	No
54	Chiwawa R. Wenatchee R., WA	Spring Chinook	Rock Island Recertification	Ongoing	No
55	Wenatchee R., WA	Summer Chinook	Rock Island Recertification	Ongoing	No
56	Wenatchee R., WA	Sockeye	Rock Island Recertification	Ongoing	No
57	Wenatchee R., WA	Summer Steelhead A-run	Rock Island Recertification	Ongoing	No
58	Methow R., WA	Summer Chinook	Rock Island Recertification	Ongoing	No
59	Similkameen R., WA	Summer Chinook	Rock Island Recertification	Ongoing	NO
60	Methow R., WA	Spring Chinook	Douglas Co. PUD	Planned	No
61	Chewuk R. Wenatchee R., WA	Spring Chinook	Douglas Co., PUD	Planned	No
62	Twisp R. Methow R., WA	Spring Chinook	Douglas Co., PUD	Planned	No
63	Okanogan R., WA	Sockeye	Doulas Co., PUD	Planned	N

DESCRIPTION OF SUPPLEMENTATION PROJECTS

A computer program was developed to gather information on existing and 'planned supplementation projects. Copies of the program were distributed to' project leaders for data collection. The questionnaire and computer program are available upon request. In addition to the data provided by the questionnaire, data collected in the System Planning Process was used to develop a classification system for stocks, streams and strategies.

We did not, however, include monitoring and evaluation (M&E) programs proposed by the various programs in the classification because generic and particular *critical uncertainties* have not yet been identified. To reiterate, critical uncertainties are testable assumptions or hypotheses that have a largeimpact on the success or failure of a program. Evaluation programs should, among other things, assess critical uncertainties. Description of a set of *generic* critical uncertainties - testable assumptions critical to the success of nearly all supplementation programs in the Basin - would provide a basis for a system-wide classification system. We feel it would be premature to develop a system-wide M&E classification system until generic critical uncertainties have been described.

Steelhead and sockeye projects were not included in the same classification system with spring and summer chinook because of major life-cycle differences; and because the computer simulation model does not yet accommodate these species' complicated life histories. Fall chinook were omitted primarily because data for major fall chinook programs have not yet been received.

We have summarized the existing database by reducing it to 14 categories:- five for stocks, three for streams, and six for strategies. These categories should be interpreted simply as an attempt to describe a large number of individual pieces of data in a few composite categories. Data was lumped together subjectively, on the basis of an a priori judgement of related effects. The reader is cautioned not to view these categories as anything more than a descriptive device intended to give a "feel" for the data; the categories *do not* represent a classification scheme.

Description of stocks

Stocks were described by five criteria. Each is described below.

Spawner survival index. This quantitative category represents the estimated cumulative survival of returning adults as they negotiate the Columbia, pass through the terminal fishery, and experience pre-spawning mortality. Raw scores for the spawner survival index were calculated as the product of upstream survival, (1 - terminal exploitation) and pre-spawning survival. Cumulative spawner survival for the stocks surveyed ranged from 26 to 77 percent, with most stocks clustering between 40 and 45 percent.

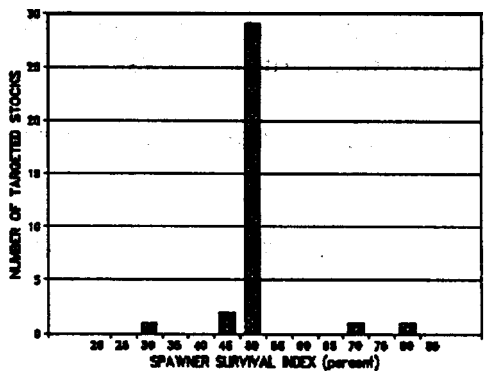
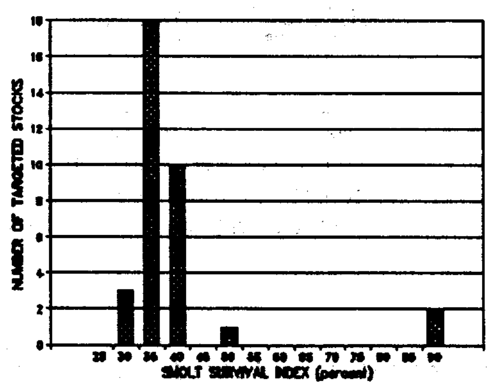


Figure 5.1 Frequency distribution of adult survival indices for chinook stocks targeted by ongoing or planned supplementation projects.

Smolt survival index. This is another quantitative category based on System Planning Model data. Raw scores were calculated as the product of smolt-to-smolt survival and cumulative survival through the Columbia (to a point below Bonneville Dam). Cumulative smolt survival for the stocks surveyed ranged from 27.4 to 85.8 percent, with most stocks clustering in the middle third of the range, between 33 and 40 percent.



igure 5.2 Frequency distribution of smolt survival index for chinook stocks targeted by ongoing and planned supplementation projects.

Mean fecundity per adult. Mean fecundity per adult (MFPA) is intended to quantify the "inherent reproductive capacity" of the targeted stock. It was assumed that a stock with a higher proportion of females, and a higher distribution of females in the older, more fecund age-classes, would have a fundamentally greater reproductive capacity than a stock with proportionately fewer, younger and less fecund females. The category was calculated by the following expression:

$$\sum_{i}^{k} \textit{(fraction age-i) (fraction age-i female) (fecundity age-i)}$$

Mean fecundity per adult ranged from 1,617 to 3,805 eggs. Most surveyed stocks clustered in the middle third of the range, with 1,900 to 2,300 eggs per adult.

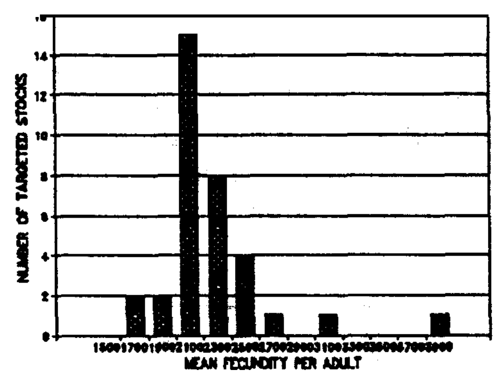


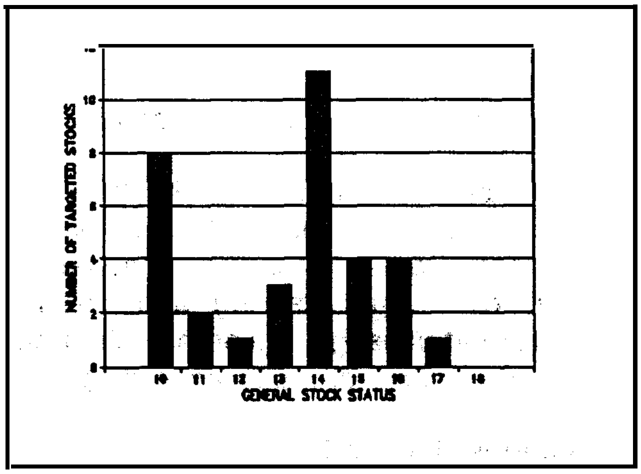
Figure 5.3 Frequency distribution of mean fecundity per adult for chinook stocks targeted by ongoing and planned supplementation projects.

General Stock Status. This category integrates a number of features relating to population stability and numerical abundance. Genetic risk assessment, stock seeding and population trend were assigned point values ranging from 1 to 3, with higher values given for higher genetic risk,' lower stock status and declining abundance trends. The raw score for "general stock status" was calculated as the *sum* of the points. Point assignments are indicated in Table 5.2.

Table 5.2. Point value assignments for general stock status.

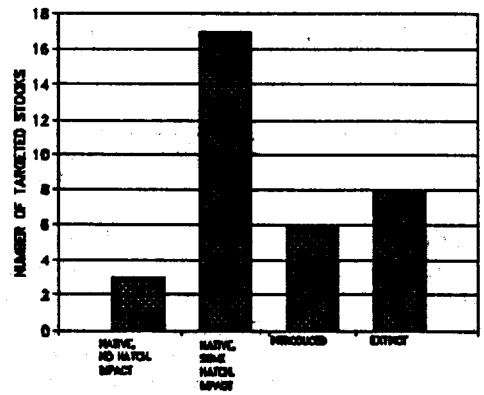
Factor	3 points	2 points	1 point
Extinction Risk	High	Moderate	Low
Risk of Genetic Drift	High	Moderate	Low
Risk of Genetic Identity Loss	High	Moderate	Low
Domestication Risk	High	Moderate	Low
Population Trend	Declining	Stable	Increasing
Stock Status	<20% K	20-50% K	>50% K

Over all stocks surveyed, raw scores for general status ranged from 11 to 17, with most stocks clustering in the middle third of the range (between 10 and 14; the eight extinct populations targeted for reintroduction are not included).



igure 5.4 Frequency distribution of general stock status for chinook stocks targeted by ongoing and planned supplementation projects.

<u>Stock history</u>. All projects classed either as "native, negligible hatchery impact"; "native with some hatchery impact"; or "introduced". Of the stocks surveyed, three were classed as native with negligible hatchery impact, 17 were classed as native with appreciable hatchery impact, and six were classed as introduced. Eight "stocks" are extinct.



igure 5.5 Frequency distribution of stock history for chinook populations targeted by ongoing and planned supplementation projects.

Description of Streams

Steams were described by three criteria,. as described below.

Qualitative limitina factor. Respondents to the SUPQUEST questionnaire listed one of the following as the most important factor limiting natural production from the standpoint of habitat *quality:* adult passage, spawning conditions, incubation conditions, early rearing; overwinter. rearing and in-basin smolt passage. No respondents listed in-basin smolt passage as a primary limiting factor, so this item was dropped. The remaining items were grouped according to which of the following elementary phases of the freshwater fife-cycle were identified: spawning (adult passage, spawning' conditions, incubation conditions); early rearing; or overwinter rearing. Over all streams surveyed, 20 are limited by spawning-related factors, 10 by early rearing conditions, and four by winter rearing conditions.

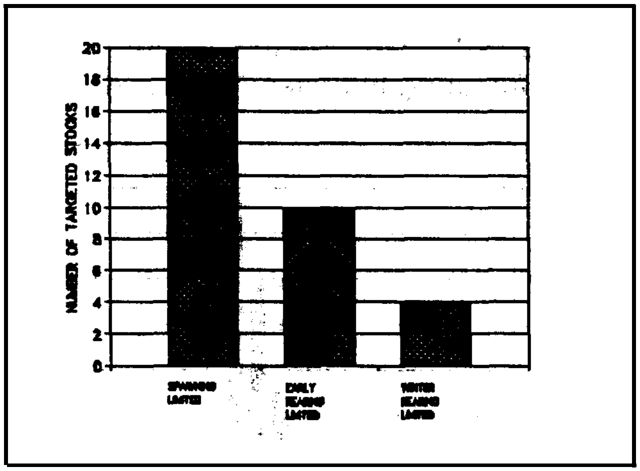


Figure 5.6 Frequency distribution of qualitative limiting factors for spring chinook stocks targeted for supplementation.

Productive capacity. This index was based on the estimated summer smolt carrying capacity of the targeted drainage as reported in Subbasin Plans and the SUPQUEST questionnaire. Of the streams surveyed, six had a carrying capacity of less than 100,000, 25 had a capacity between 100,000 and 1 ,OOO,OOO, and three had a capacity greater than 1 ,OOO,OOO.

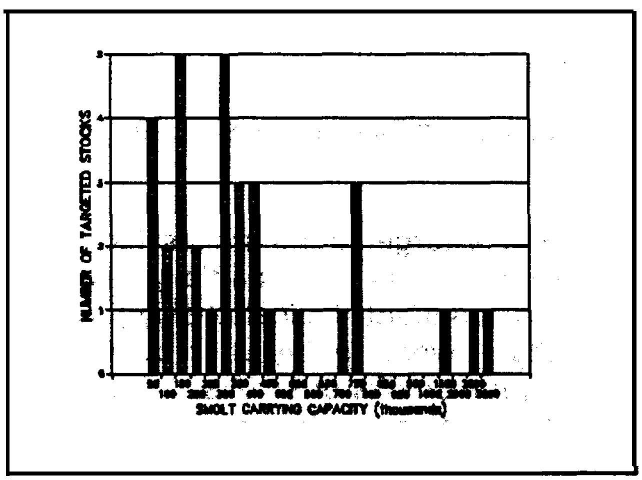


Figure 5.7 Frequency distribution of summer smolt carrying capacity for chinook populations targeted by ongoing and planned supplementation projects.

Juvenile broductivitv index. We assumed that the "zero-density egg-to-smolt survival rate" (S_0), as documented by the SPM, represents an integrated index of all factors affecting freshwater productivity. The theoretical maximum of S_0 for spring chinook populations is estimated as 26%. Of the streams surveyed, S_0 ranged from 6.5 to 26%, with most streams clustering between 16 and 20%.

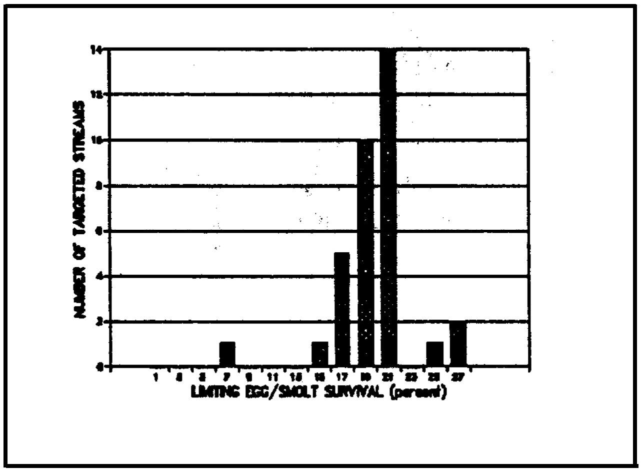


Figure 5.8 Frequency distribution of limiting egg-to-smelt survival rates for chinook streams targeted by ongoing or planned supplementation projects.

Descriotion of Strateaieq

Supplementation strategies were described by six criteria, each of which is described below.

Life staae. Of the six possible targeted life stages (adults, eggs, fry/parr, fall pre-smolts, continuously reared smolts and partially reared smolts) listed in the SUPQUEST questionnaire, respondents indicated only three - fry/parr, pre-smolts and continuously reared smolts - were to be utilized.. Accordingly, strategies were classified as using fry/part, pre-smolts or smolts. Of the projects surveyed, 24 use smolts, five use pre-smolts and five use fry or parr.

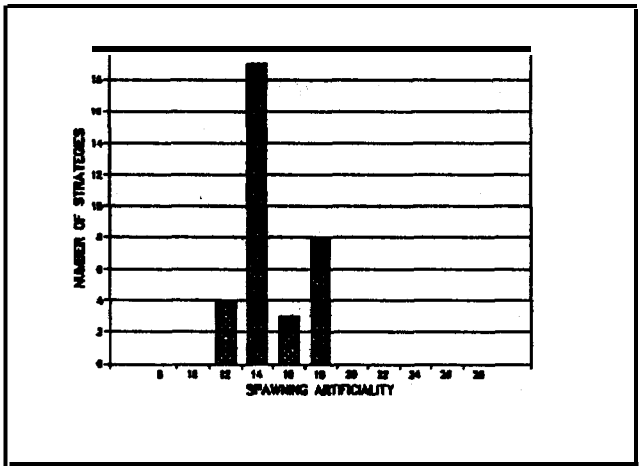
Broodstock Oriain. Responses to two items on the SUPQUEST questionnaire indicated that broodstock will have only three basic origins: "All wild/natural broodstock from the targeted stream," "a mixture of hatchery and wild/natural fish from targeted stream," and "all hatchery fish or wild/natural fish from another stream". As these categories also represent fundamental genetic distinctions in the matter of broodstock selection, they were preserved in the classification. Of the projects surveyed, six will obtain broodstock exclusively from wild/natural fish in the targeted stream, 16 will obtain broodstock from a mixture of wild/natural and hatchery fish in the targeted stream, and 12 will obtain broodstock exclusively from hatchery fish and/or from wild/natural fish in an adjacent subbasin. None of the surveyed projects proposes to use hatchery or wild/natural fish from a *distant* subbasin.

Artificiality of Soawning. This category integrates a number of features relating to the risk of imposing artificial selection on hatchery-reared fish by the way in which broodstock are selected, the conditions under which they are held, the number of fish spawned and the way in which they are spawned, and the duration of the project (finite or continuous). All of these factors were assigned point values ranging from 1 to 3, with higher values indicating a greater possibility of artificial selection. The raw score for "artificial selection risk" was calculated as the *sum* of the points, and has a possible range of 9 (low selection) to 27 (high selection). Point assignments were as indicated in Table 5.3.

Over all projects surveyed, raw scores for artificial selection risk ranged from 11 to 18, with most projects clustering in the lower third of the range, between 12 and 15.

Table 5.3. Point value assignments for artificial selection risk.

Factor	3 points	2 points	1 point
Mating Strategy	None, or more than 1 male/female	One male per female	Less than 1 male per female
Brood Stock Number	Fewer than 200	200-500	>500
Brood Stock Selection	Not representatively through run		Representatively through run
Adult Holding	Low adult holding survival		High adult holding survival
Sex Ratio	Broodstock differs from wild		Broodstock and wild equal
Age Distribution	Broodstock differs from wild		Broodstock and wild equal
Sexual Maturity (Timing)	Broodstock differs from wild		Broodstock and wild equal
Hatchery Influence on Brood stock	More than 5 generations of impact	2-5 generations of impact	Negligible impact form hatchery
Project Duration	Continuous		Finite



igure 5.9 Frequency distribution of a measure of the possibility of artificial selection during spawning for supplementation projects targeting chinook salmon.

Rearina Risk. **This category integrates a number of features assumed to relate to the risk of impairing adaptive behavior, undermining health, putting adverse competitive pressures on wild conspecifics and imposing artificial selection by rearing practices. The following rearing practices were considered: health management during incubation and rearing; mixed/separate pond management; hatching and growth programming; and the degree to which fish are reared under natural conditions. All of these factors were assigned point values ranging from 0 to 3, with higher values indicating a greater presumptive risk in one or more of the four types specified above. The raw score for "rearing risk" was calculated as the *sum* of the points. Point assignments were are indicated in Table 5.4.**

Table 5.4 Point value assignments for, rearing risk.

Factor	3 points	2 pints	1 point	0 points
Incubation health management	minimal		extensive	
Rearing health management	minimal		extensive	
Pond management	mixed		separate	
Hatching timing	altered		mimics wild	
Grading	with culling	with all saved	no grading	
Pond loading	higher third of range	middle third	lower third	
Pond density	higher third of range	middle third	lower third	
Growth programming	differs from natural		mimics natural	
Rearing/release	conventionally reared, unacclimated smolts	conventionally reared, acclimated smolts	acclimated; "naturally reared" smolts	release before smolt stage

Over all projects surveyed, raw scores for rearing risk ranged from 11 to 21, with most projects clustering in the middle of the range (between 14 and 21; the possible range of scores is 8 to 27).

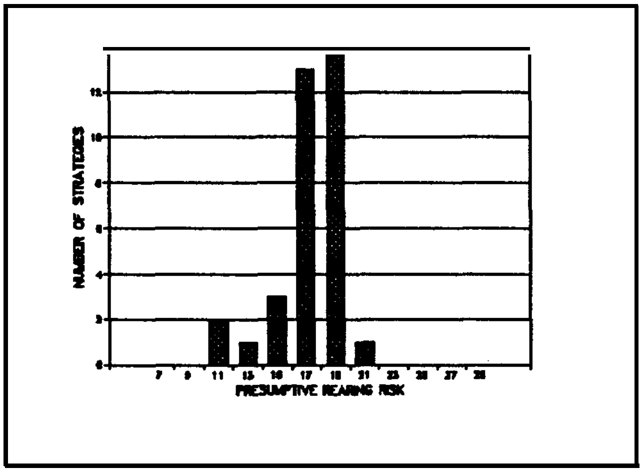


Figure 5.10 Frequency distribution of a measure of presumptive rearing risk in the strategies employed by supplementation projects targeting chinook salmon.

Release Risk. This category integrates a number of features relating to the presumed risks associated with the conditions under which fish are released: specifically, the risk of exposing hatchery-reared fish to elevated predatory or environmental mortalities by releasing them before they have recovered from the stress of transport; risks of hatchery/wild competition and/or predation associated with releases concentrated in space; and the risk of imposing adverse competitive or predatory pressures on wild conspecifics (or on hatchery fish themselves) by releasing hatchery fish that differ from wild fish in size or age.

The following release conditions were considered: on-station vs. target stream releases at one or a number of points; direct release vs. acclimated release; size at release mimics wild vs. size at release differs from wild; age at release same as wild vs. age at release differs from wild; and release timing coincident with wild outmigration vs. release timing not coincident with wild outmigration. All of these factors were assigned point values ranging from 1 to 3, with higher values indicating greater presumptive risk in one or more of the three types specified above. The raw score for "release risk" was calculated as the *sum* of the points. Point assignments are indicated in Table 5.5.

Table 5.5. Point values assigned for release risk.

Factor	points	points	point
Release point(s)	on-station	in target stream, single point	in target stream multiple points
Acclimation	none		acclimated release
Size at release	differs from wild		mimics wild
Release timing	fixed or not coincident with wild outmigration		coincident with wild outmigration
Age at release	differs from wild		same as wild

Over all projects surveyed, raw scores for release risk ranged from 5 to 13, with most projects clustering in the middle third of the range (between 8 and 12; the possible range of scores is 5 to 15).

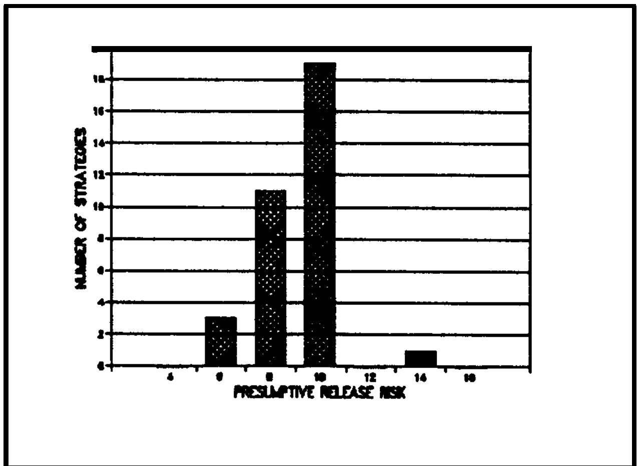


Figure 5.11 Frequency distribution of a measure of presumptive release risk in the strategies of supplementation projects targeting chinook salmon.

Relative Stocking Level. This category estimates the magnitude of the outplanting effort, expressed relative to the estimated carrying capacity of the targeted stream. Of the projects surveyed, 11.8% proposed stocking levels below 20% of carrying capacity, 29.4% proposed levels between 20 and 50% of carrying capacity, and 23.5% proposed stocking levels between 50 and 100% of carrying capacity. The largest proportion of surveyed projects -- 35.3% -- proposed to stock at levels exceeding 100% of carrying capacity.

6. SUPPLEMENTATION MODELS

This chapter describes the conceptual and spreadsheet models of supplementation developed by RASP. The models are described as well as their relationship to other existing models, and sample outputs from the spreadsheet model are displayed.

RELATIONSHIP TO EXISTING MODELS

The RASP models draw from data and concepts found in recent models of prod&ion, life history, and supplementation in the Columbia Basin. Specifically, we used the data base contained in the System Planning Model (SPM) (Northwest Power Planning Council 1989) and the life history and fitness concepts developed by Bjornn, and Steward (1990).

The spreadsheet model uses the basic data base contained in the SPM. For example, transfer coefficients, maturity schedules, fecundity, carrying capacities, and survival at zero density will be drawn from the SPM unless updated information is available for a specific basin or stock.

The model developed by Bjornn and Steward (1990) tracks six genetic groups through successive life history stages and generations. Bjornn and Steward (1990) -assigned a lower fitness to hatchery reared fish in the natural environment relative to their native counterparts. Reduced fitness imparted by the hatchery improved with each successive generation.' of natural spawning. The RASP models build on these concepts in two important ways. First, RASP has developed a separate estimate of fitness for six categories of hatchery practices and supplementation strategies. In addition, the RASP model contains the option of using three different scenarios for the rate of change in fitness of the progeny of hatchery fish over generations (see Genetic Yardsticks below for more detailed explanation). Second; the RASP' spreadsheet model tracks four genetic groups as opposed-to six in Bjornn and Steward (1990). Given the level of understanding or lack of understanding of the effects of hatchery practices on fitness in the natural habitat, there is little to be gained by increasing the number of genetic groups beyond four. However, the matrix of four genetic groups and three fitness scenarios could easily be expanded in the RASP model.

Survival of first generation hatchery fish is commonly 10% to 50% of that estimated for their wild counterparts in the same drainage basin, even for hatchery fish of local wild parentage; The SPM discounts the survival of hatchery fish relative to the survival of wild fish by (50%). Hatchery and wild fish survive at different rates because of genetic, behavioral and physiological changes' induced by the hatchery environment. The SPM model does not recognize nor try to account for the different pathways by which the hatchery environment alters survival.

The RASP spreadsheet model accounts for reduced survival and reproductive success in hatchery fish due to behavioral and physiological changes induced by the hatchery environment. However, our estimates of survival are preliminary and need further work. Behavioral modification in the hatchery and its effect on survival was the subject of a recent workshop hosted by the Yakima/Klickitat Fishery Project (YKFP). Using the information obtained at the workshop as a base, we will search the literature and consult with experts to build a revised set of behavioral yardsticks - estimates of the effects of hatchery induced behavior on survival of first generation hatchery fish.

The model developed by Lee and Hyman (1991) improved on the SPM model by incorporating stochastic variation at each life history stage; however, their model did not recognize differences in fitness in the hatchery and wild populations. The RASP spreadsheet model currently does not employ stochastic processes to simulate environmental variation, We will continue to improve the RASP model and will incorporate stochastic processes similar to those employed by Lee and Hyman (1991) in future versions of the model.

CONCEPTUAL MODEL

Development of the basic conceptual framework for assessing he risks and benefits of supplementation is essentially complete; however, we expect the concepts will continue to evolve as new information becomes available. The model and its framework will be updated through the life of the project. Hopefully the model will have sufficient educational value for decision makers and will be improved and updated after RASP has finished its work. Six major elements. 'comprise the conceptual model's general framework: management objectives, supplementation strategies, yardsticks - genetic, behavioral and physiological, life history and demographics, environmental variation, population dynamics, and risks and benefits (Figure 6.1).

Manaae ment Objectives

Supplementation is a tool used to achieve a specific management objective, The management objective places important constraints on the choice 'of supplementation strategies, as well as, how risks and benefits are determined. For example, a stock or stream managed to preserve the characteristics of the native population will have a different range of supplementation options compared to a stream managed to reestablish an anadromous population in barren habitat.

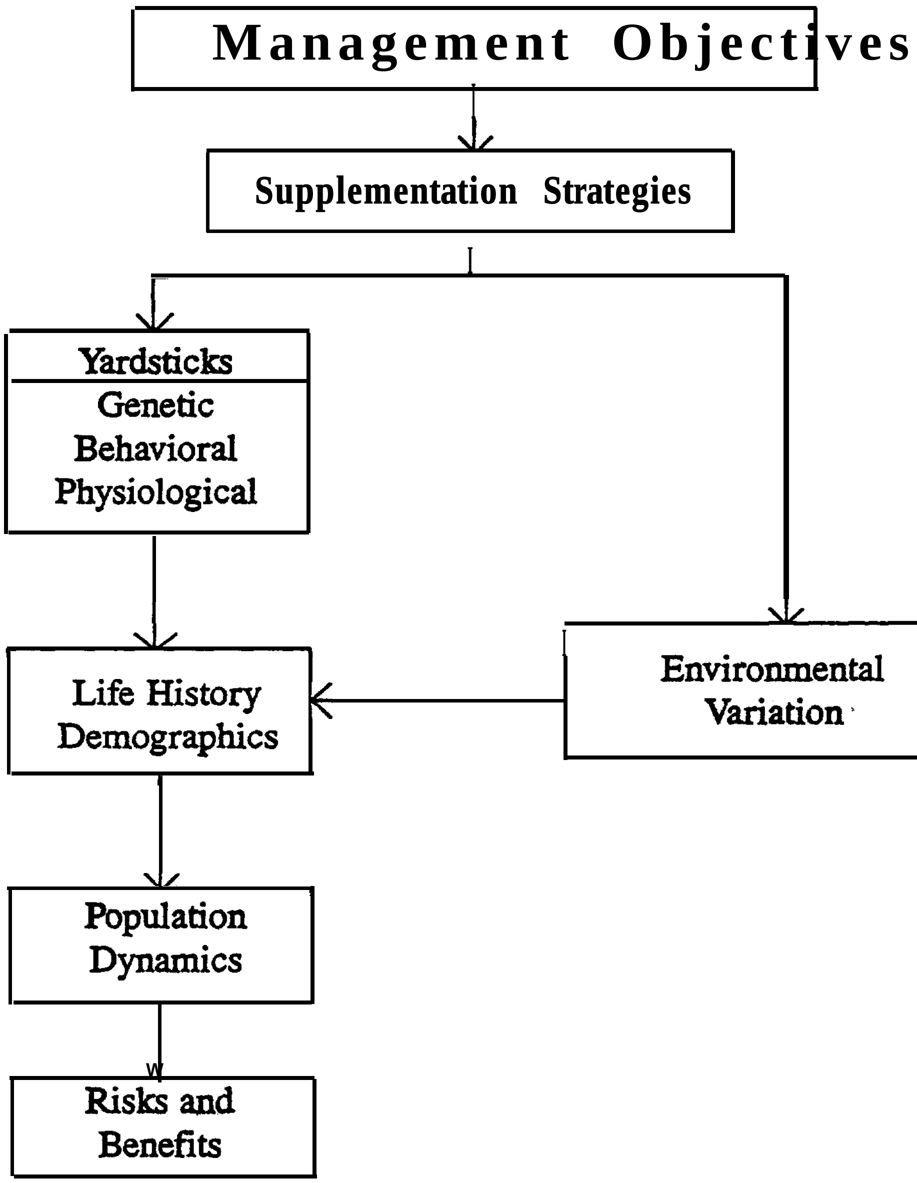


Figure 6.1 Schematic diagram of a conceptual model of risks and benefits of supplementation.

Riggs (1990) described a set of management opportunities which in a general sense are broad descriptors of management objectives (Table 6.1). Management opportunities C through F (Riggs 1990) are candidates for supplementation. However, the management opportunities in Riggs (1990) are too general to stand alone as useful objectives. A statement of management objectives must include a set of criteria and expectations against which model output and program results are evaluated. As an aid to managers developing supplementation objectives, RASP has defined the ecological dimensions of supplementation objectives; developed an valuative currency, and a procedure for setting objectives (see Section 4, Objectives and Evaluation).

Table 6.1 Management opportunities presented in Riggs (1990)

Opportunity A	Conserve nature populations for reasons of genetic potential, legal mandate, or social or cultural imperative.
Opportunity B	Facilitate natural population productivity in situations where no hatchery supplementation now occurs.
Opportunity C	Maintain natural stock identify and productivity in situations where hatchery supplementation must be used.
Opportunity D	Improve hatchery stock naturalization in situations where hatchery and natural production are intended to be complementary.
Opportunity E	Increase hatchery stock productivity in situations where little or no contribution by native or naturalized populations occurs or is desired.
Opportunity F	Introduce or test a new stock (or stocks) derived from genetically and ecologically appropriate source.

The spreadsheet model provides a variety of outputs which are described in the next section of this report. We tried to anticipate the range of management objectives and selected the outputs we believed would be useful in evaluating alternative supplementation strategies.

Supplementation Strategies

RASP developed and distributed a questionnaire designed to define the supplementation strategies and to characterize the recipient stocks and streams for planned and ongoing supplementation projects. The questionnaire was given the title of SUPQUEST, and it covered eight categories of supplementation strategies: project longevity, targeted life stage, brood stock strategies, mating, incubation strategies, rearing strategies, release strategies, and quality control strategies. Answers to SUPQUEST (see Section 5 Classification of Stocks, Streams and Strategies and for a complete description of the questionnaire, and see the February 14, 1991, RASP progress report) give a detailed description of the supplementation strategies employed in specific programs. This information will be used in the model in three ways: 1) A review of the answers to the questionnaire will identify the appropriate genetic yardstick to employ in the model (see Figure 6.2). 2) Answers to the questionnaire will also be reviewed to estimate behavioral effects. 3) The supplementation strategy describes at what life history stage the hatchery-reared fish are introduced to the target stream. The age/time of introduction has important implications in the model when the life stage released precedes or coincides with a life stage subject to density-dependent regulation in the target stream.

Yardsticks

RASP uses the term yardstick to describe indices of relative effects on the risks and benefits of supplementation due to the use of various broodstock, propagation, rearing and release strategies. Yardsticks enter the spreadsheet model as modifiers of the natural survival rate between life history stages for the donor or target stock. RASP uses yardsticks to estimate an effect when its existence is inferred from existing literature, but the exact nature and extent of the effect cannot be determined for all supplementation strategies. The term yardsticks implies a range of possible effects. In this report, yardsticks are estimates obtained either from consultation with experts (the case for genetic yardsticks) or the result of discussion among the members of RASP (the case for first year behavioral yardsticks). Single estimates of the yardsticks are employed in the spreadsheet model in this report, however, RASP intends to incorporate ranges in subsequent versions of the model. In addition, RASP will refine and document the Yardsticks through literature review and more consultation with experts.

Genetic/Life History Yardsticks Artificial propagation of salmonids can pose risks of genetic change to the propagated and supplemented stocks (Busack 1990). In addition, life history traits have been altered by artificial propagation. These changes may translate to reduced productivity of the stock with obvious consequences to the risks and benefits of supplementation. The genetic/life history yardsticks developed

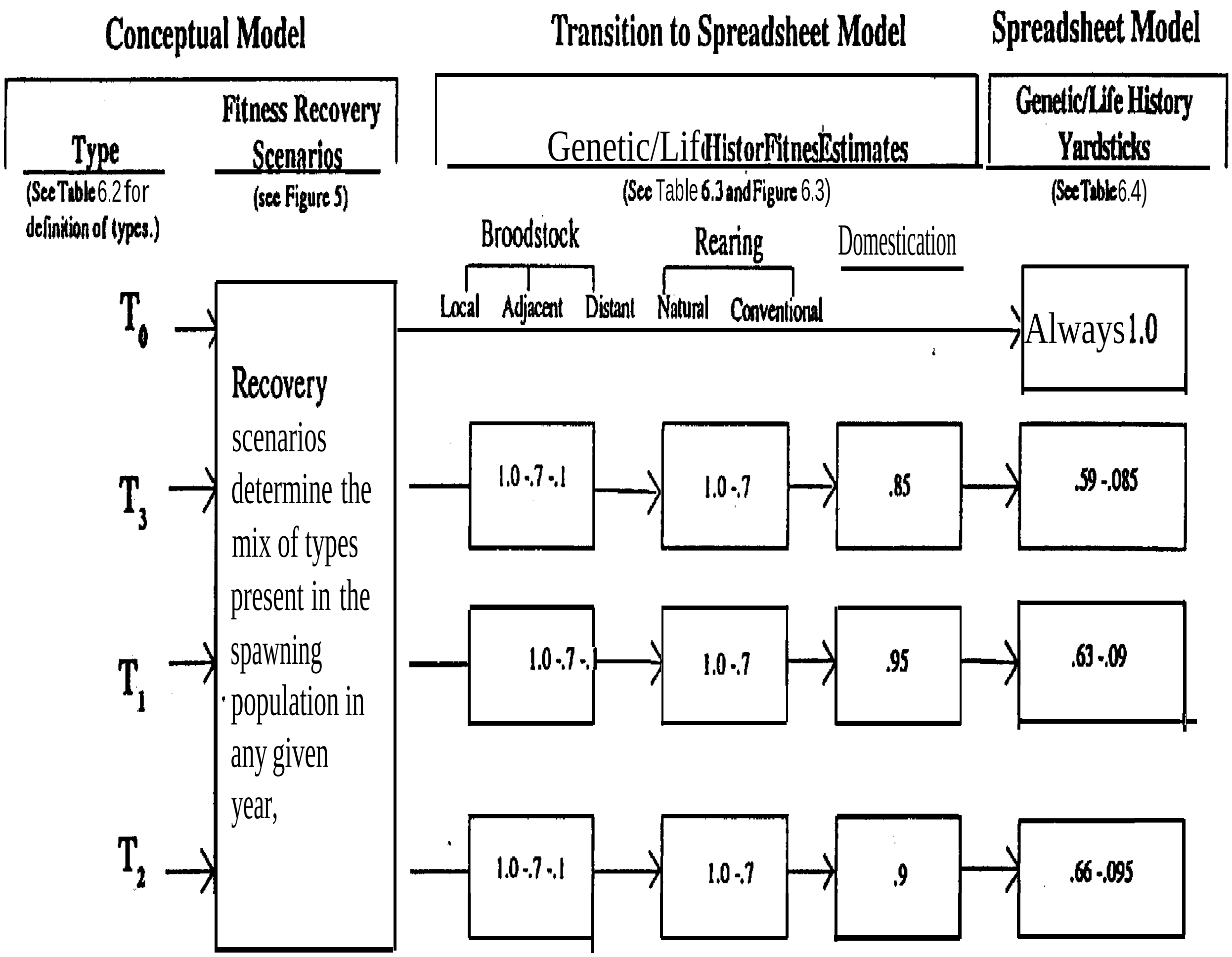


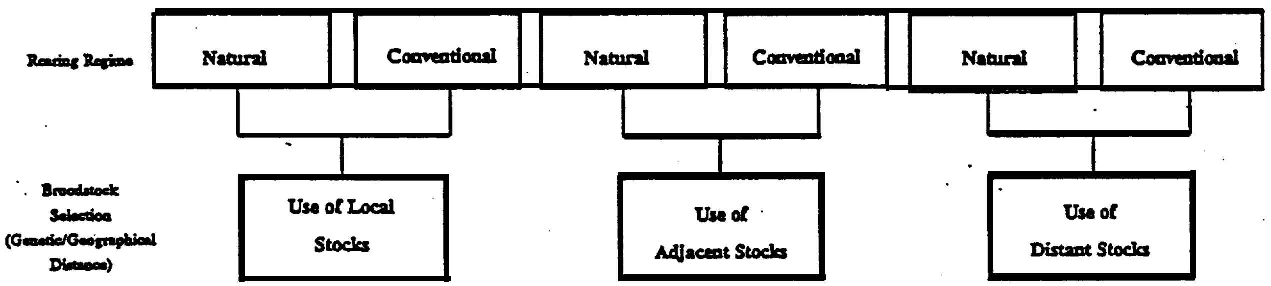
Figure 6.2 Development of **Genetic/Life** History **Yardsticks.** The genetic/life history yardsticks **start** with the concept that a supplemented population is comprised of **at** least four types **(T_0-T_3)** of fish based on parental and rearing history, **These** types are called conceptual because their identification **in** the population may not be possible, In the conceptual **model,** the three hatchery influenced **types** are assumed to have different **fitness** (survivals) in the natural habitat relative to the **wild fish (T_0)** which always has a fitness of 1.0. The recovery scenarios represent different assumptions **regarding** the change in fitness of **hatchery-reared** fish toward the fitness of the wild population, To convert the types of fish **assumed** to be present in the population under different recovery scenarios to a numerical modifier of survival in the spreadsheet model, fitness of the three **hatchery** influenced types was estimated for three **broodstock collection,** 'and two rearing **strategies,** and domestication, The appropriate fitness **estimates** are multiplied to arrive at a yardstick.

in the conceptual model and employed in the spreadsheet model are tests of assumptions about the magnitude and consequences of genetic change and their impact on the risks and benefits of supplementation.

Figures 6.2, 6.3 and 6.5 and Tables 6.2, 6.3 and 6.4 illustrate the development of the genetic/life history yardsticks from the concept of fish types based on parental history through the calculation of numerical fitness estimates. Two geneticists were asked to estimate fitness in the natural environment for salmon subjected to six broad categories of hatchery practices (Figure 6.3 and Tables 6.3 and 6.4). In the spreadsheet model, the estimates of fitness modify (increase or decrease) transfer coefficients (survival rates) between life history stages. For example, if a hatchery practice reduces fitness by half, the cumulative, natural survival between life history stages will be reduced by half. Wild fish are always assigned a fitness of 1. Hatchery fish are assigned an appropriate fitness fraction based on the advice obtained from geneticists. The spreadsheet model tracks four types (each type may have a different fitness) through several life history stages and generations (Table 6.2). The four types represent a combination of parental and rearing histories.

A critical question addressed by the conceptual model is the rapidity with which the hatchery influence on fitness diminishes with successive generations of natural spawning and whether or not progeny of hatchery-reared parents ever approach the fitness of their native or wild counterpart. Because of the lack of information on this subject, the RASP developed three scenarios based on different assumptions as to the rate of recovery of fitness in the progeny of hatchery fish (Figure 6.4). The first scenario makes the assumption that progeny of fish one generation removed from the hatchery (Type T_2) attain the fitness of wild fish (Type T,). The second scenario makes the assumption that hatchery fish and their progeny never attain the fitness of wild fish. The third scenario is intermediate and makes the assumption that the progeny of a hatchery X wild cross (Type T,) that mates with a wild fish attains the fitness of wild fish (Type T_0).

Types (See Table 6.2)	T_3	T_2	T_1	T_0
Fitness	(F_3)	(F_2)	(F_1)	(1)*



Genetic Yardsticks

*Native fish are always assigned a fitness coefficient of 1.

Figure 6.3 Categories of broodstock and rearing regimes for which estimates of fitness were obtained from geneticists. Natural rearing refers to rearing conditions that mimic the natural environment. Conventional rearing 'refers to standard hatchery rearing ponds and practices. Natural and conventional also refer to the duration of rearing. Fry plants would be considered natural and full term smolt releases conventional.

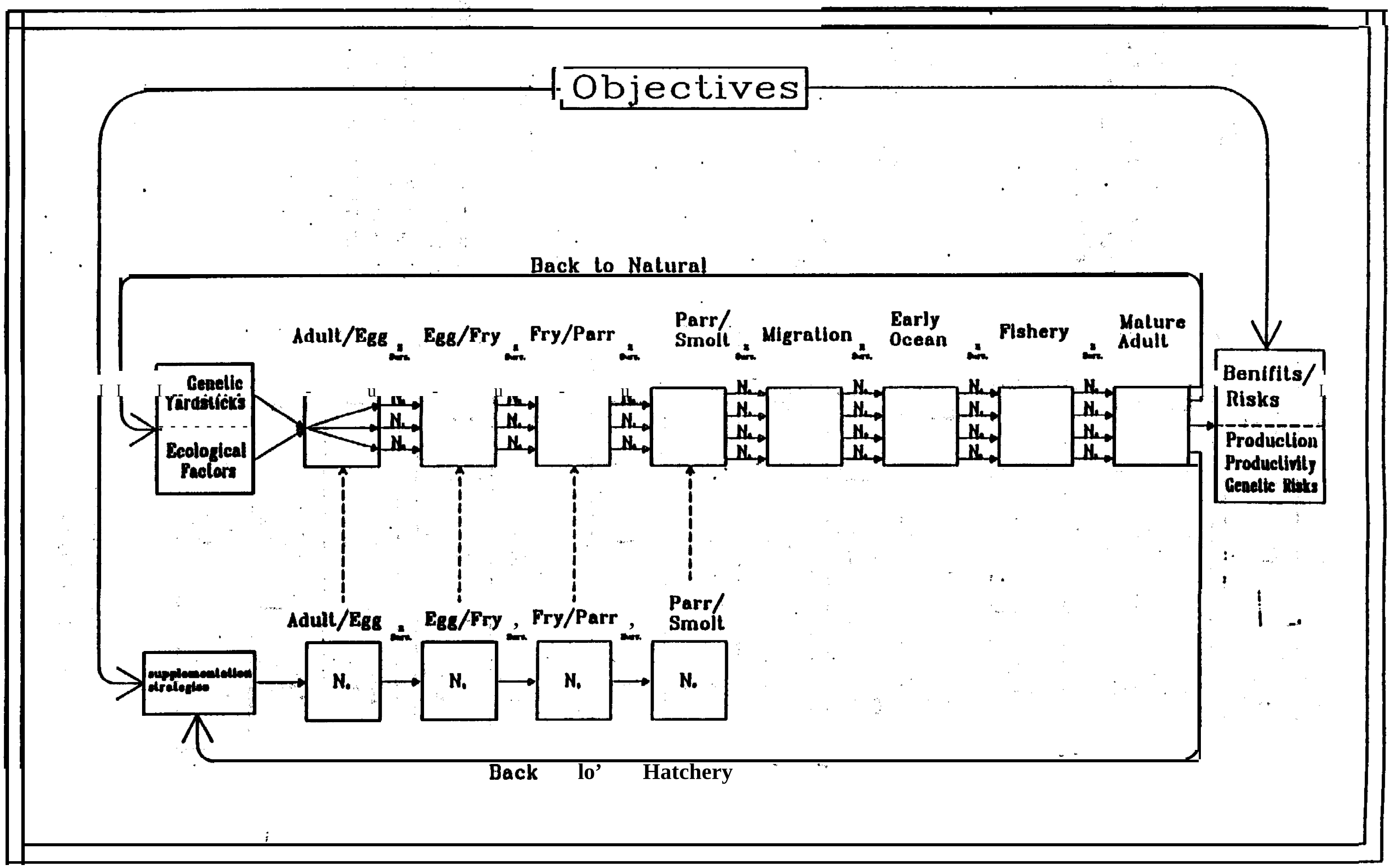


Figure 6.4 Diagram of the conceptual framework for a model to assess the benefits and risks of supplementation, N_0-N_3 are genetic groups tracked through the successive life history stages In the hatchery and natural environment (see Table 6.2). Genetic yardsticks and ecological factors modify transfer coefficients (survival) between life history stages. Behavioral yardsticks discussed In the text are not shown. in the diagram. N_0-N_3 signify the actual number of fish surviving between life history stages, corresponding to the types (T_0-T_3) discussed in the text.

	T_3	T_2	T_1	T_0
T_3	T_2	T_1	T_1	T_1
T_2	T_1	T_0	T_0	T_0
T_1	T_1	T_0	T_0	T_0
T_0	T_1	T_0	T_0	T_0

SCENARIO I

Progeny of flsh one generation removed **from the** hatchery **(T_2) attain** all the **characteristics** of the native stock.

	T_3	T_2	T_1	T_0
T_3	T_2	T_1	T_1	T_1
T_2	T_1	T_2	T_1	T_1
T_1	T_1	T_1	T_1	T_1
T_0	T_1	T_1	T_1	T_0

SCENARIO II

Hatchery fish never attain all the characteristics of the **native** fish.

	T_3	T_2	T_1	T_0
T_3	T_2	T_1	T_1	T_1
T_2	T_1	T_2	T_1	T_1
T_1	T_1	T_1	T_1	T_0
T_0	T_1	T_1	T_0	T_0

SCENARIO III

Intermediate between Scenario I and II. Native fish that mate with the progeny of hatchery x native **crosses (T_1)** attain the **characteristics** of native **fish (T_0).**

Figure 6.5 Possible breeding outcomes for the four types and the three fitness scenarios.

Table 6.2 Description of fish types developed in the conceptual model and tracked in the spreadsheet model.

T_3	Hatchery produced fish that return to spawn naturally.
T_2	Progeny whose parents were both hatchery produced fish (T_3) that spawned naturally.
T_1	Progeny with one native and one hatchery parent.
T_0	Progeny whose parents were naturally produced.*

- T, takes on a different definition in Scenario I, II, and III (see Figure 6.4)

Dr. Craig Busack and Dr. Graham Gall provided estimates of fitness for each hatchery influenced type (Table 6.2) and combination of treatments (Figure 6.3). The fitness estimates (Table 6.3) obtained from Drs. Busack and Gall are multiplicative so, for example, a first generation hatchery fish (T_3) reared under conventional hatchery conditions whose parents came from the local stock was assigned a fitness'of 0.59 (Table 6.4). Table 6.4 constitutes the existing genetic yardstick incorporated into the spreadsheet model. We plan to expand the range of treatments, and obtain fitness estimates from several additional geneticists in the next year. RASP recognizes the limitations in using this approach to test assumptions about genetic change. Through the use of yardsticks, the conceptual and spreadsheet model incorporates ideas and assumptions about genetic change that cannot be measured or have not been measured in actual practice. We have documented the conceptual framework used to arrive at the yardsticks and have attempted to obtain reasonable estimates of fitness.. We feel it is important to test these assumptions in the spreadsheet model, while recognizing the limitation in the numbers. The alternative - to wait until'fitness is measured under actual conditions - would leave the managers with no help in making their decisions.

Table 6.3 Changes in fitness of hatchery fish exposed to different broodstock selection and rearing practices. Fitness are relative to a wild standard of 1 .O and are multiplicative. The estimates were provided by Dr. Craig Busack and reviewed by Dr. Graham Gall.

Category	Treatment or Pedigree	Fitness
Domestication Effects	T_3 T_2 T_1	.85 .9 .95
Brood Stock Obtained from:	Local Stock Adjacent Stock Distant Stock	1.0[1] .7 .1
Rearing Program (Inadvertent Selection)	Natural Conventional	1.0[1] .7

[1] No loss of fitness.

Table 6.4 Fitness estimates used in the spreadsheet model for fish types, three broodstock and two rearing strategies.

Brood Stock	Rearino Reaime	TYPES T_3	T_2	T_1
Local	Conventional	.59	.63	.665
	Natural	.85	.9	.95
Adjacent	Conventional	.46	.441	.466
	Natural	.59	.63	.665
Distant	Conventional	.06	.063	.066
	Natural	.085	.09	.095

Behavioral Yardstick. In their first year after release, hatchery-reared fish generally exhibit a lower survival than their wild counterparts. Behavioral modification imparted by the hatchery experience causes part of the differential in survival. For example, feeding efficiency might be impaired by learned behavior in the hatchery. Lack of exposure to predators may produce behavior that makes the hatchery fish vulnerable to predation when released into the natural environment.

Behavioral modification by the hatchery environment was the subject of a recent workshop organized and hosted by the YKFP. The workshop reinforced the hypothesis that reduced survival in the first year after release from the hatchery is due at least in part to the acquisition of maladaptive behavioral patterns during hatchery rearing. The RASP model now contains an estimate of the effects of hatchery rearing on survival in the first generation based on observations from the Yakima and Clearwater Rivers. A proposed format and set of draft yardsticks are shown in Table 6.5 for the purpose of obtaining comment from reviewers of this report.

Life History and Demographics

The model tracks four fish types through several life history stages (Figure 6.2). A transfer coefficient (natural survival rate) moves a fraction of the fish from one life history stage to the next. The genetic and behavioral yardsticks enter the model as a modifier of the transfer coefficients. The schematic (Figure 6.5) of the conceptual model shows several life history stages. In reality some of these will be combined into life history stages that cover larger segments of the entire life cycle. The number of life history stages actually treated in the model will depend on the availability of transfer coefficients. Basic demographic features of the population such as maturity schedules and fecundity are incorporated into the modet at the appropriate life history stage.

Environmental Variation

The RASP model is entirely deterministic at this time. However, environmental variation will be introduced in a manner similar to Lee and Hyman (1991). Variation in population size due to environmental fluctuation becomes critical in the assessment of genetic risks and risks of extinction at small population size.

Risks and Benefits

The benefits of supplementation will be measured as increased production and productivity of the combined natural and hatchery stock. Risks will be measured in terms of the four genetic risks (see page 7.13 for an explanation of the four genetic risks) defined by Busack (1990) and as reduced production and productivity in the naturally spawned population and in the supplemented reach or in adjacent nontarget reach.

Table 6.5 Values considered for relative survival of hatchery produced fish (hatchery relative to natural fish). Three values for each life stage: Poor (P), Average (A), and Good (G). Schematic table only. These. values are being refined based on expert opinion and literature.

LIFE STAGE	LIFE STAGE RELEASED														
	Egg			Fry			Presmolt			Smolt			Adult		
	P	A	G	P	A	G	P	A	G	P	A	G	P	A	G
Relative survival by life stage.															
egg-fry	0.2	1.0	2.0												
fry-presmolt	0.2	0.6	1.0	0.1	0.3	0.7									
Presm-smolt	0.4	0.9	1.0	0.2	0.7	0.9	0.1	0.3	0.7						
smolt-smolt	1.0	1.0	1.0	1.0	1.0	1.0	0.7	0.9	1.0	0.2	0.4	0.6			
juv. pass	1.0	1.0	1.0	1.0	1.0	1.0	.90	.90	1.0	.60	.60	.80			
estuary	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	.70	.80	.90			
ocean	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	.90	.90	1.0			
adult pass	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0			
prespawn	0.8	.95	1.0	.80	.95	1.0	.80	.95	1.0	.95	.95	1.0	.5	.8	1

SPREADSHEET MODEL

The spreadsheet model is a salmon/steelhead lifecycle simulator. It is a spreadsheet model, written in Quattro Pro (Ver. 2.0 by Borland).

The spreadsheet model is in the process of revision. A detailed technical description and a user's guide will be distributed with a future report. Some of the main features and assumptions used are listed below.

The model moves an initial population through its lifestages by applying a set of transfer coefficients, referred to on the input screen (see Table 6.6) as base values. Most of the transfers between life stages are linear and density independent. The exceptions are the survivals from fry to presmolt (in the fall) and from presmolt to smolt, these stages are assumed to follow the Beverton-Holt survival function. Differences in transfer coefficients between the four types are incorporated through a set of multiplicative correction factors.

The model tracks 4 fish types by sex and by 4 ocean age classes. Two fresh' water life history patterns are accommodated.

Supplementation can occur at one or more points in the freshwater life stages. It can be interrupted or modified once within a single run.

Preterminal harvest rates (including mainstem Columbia fisheries) are fixed rates. Terminal harvest (within subbasin) may be a fixed or variable harvest rate and/or a fixed or variable numeric spawning escapement objective.

For additional information and copies of the model, please contact one of the RASP participants.

Table 6.6 Model Input Structure

INPUT SECTION-->		SUBJECT:	Hypoth. Spr. Chin.			TREATM.:	SMOLT SUPPL.		
TRANSFER COEFF.			BASE VALUES				CORRECTION FACTORS		
NAME		AGE1/ALL	AGE 2	AGE 3	AGE 4	ENVIR. (all N's)	TRTMNT (N3 in Nat) (NO in Hat)	GENETIC (N2)	GENETIC (N1)
Carrying Capacity	summer	1,000,000				0.0			
	winter	1,000,000				0.00			
Random(0) or Hatch only(1)		0							
Terminal huv	x =	20%	0%	0%	0%	0.00			
=max(x,y*(run-z)/run) y	=	0%	0%	0%	0%	0.00			
	z =	0	0	0	0	0.00			
Pre-spawning Survival	natural	80%	80%	80%	80%	0.00	0.85	0.99	1.00
	hatchery	80%	80%	80%	80%		1.00		
Eggs/Female	natural	2,038	3,795	6,064	0				
	hatchery	2,038	3,795	6,064	0				
Egg-Fry Survival	natural	60%				0.00	1.00	0.99	1.00
	hatchery	90%					1.00		
Fry-Fall Presmolt Surv.	natural	66%				0.00	1.00	0.99	1.00
at low Density	hatchery	85%					1.00		
Presmolt-Smolt Surv.	natural	66%				0.00	1.00	0.99	1.00
at low Density	hatchery	85%					1.00		
AGE at outmigration (0 or 1)	nat & hat	1							
Post-release Surv.	spawner	100%				0	1.00		
(hatchery only)	egg	100%				0	1.00		
	fry	100%				0	1.00		
	presmolt	100%				0	1.00		
	smolt	100%				0	1.00		
Smolt-smolt Surv	nat & hat	71%				0.00	0.60	0.99	1.00

Table 6.6 *continued* Model Input Structure

TRANSFER COEFF.		BASE VALUES				CORRECTION FACTORS			
NAME		AGE1/ALL	AGE 2	AGE 3	AGE4	ENVIR. (all N's)	TRTMNT (N3 in Nat)	GENETIC (N2)	GENETI((N1)
Smolt-Adult Surv.							(No In Hat)		
juv passage	natural	50%				1.00	0.60	0.99	1.0
estuary	natural	13%				1.00	0.80	0.99	1.0
nat ocean	natural	50%	60%	70%	80%	1.00	0.90	0.99	1.0
ocean harv rate	natural	2%	1%	4%	4%	1.00	1.00	1.00	1.0
in-river har rate	natural	7%	7%	7%	7%	1.00	I.00	1.00	1.0
adult passage	natural	60%	60%	60%	60%	1.00	1.00	0.99	1.0
Homing Fidelity (percent not straying)	natural	97%				0.00	1.00	1.00	1.0
Repmd Effic.	all jacks	100%					1.00		
INITIAL POPULATION		males	females						
Returns to Subbasin (jacks included)	nrtunl-NO	1,500	1,500						
	N1	0	0						
	N2	0	0						
	hatchery-N3	0	0						
Age/sex distribution (Steady State- Input)	natural-m	11%	82%	7%	0%				
	natural-f	1%	89%	10%	0%				
	hatch-m	11%	82%	7%	0%				
	hatch-f	1%	89%	10%	0%				

.I .

Table 6.6 *continued* Model Input Structure

SUPPLEMENTATION STRATEGY

ANNUAL PLANTING GOAL	Number	Duration (Years)
Spawners (Imported)	0	0
Eggs	0	0
Fry	0	0
Presmolt	0	0
Smolt	1,000,000	0

BROOD COLLECTION SCHEDULE

DESTINATION	SOURCE Imported	pre t-har	post harv	spwng grd[2]	fry	presmolt
Spawners [1]	0%	0%	0%	0%	0%	0%
Eggs	0%	0%	0%	0%	0%	0%
Fry	0%	0%	0%	0%	0%	0%
Presmolt	0%	0%	0%	0%	0%	0%
Smolt	0%	100%	0%	0%	0%	0%

[1] AU Imported

BROOD COLLECTION POLICY	YEARS 1 to	50 lo	51
Mln % Natural Brood Stock	100%	100%	
(Sel (0=Random, 1=100% Natural)			
Sex Ratio (percent females)	50%		
Max % Used of nat run	20%	20%	
of total run	100%	100%	
[illegible] % N3's allowed In NatEsc (excess b removed)	100%	100%	

GENETIC RECOVERY RATE	
scenario 1,2, or 3	3

MODEL OUTPUT EXAMPLE

Model output is intended to indicate relative risks and benefits along the four population response dimensions described in above' (4. OBJECTIVES, STRATEGIES AND EVALUATION). It is important to keep in mind that the model only provides a partial picture of trends and tendencies. It does however provide some insight into each of the four response areas.

The graphic model results that follow (Figures 6.6 - 6.12) are a sampling of the outputs from a hypothetical stock, described by the inputs shown in Table 6.6. The output is presented without comment. The intent here is not to provoke discussion about the merits of supplementation, but simply to illustrate the kinds of feedback the model can offer to planners and researchers.

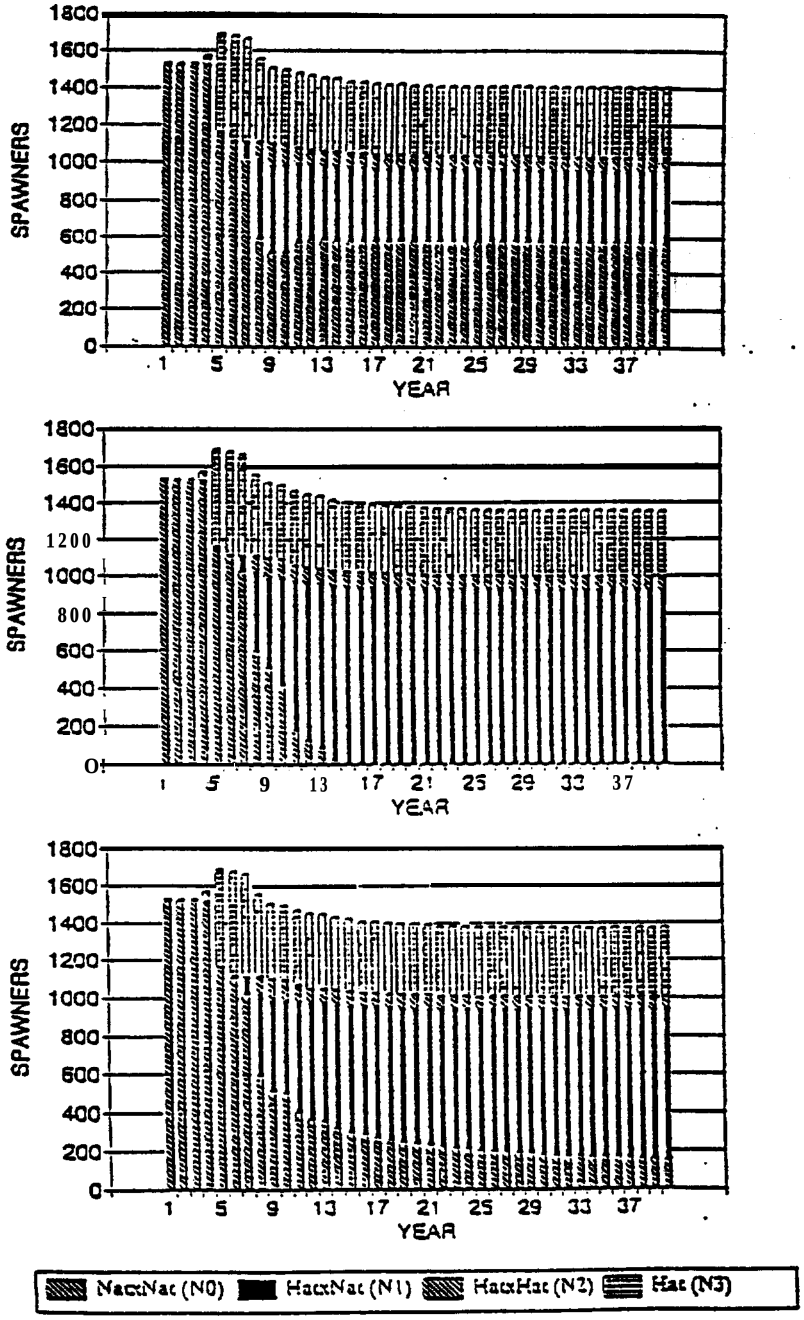


Figure 6.6 Abundance and **genetic** composition of natural **spawner** escapement for a supplemented **hypothetical stock under the three** genetic recovery scenarios (I, II, **and III from top to bottom).**

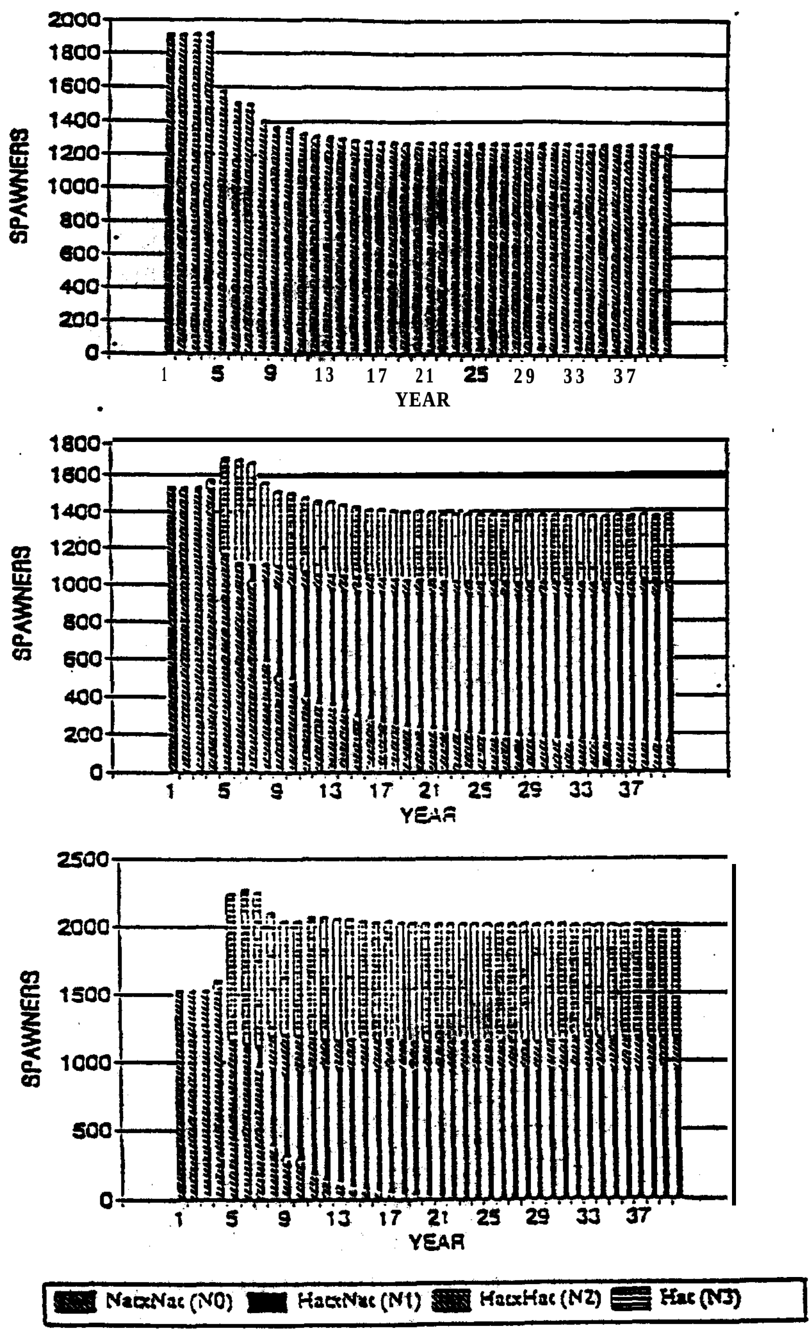


Figure 6.7 Abundance and genetic composition of natural spawner escapement for unsupplemented (top), supplemented (middle), and supplemented with improved post release survival (bottom) hypothetical stock.

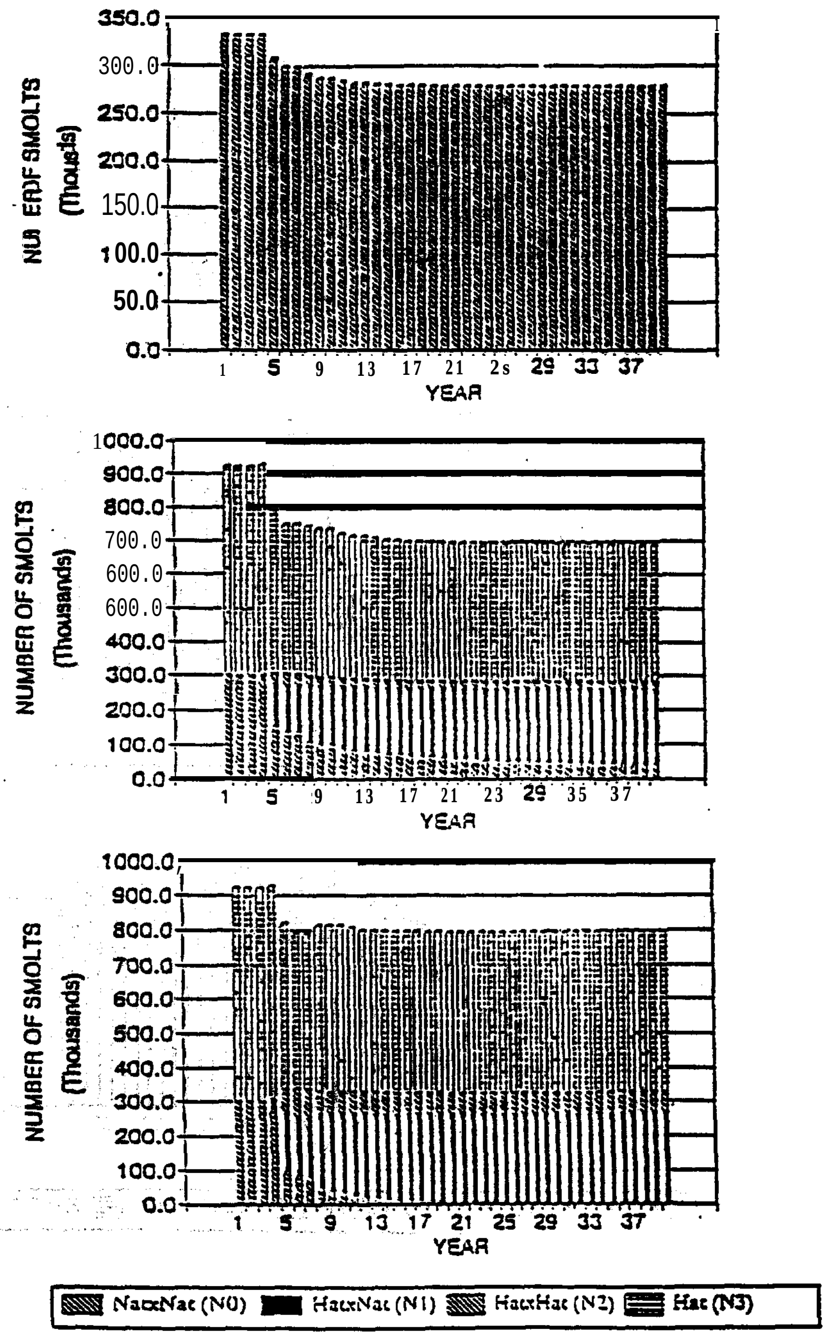


Figure 6.6 **Smolt yield** by year for respectively; **unsupplemented(top), supplemented (middle), and improved PRS supplemented (bottom) hypothetical stock.**

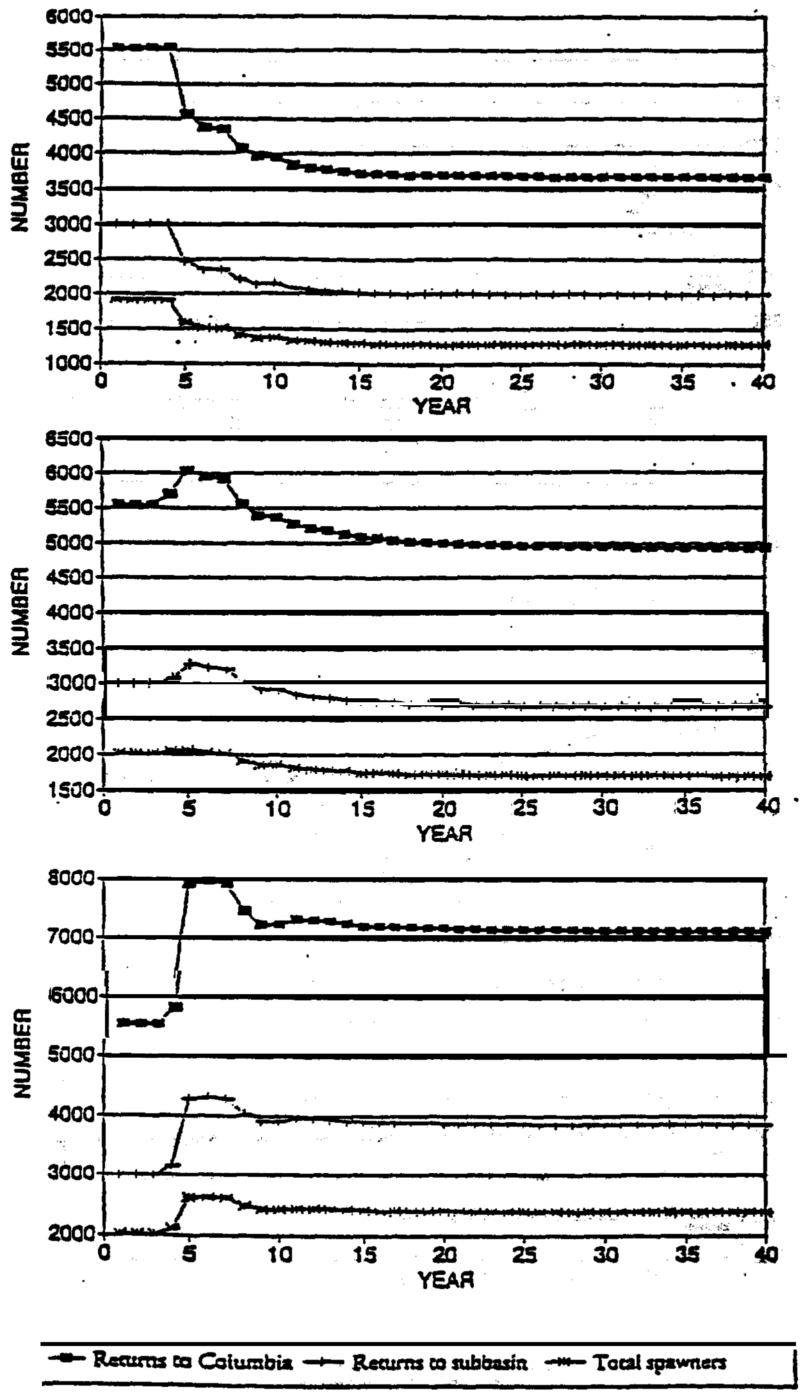


Figure 6.9 **Adults returning to the Columbia, the subbasin, and the spawning grounds** by year for **unsupplemented** (top), **supplemented (middle), and supplemented with** imprbved 'post release **survival (bottom1 hypothetical** stock.

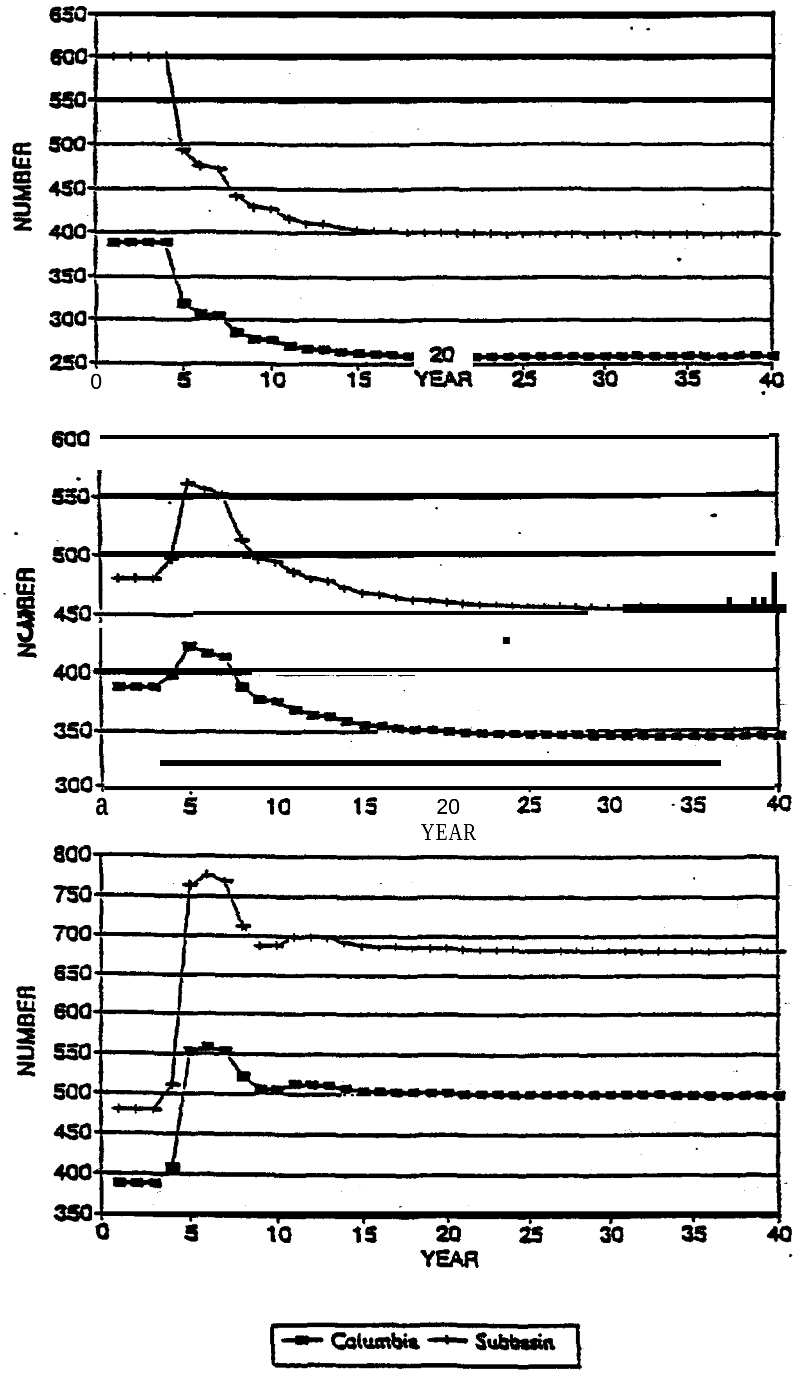


Figure 6.10 Mainstem (Columbia} and terminal (subbasin) harvest by year for unsupplemented (top), supplemented (middle), and supplemented with improved post release survival (bottom) hypothetical stock.

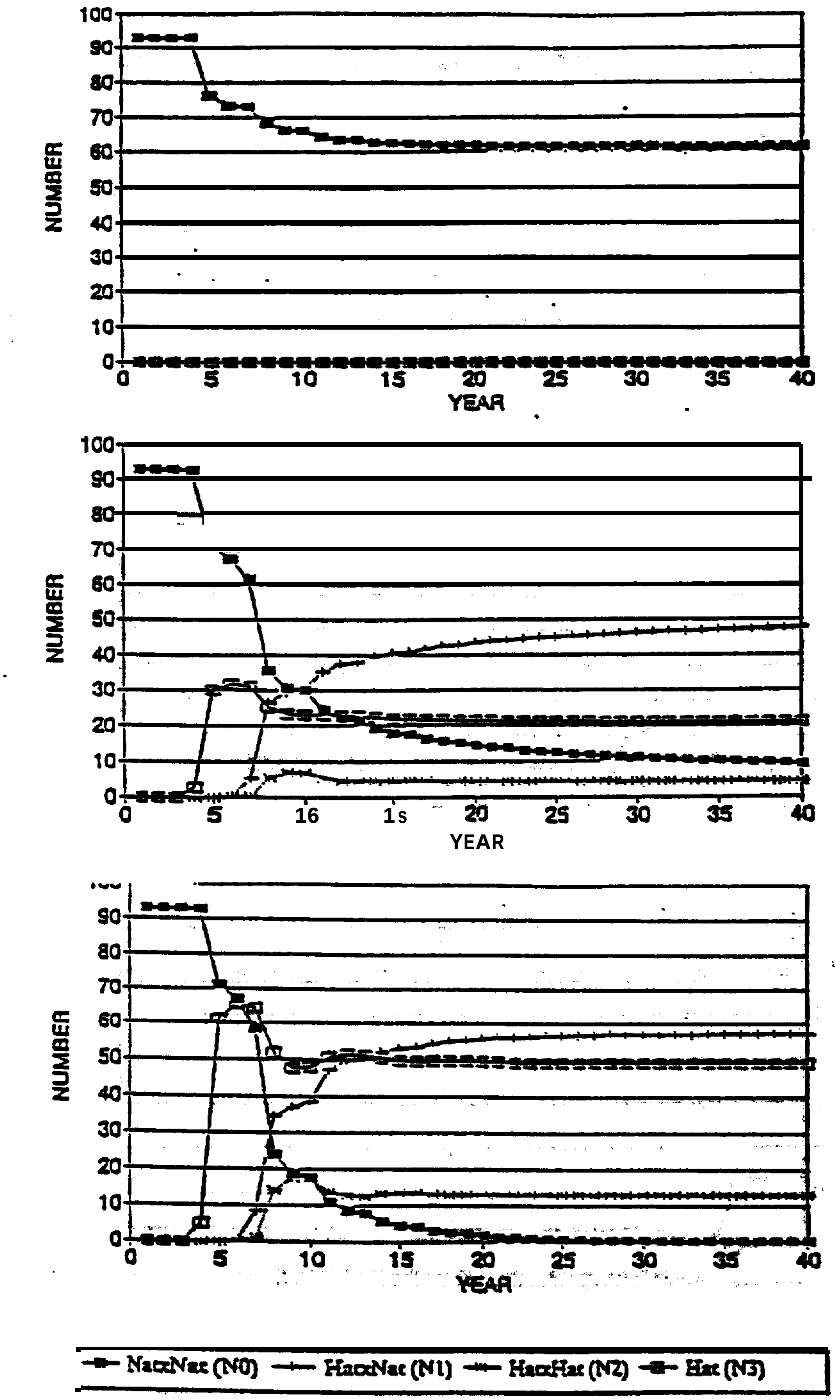


Figure 6.11 Numbers of fish straying outside subbasin by year for unsupplemented (top), supplemented (middle), and supplemented with improved post release survival (bottom) hypothetical stock.

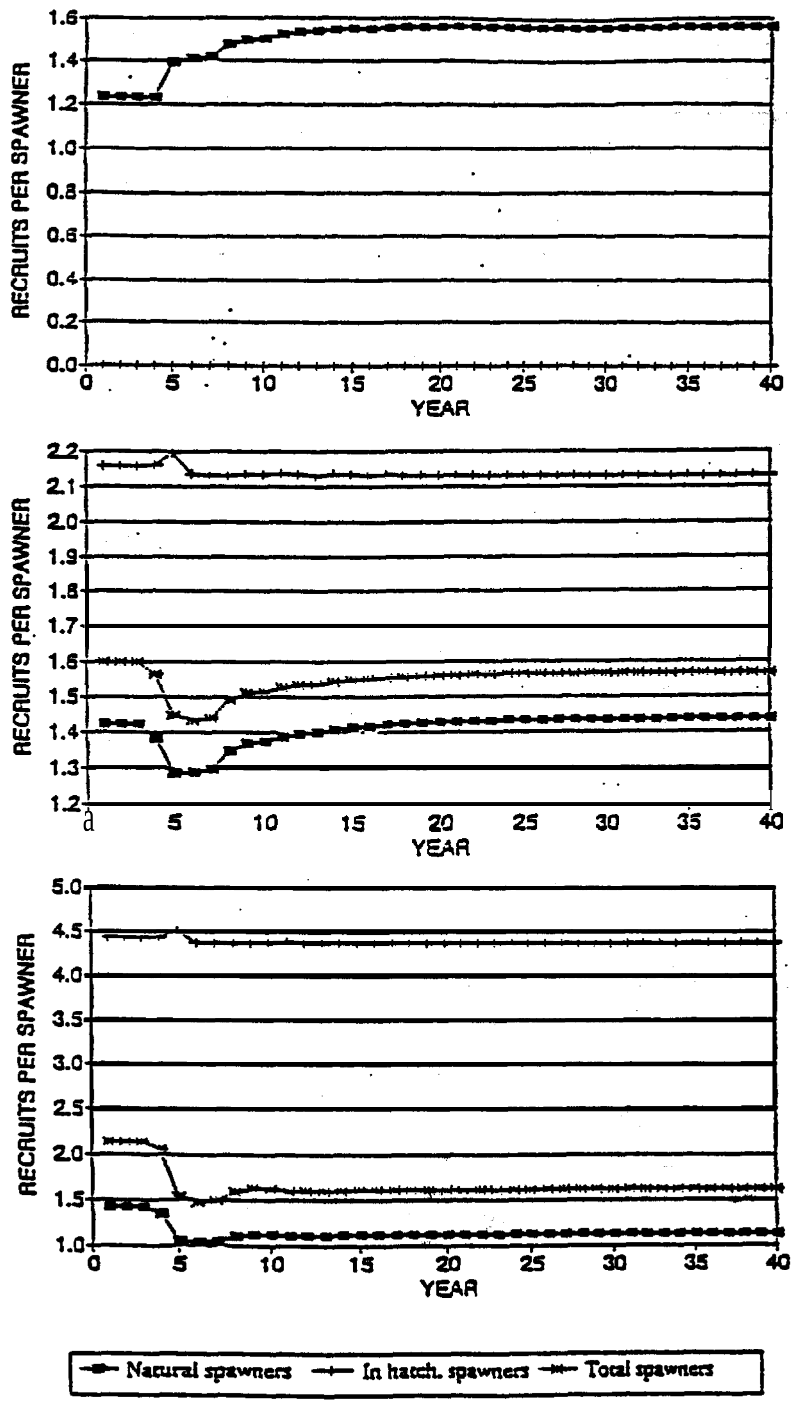


Figure 6.12 Recruits to subbasin per spawner by year for unsupplemented (top), supplemented (middle), and supplemented with improved post release survival (bottom) hypothetical stock.

7. UNCERTAINTIES

Implementation of successful supplementation projects requires a better understanding of the effects of the strategies employed on the performance of both hatchery and naturally produced fish. Questions, or critical uncertainties, exist regarding the relationships between project activities and the responsesof fish populations involved. These questions pertain primarily to the effects of supplementation strategies on the survival and performance of first generation hatchery fish, the longer term fitness of their progeny produced by natural spawning, and ecological implications and constraints.

The purpose of this section is to develop an approach to identify, and rank by importance, the uncertainties connected with achieving success in supplementation projects. The extent to which these uncertainties can be described and ranked by their relative importance will determine how clearly direction and priorities can be set for program planning and research and development. More specifically, identifying the most critical uncertainties related to supplementation will:

- help identify the range of possible outcomes and risks of supplementation projects
- help identify critical program components requiring special attention in planning and development
- provide a means of establishing research priorities
- provide a basis for formulating experimental hypotheses
- help identify needs for developing evaluation or monitoring methods.

Uncertainties about supplementation can be grouped into three categories:

1. The effects of hatchery practices on the survival and reproductive success of first generation hatchery fish. These are expected to be mainly related to *behavioral or physiological changes* resulting from hatchery practices, though some genetic changes could also occur.

2. The longer term effects of supplementation activities on the fitness of fish within a supplemented population. These effects would result from genetic *changes* which could occur within the population due to supplementation.

Table 7.1 Survival related attributes of salmonids potentially altered by hatchery practices within the first generation of hatchery experience.

Attribute	Description
Aggressiveness	Extent of inter- or intra-specific aggressive behavior within the natural environment.
Dispersiveness	Extent and rate of dispersal within the natural environment.
Downstream emigration pattern	Timing and rate of travel of seaward migration.
Upstream immigration pattern	Timing and rate of travel of the upstream spawning migration.
Amount of body fat	Quantity of body fat related to nutrition and exercise.
Feeding behavior	Use of foraging areas, prey selection, and associated energetics of feeding.
Habitat selection	Use of habitats by season, including depth, velocity, substrate type, and shelter.
Health	Overall health related to history of nutrition, exposure to pathogens and stressors, and exercise.
Homing/straying	Degree of homing to the home spawning stream (or stream of release).
Disease resistance	Immunity to disease, either due to immunogenetic resistance or antibodies from prior exposure.
Maturation	Age at sexual maturity, or relative timing of sexual maturity within a particular season.
Predator recognition	Ability to detect both presence and associated danger of predators.
Prey recognition	Ability to locate suitable prey items.
Size	Length and associated condition factor of fish at time or age.
Smoltification	Timing and degree of physiological transformation in preparation for seaward migration/entry.
Saltwater transfer efficiency	Effectiveness of successfully making transition from fresh to saltwater.
Swimming ability	Burst speed, maneuverability, and stamina associated with swimming.
Social interaction	Set of behaviors associated with dispersal, territoriality, hierarchial associations, and schooling.
Catchability	Effectiveness, or lack thereof, at avoiding capture by a fishery.

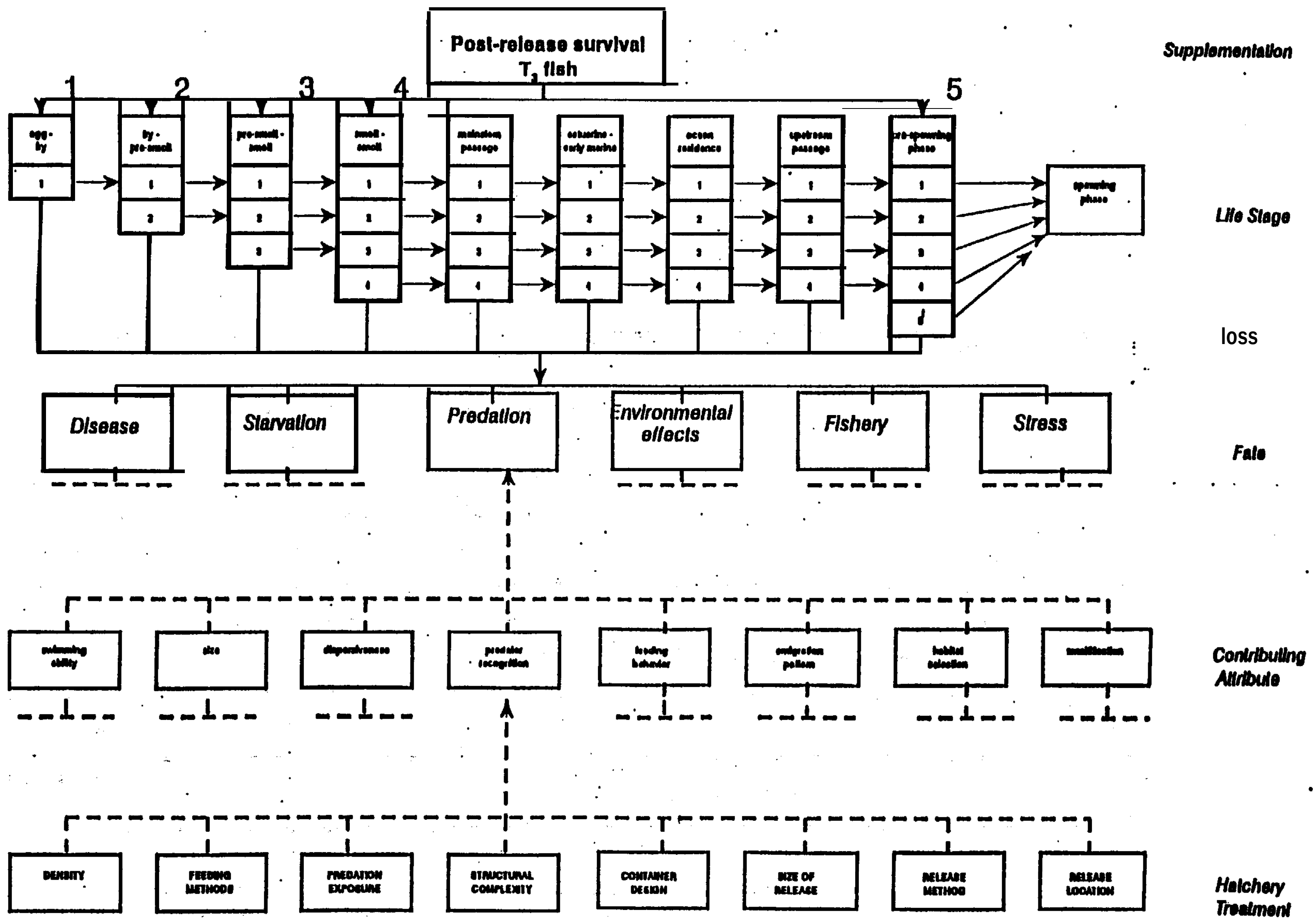


Figure 7.1 Schematic of effects of hatchery treatment on survival related attributes of first generation hatchery fish outplanted at different life stages.

Table 7.4 Potential pathways of effect between hatchery treatments and attributes of salmonids within the first generation of hatchery experience. Pathways are categorized as being principally behavioral, physiological, or genetic. This table should be regarded as a DRAFT ONLY, and is intended to stimulate discussion on mechanisms of treatment effects.

Treatment	Attribute affected				
	Aggressiveness	Dispersiveness	Emigration pattern	Immigration pattern	Amount of body fat
Broodstock origin	genetic influence	genetic influence	genetic influence	genetic influence	genetic influence
Broodstock capture	none expected	none expected	genetic influence	genetic influence	none expected
Mating practices	none expected	none expected	genetic influence	genetic influence	none expected
Incubator/substrate	behavioral/physiological response	behavioral/physiological response	behavioral/physiological response	none expected	physiological influence
Diet	none expected	none expected	physiological influence	physiological influence	physiological condition
Growth schedule	physiological response	physiological response	physiological influence	physiological influence	physiological influence
Feeding method	behavior/genetic response	behavioral response	behavior/physiological/ genetic influences	physiological/genetic influences	physiological influence
Density	behavioral response	behavioral conditioning	behavioral response	none expected	physiological influence
Grading	genetic influence	genetic influence	genetic influence	genetic influence	physiological influence
Predation exposure	none expected	behavioral conditioning	behavioral conditioning	none expected	none expected
Structural complex.	behavior conditioning	behavioral conditioning	behavioral conditioning	none expected	physiological effect
Container design	behavior conditioning	behavioral conditioning	behavioral conditioning	none expected	physiological effect
Flow	none expected	behavioral response	behavioral response	none expected	physiological effect
Water temperature	none expected	physiological response	physiological response	none expected	physiological effect
Disease control	none expected	none expected	physiological influence	physiological influence	none expected
Hygiene	none expected	none expected	not expected	none expected	none expected
Marking method	none expected	none expected	none expected	physiological influence	none expected
Transport method	none expected	none expected	physiological influence	none expected	none expected
Size of release	behavioral response	behavioral response	behavioral response	none expected	none expected
Release method	behavioral response	behavioral response	behavioral response	none expected	none expected
Release location	behavioral response	behavioral response	behavioral response	physiological influence	none expected
Release timing	none expected	physiological response	physiological response	none expected	none expected

Table 7.4 *continued*. Pathways of effect between hatchery treatments and attributes.

Treatment	Attribute affected				
	Feeding behavior	Habitat selection	Health	Homing/straying	Disease resistance
Broodstock origin	genetic influence	genetic influence	genetic influence	genetic influence	genetic influence
Broodstock capture	none expected	none expected	none expected	genetic influence	physiological influence
Mating practices	none expected	none expected	genetic influence	genetic influence	genetic influence
Incubator/substrate	behavioral/physiological	none expected	physiological response	none expected	none expected
Diet	behavioral conditioning	behavioral conditioning	physiological influence	none expected	none expected
Growth schedule	behavioral/physiological response	behavioral conditioning	behavioral/physiological influence	none expected	none expected
Feeding method	behavioral/genetic response	behavioral conditioning	behavioral/physiological influences	none expected	none expected
Density	behavioral response	behavioral conditioning	behavioral/physiological influence	none expected	physiological influence
Grading	genetic influence	genetic influence	genetic influence	none expected	genetic/physiolog. effect
Predation exposure	behavioral conditioning	behavioral conditioning	none expected	none expected	none expected
Structural complex.	behavioral conditioning	behavioral conditioning	behavioral influence	none expected	none expected
Container design	behavioral conditioning	behavioral conditioning	behavioral/physiological influence	none expected	physiological effect
Flow	behavioral conditioning	behavioral response	physiological influence	none expected	physiological effect
Water temperature	physiological response	none expected	physiological influence	none expected	physiological effect
Disease control	none expected	none expected	physiological condition	none expected	physiological effect
Hygiene	none expected	none expected	physiological response	none expected	none expected
Marking method	none expected	none expected	physiological influence	physiological influence	physiological influence
Transport method	none expected	none expected	physiological influence	physiological influence	physiological influence
Size of release	behavioral response	behavioral response	behavior/physio. influence	none expected	none expected
Release method	behavioral response	behavioral response	behavioral/physiological influence	physiological response	none expected
Release location	behavioral response	behavioral response	physiological influence	physiological response	none expected
Release timing	none expected	none expected	physiological response	physiological response	none expected

Table 7.4 *continued.* Pathways of effect between hatchery treatments and attributes.

Treatment	Attribute affected				
	Maturation	Predator recognition	Prey recognition	Size	Smoltification
Broodstock origin	genetic influence	none expected	none expected	genetic influence	genetic influence
Broodstock capture	genetic influence	none expected	none expected	physiological influence	physiological influence
Mating practices	genetic influence	none expected	none expected	genetic influence	genetic influence
Incubator/substrate	none expected	none expected	none expected	physiological influence	none expected
Diet	none expected	none expected	behavioral conditioning	physiological influence	physiological influence
Growth schedule	physiological influence	none expected	none expected	physiological influence	physiological influence
Feeding method	none expected	behavioral conditioning	behavioral conditioning	behavioral/physiological influence	physiological influence
Density	none expected	behavioral conditioning	behavioral conditioning	behavioral/physiological influence	physiological influence
Grading	genetic influence	none expected	none expected	physiological/genetic influence	physiological/genetic influence
Predation exposure	none expected	behavioral conditioning	none expected	none expected	none expected
Structural complex.	none expected	behavioral conditioning	none expected	behavioral/physiological influence	none expected
Container design	none expected	behavioral conditioning	behavioral conditioning	physiological influence	none expected
Flow	none expected	none expected	behavioral conditioning	physiological influence	physiological effect
Water temperature	none expected	none expected	none expected	physiological influence	physiological effect
Disease control	none expected	none expected	none expected	none expected	physiological effect
Hygiene	none expected	none expected	none expected	physiological influence	physiological effect
Marking method	none expected	none expected	none expected	none expected	physiological effect
Transport method	none expected	none expected	none expected	physiological influence	physiological effect
Size of release	none expected	behavioral influence	behavioral conditioning	behavioral influence	behav./physio. influence
Release method	none expected	behavioral/physiological influence	behavioral/physiological influence	behavioral/physiological influence	physiological influence
Release location	none expected	behavioral/physiological	behavioral conditioning	behavior/physiological	none expected
Release timing	none expected	none expected	physiological influence	physiological influence	physiological influence

Table 7.4 *continued.* Pathways of effect between hatchery treatments and attributes.

Treatment	Attribute affected			
	Saltwater transfer efficiency	Swimming ability	Social interaction	Catchability
Broodstock origin	genetic influence	none expected	genetic influence	genetic influence
Broodstock capture	genetic influence	none expected	physiological influence	physiological influence
Mating practices	genetic influence	none expected	genetic influence	genetic influence
Incubator/substrate	none expected	none expected	physiological influence	none expected
Diet	none expected	behavioral conditioning	physiological influence	physiological influence
Growth schedule	physiological influence	none expected	physiological influence	physiological influence
Feeding method	none expected	behavioral conditioning	behavioral/physiological influence	physiological influence
Density	none expected	behavioral conditioning	behavioral/physiological influence	physiological influence
Grading	genetic influence	none expected	physiological/genetic influence	physiological/genetic influence
Predation exposure	none expected	none expected	none expected	none expected
Structural complex.	none expected	none expected	behavioral/physiological influence	none expected
Container design	none expected	behavioral conditioning	physiological influence	none expected
Flow	none expected	behavioral conditioning	physiological influence	physiological effect
Water temperature	none expected	none expected	physiological influence	physiological effect
Disease control	none expected	none expected	none expected	physiological effect
Hygiene	none expected	none expected	physiological influence	physiological effect
Marking method	none expected	none expected	none expected	none expected
Transport method	none expected	none expected	none expected	none expected
Size of release	none expected	behavioral conditioning	behavioral influence	behav./physio. influence
Release method	none expected	behavioral/physiological influence	behavioral/physiological influence	physiological influence
Release location	none expected	behavioral conditioning	behavior/physiological influence	none expected
Release timing	none expected	physiological influence	physiological influence	physiological influence

Table 7.5 displays a worksheet, still in draft form, that would be used to rank the relative importance of attributes and treatments in effecting survival. A hypothetical example is provided to illustrate how the rankings would be done. The example considers how hatchery fish survival would be affected within one life stage, smolt to smolt (i.e. smolt migration within an individual subbasin). The same exercise would be repeated for all life stages considered in the life history simulation model.

The reader should note that one page of a completed worksheet will appear largely blank due to one entire row being required for each treatment associated with each attribute. The rank for each treatment occurs in only one column on the far right side of the worksheet, leaving blank spaces to the left.

The example is described here in some detail to facilitate a complete understanding of how the worksheet would be used. Beginning in the far left column, the life stage of interest is entered in the first space; in this case, smolt to smolt. For the life stage of interest, an estimated survival, based on literature or expert opinion, for naturally produced fish with no hatchery parents (T fish) is entered on the same line in the next column to the right., In this case, natural fish survival in the smolt to smolt life stage is set at 1 .0 (100%) for simplicity.

The block of five narrow columns toward the middle of the worksheet provides two types of values, distinguished by the shading. The shaded spaces are used to enter estimates of the relative survival of hatchery produced (t) fish supplemented at different life stages (egg, fry, pre-smolt, smolt, adult). Relative survival is an estimate of how well hatchery fish survive compared to natural (T) fish in the life stage of interest (here, smolt to smolt). The worksheet considers that relative survival within a particular life stage can vary depending on when outplanting occurred (i.e., egg, fry, etc.).

For this example, the relative survival in the smolt to smolt stage of hatchery fish outplanted as eggs is estimated to be 1 .0, or equivalent to that of T fish. In contract, the relative survival during the same life stage for fish outplanted as smolts is estimated to be 0.5, or half that of T fish. No value is given for the smolt to smolt stage when adults are supplemented.

The ranks that occur beneath relative survival values need to be understood in relation to the next column to the right, labeled-"affected attributes." For this example, only five attributes are considered due to space limitations: dispersiveness, feeding behavior, health, predator recognition, and swimming ability. These are 'listed down the column (including pages 2-3 of the table), allowing enough rows in between to list treatments that can affect each attribute. For the example, only certain treatments were listed due to space constraints.

Rankings are then applied. Treatments are ranked by considering each attribute separately. No consideration-is given to how the treatment-attribute relation may differ for different life stages being supplemented. In the example, density within the hatchery environment is ranked first (number 1) as likely having the greatest influence on the attribute of dispersivenss, exhibited during the smoit to smolt stage. In contrast, broodstock origin is ranked lowest (number 7) as influencing dispersiveness during the smolt to smolt state, A different rank is given to each treatment. The process is completed for all treatments listed for each attribute.

The attributes are ranked against each other for each life stage supplemented, in the section beneath relative survival values. Attributes associated with each life stage supplemented can be given the same rank. In the example, ail of the attributes shown except health are given little or no importance in affecting the relative survival of hatchery fish during the smolt to smoit stag8 outplanted as eggs. Thus for egg outplants, those attributes are ranked, with a 5 which health is ranked with 1. In contrast, predator recognition is ranked 1 for smolt outplant. Rankings shown are strictly hypothetical.

The worksheet illustrates that, for the case shown, different attributes are believed to contribute more of less importantly to the survival of fish supplemented at different life stages based on some form of relative importance ranking of each. Likewise, the role of different hatchery treatments are ranked by their expected contribution to altering the associated attribute.

By completing this process, a semi-quantitative means can be used to assess expected levels of importance of various hatchery treatments in altering attributes and, in turn, survival. Work is continuing to develop this process and determine the most effective manner of soliciting input for ranking the components of the table. The rankings that are assembled will be documented by citing sources of information, whether these are solicited expert opinion or literature.

The data will be assembled in a computerized date base for summarization and analysis. The data base will be designed to that it can be updated as new information becomes avaiiabl8.

Table 7.5 Worksheet for ranking expected relative Influence of different hatchery treatments, and associated changes in a fish's attributes compared to a wild counterpart, in affecting the survival of hatchery produced fish (T_3) outplanted at different life stages. Relative survival of T_3 fish is given in relation to the survival of wild fish (T_0). Hypothetical ranks are assigned for illustrative purposes only. Five attributes only are considered in thls example for survival of one life stage (smolt to smolt or downstream migration). Survival of T_0 fish is set at 1 .O for simplicity.

Life stage	T_0 Survival for stage (S_0)	Relative survival of T_3 fish by life stage supplemented (S_3/S_0) Rank of attribute affecting survival change[1]					Affected [illegible]	Hatchery influence	
		Egg	Fry	Pre-smolt	Smolt	Adult		Treatment	Rank[2]
smolt-smolt	e.g. 1.0	e.g. 1.0	e.g. 0.9	e.g. 0.8	e.g. 0.5	na	/////////////////////////////////	///////////////////////////////	////////
		5	1	1	2	na	dispersiveness	broodstock origin	7
								incubator/substrate	5
								feeding methods	2
								density	1
								structural complexity	3
								flow	6
								size of release	4
								other	
		5	2	3	5	na	feeding behavior	diet	5
								growth schedule	6
								incubator/substrate	9
								feeding methods	1
								density	2
								predation exposure	7
								structural complexity	4
								oontdnu design	3
								flow	8
								other	

Life stage	T_o Survival for stage (S_o)	Relative survival of T_s fish by life stage supplemented (S_s/S_o) — Rank of attribute affecting survival change[1]					Affected attribute	Hatchery influence	
		Egg	Fry	Pre-smolt	Smolt	Adult		Treatment	Rank[2]
		1	4	4	4	na	health	broodstock origin	3
								incubator/substrate	11
								diet	7
								growth schedule	8
								feeding methods	9
								density	2
								structural complexity	12
								container design	6
								flow	5
								water temperature	4
								disease control	1
								hygiene	3
								release method	10
								other	
		5	3	2	1	na	predator recognition	feeding methods	2
								density	4
								predation exposure	1
								structural complexity	3
								container design	5
								size of release	7
								release method	6

Life stage	T_e Survival for stage (S_e)	Relative survival of T_3 fish by life stage supplemented (S_3/S_e) — Rank of attribute affecting survival change[1]					Affected attribute	Hatchery influence	
		Egg	Fry	Pre-smolt	Smolt	Adult		Treatment	Rank[2]
								release location	8
								release timing	9
								other	
		5	5	5	3	na	swimming ability	incubator/substrate	6
								feeding method	4
								density	2
								structural complexity	5
								container design	3
								flow	1

1. Five attributes are ranked with 1 being most important and 5 least; attributes are ranked separately for each life stage supplemented.

2. Treatments are ranked against each other for each attribute, with 1 deemed most important.

APPROACH TO LONG TERM FITNESS UNCERTAINTIES

Many of the same hatchery practices that create the first generation effects identified in the previous section can also cause changes in the diversity or distribution of genetic information in the population and thus cause changes in the long-term fitness. For example, all the attributes listed in Table 7.1 probably have a genetic, as well as, an environmental component. The attributes are subject to short-term modification by the hatchery environment. In addition, the genetic component is also susceptible to change as a result of selection (nonrandom mortality) exerted by hatchery practices such as broodstock selection or grading. The hatchery treatments shown in 'Table 7.3 are capable of adverse genetic impact if the treatment creates an environment in the hatchery sufficiently different from the natural environment to cause nonrandom mortality. Tables 7.1-7.4 should be consulted with reference to tong-term fitness, as well as, first-year effects.

While the processes that generate first-year effects and changes in long-term fitness show significant overlap, our understanding of the mechanisms and impacts of first-year effects is more advanced than our understanding of the mechanisms and impacts on long-term fitness. Therefore, the effects of hatchery practices on long term fitness are not amendable to display in a format comparable to Table 7.5. We simply do not have the level of understanding of genetic effects required to fill out a table comparable to Table 7.5 for them.

Long-term fitness is a surrogate term for genetic risks. Busack (1990) identified four types of genetic risk associated with supplementation projects. His risks included: extinction, loss of within population variability, loss of between population variability, and domestication. The following discussion of genetic risks was ado&d from (Busack 1990).

Extinction

The extinction of a population and the loss of genetic resources it contains contributes to an overall loss of genetic variability and, therefore, poses a genetic risk. The actual cause of extinction is usually a combination of environmental and demographic factors. Populations reduced to a small fraction of their normal abundance are susceptible to extinction when faced with random events such as floods or droughts that occur in consecutive years. However, genetic process can also contribute to extinction. For example, inbreeding in depleted populations can accelerate the processes leading to extinction. Supplementation may be employed to prevent extinction, however, if used improperly, supplementation could contribute to the extinction of a depleted stock.

Loss of Within Population Variabiiitv

This genetic risk is commonly associated with hatcheries and is brought about by the random loss of genetic variability in small populations (genetic drift) and the loss of variability due to the nonrandom selection of broodstock from the donor population (founder effect).

Loss of Between Population Variability

When two populations are mixed such that they freely interbred, the unique identity of both populations may be lost. Coadapted complexes of genes may also be lost in the mixing of the two populations and recombination of their genetic material. A frequent concern associated with this type of risk is the scale of straying from the target stream into spawning areas of nontarget stocks.

Domestication

By virtue of the fact that hatchery environments are different from the natural environment, the possibility of selection and domestication of the hatchery stock exists. Whether domestication is an inevitable result of hatchery rearing or is a consequence of correctable hatchery practices remains to be demonstrated. However, recent studies raise the possibility of domestication in hatchery stocks (Reisenbichler and McIntyre 1977 and Chilcote et al. 1986). Domestication is the subject of debate and uncertainty, however its possibility needs to be taken into consideration when planning supplementation projects.

Uncertainties regarding the long term fitness can be partitioned among the four types of genetic risks (Table 7.6). RASP plans to consult with geneticists and the literature to expand and document the list of uncertainties and to frame them as research hypotheses that can be addressed in the global design.

Table 7.6 Hatchery treatment and critical uncertainties associated with four genetic risks.

GENETIC RISK	HATCHERY TREATMENT/UNCERTAINTY
Extinction	1 Donor population reduced below MVP by removal of hatchery broodstock. 2 Supplemented population has different genetic makeup, life history or rearing environment than the hatchery stock. 3 Hatchery stock strays into nontarget spawning areas. 4 Mixed stock fisheries reduce target or nontarget population below MVP.
Loss of Within Population Variability	1 Hatchery broodstock less than the minimum effective population sixe (NJ 2 Mating design and fertlixation protocol reduces N_e below minimum. 3 Hatchery pratices increases natural variation in family size. 4 Nonrandom selection of brood fish from the donor population. 5 Mixed stock fisheries reduces nontarget population below N,. 6 Failure to recognize and compensate (during brood selection) for the impact of a selective fishery.
Loss of Between Population Variability	1 The occurence and magnitude of outbreeding depression in salmon needs documentation. 2 Hatchery broodstock is taken from a genetically distant donor stock. 3 The scale of the supplementation program causes excessive strays into nontarget streams. 4 Hatchery practices causes abnormal rates of straying into nontarget streams. 5 Failure to identify the smallest group of interbreeding individuals of evolutionary significance in a subbasin.
Domestication	1 Hatchery brood stock not collected from all Portions of the run. 2 Grading, ponding, outplanting or other hatchery practice causes nonrandom mortality. 3 Broodstock not Selected randomly among age classes and life histories. 4 Rearing and release strategy is not consistent with natural life history pattern.

Adopted from Kapuscinski, A, R., C. R. Steward, M. L. Goodman, C.C. Krueger, J. Holt Williamson, E. Bowles and R. Carmichael. Genetic conservation guidelines for salmon and steelhead supplementation. Draft report prepared as part of the Northwest Power Planning Council's Sustainability Workshop. Northwest Power Planning Council. Portland Or.

EFFECTS ON ENVIRONMENTAL INTERACTIONS

Juvenile salmon and steelhead released into a stream as part of a supplementation project are expected to return to the stream (if not harvested), spawn and contribute to an increase in natural production. The rate at which they return (survive) is determined largely by their physiological state, their behavior, especially maladapted behavior learned in the hatchery environment, their genetic fitness, and the ecological interactions between the fish and the physical and biological habitat. The last category is probably the one we know the least about. Many of the first generation and genetic changes are expressed as reduced survival; however, the specific mortality factor may be expressed as one of the ecological interactions.

Ecological interactions are partitioned into three general areas: Interaction between salmon and their habitat, interactions that impact target species, and interactions that impact nontarget species/races (Table 7.7).

Habitat

The stream habitat that hatchery fish are released into may have a severe production bottleneck which will have to be removed before supplementation can increase natural production. In streams with headwater impoundments and controlled flows, the seasonal hydrograph and temperature regime may be out of synch with the natural life history of the target species. If the life history patterns respond to flow or temperature cues, the timing of critical events such as incubation or emergence, juvenile migrations, and spawning will be disrupted with a loss in production.

Table 7.7 Interaction uncertainties partitioned by habitat, target species and nontarget species.

Interaction Category	Uncertainty
Habitat	Habitat bottleneck limits natural production: * Access to spawning area blocked. * Summer rearing limited * Winter rearing limited * Juvenile outmigration impeded Flows and/or temp. out of synch with life history (juvenile and adult) Altered habitat better suited to nontarget species.
Target Population	Habitat previously used by target species colonized by nontarget species/race which: * Preys on target species * Competes with target species * Forces target population into a lower stability region Supplementation strategy attracts predators.
Nontarget Population	Successful supplementation displaces nontarget species/race of economic/recreational value. Resident, nontarget species/race vulnerable to predators attracted by supplementation strategy.

Taraet Species

The colonizing species may compete and/or prey on the supplemented species with sufficient intensity to lock it in a lower stability region. Peterman (1977) worked out the theoretical basis for multiple stability regions in salmon production functions and McIntyre et al. (1988) observed empirical support for the theory in the Karluk Lake, Alaska sockeye population. Shifts in dominance following the collapse of a dominate species have also been observed in marine populations. For example, the dominance of northern anchovy after the collapse of the California sardine and the dominance of Atlantic herring after the collapse of the Atlantic mackerel (Skud 1982). Regarding the marine species, Skud (1982) quoted N. Daan's estimate that it would require a 50% reduction in the dominant species and a corresponding 50% increase in the depleted species maintained for several years to reestablish dominance. McIntyre et al. (1988) concluded that an exploitation rate of 30% to 35% on Karluk Lake sockeye would have maintained the population in a higher stability region. These observations have important implications for supplementation planning. The concept of multiple stability regions is an important uncertainty that has generally been overlooked by managers.

Nontaraet Species

One cannot assume that a stream that previously supported a now-depleted abundant and productive salmon population, has vacant habitat equivalent to the difference between the past and present populations. Depletion generally doesn't create production vacuums. The vacant habitat will, in many cases, be colonized by another species/race. Consequently successful supplementation may displace a population of another species or resident population of the same species (e.g. steelhead may displace resident rainbow). The displacement can have biological, economic and political consequences.

8. CONVERTING UNCERTAINTIES TO GLOBAL DESIGN

TESTABLE HYPOTHESES

The previous section attempted to place bounds on the universe of uncertainties that, consciously or unconsciously, become part of all supplementation plans. We believe we have captured most of the uncertainties within the framework of first year effects, long term effects and interactions. However, left alone, the uncertainties in the previous section provide little help in formulating the global research program. Uncertainties need to be restated as testable hypotheses before they can be partitioned into those that are or are not resolvable by research.

The universe of uncertainties will be stratified in the global design into those that are resolvable through research that has broad application throughout major regions of the basin, research directed at specific case histories (for example, specific project evaluations), and small scale research programs. Classification of projects and uncertainties will permit this kind of stratification in a later report.

Once the uncertainties have been restated as testable hypotheses and regrouped within the original framework of first year effects, long term effects and interactions, they can be distributed among the clustered projects (see section 5 Classification of Stocks Streams and Strategies). The joining of testable hypotheses and project clusters gives a global picture of the uncertainties and their distribution among projects, strategies, stocks and regions of the basin – the-basis of a global design.

Reducing the universe of uncertainties to testable hypotheses will be a difficult task requiring the review and advice of researchers from several technical areas. This task will have a high priority in the next year. For purpose of review, we have prepared an example of an uncertainty reduced to a testable hypothesis:

<u>Uncertainty</u>

Attribute:	Predator recognition.
Description:	Ability to detect both presence and associated danger of predators.
Fate:	Predation.
Hatchery treatment:	Lack of experience with natural predators.
Mechanism:	Behavioral conditioning.

Observation

Fish released from a hatchery typically exhibit smolt to adult survivals 10% to 50% of their wild counterparts. This observation holds even for hatchery fish whose parents were wild. A possible explanation for this observation is an differential predation rate (smolt to adult) caused by the higher vulnerability of the behaviorally naive hatchery fish. Research in this area has confirmed the plausibility of a difference between hatchery and wild fish in their ability to avoid predators (citations).

Hypotheses

General: Lack of exposure to predatory stimuli in the hatchery environment accounts for part of the differential survival between wild and hatchery fish.

- Controlled exposure of hatchery fish to predatory stimuli will improve, survival after release.

  Possible treatments: Expose hatchery fish to caged predators in the hatchery pond.

  Expose hatchery fish to artificial predatory stimuli while in the hatchery pond.

  Possible tests: Compare treatment and control groups at various collection points downstream of the release point within the subbasin. (others)

  Compare treatment and control groups through experimental exposure to predators in the lab.

  Statistical sensitivity: Are there special statistical considerations in the design of the experiments?

  Application: Global or project specific.

This development of a research hypothesis from an uncertainty and the proposed experiment are examples and subject to change over the next few months: However they do illustrate the steps that are required to convert the uncertainties into an element of the global design.

IDENTIFYING CRITICAL HYPOTHESES

Adaptive management allows us to accept management actions with uncertain outcomes provided we are able to detect significant deviations from our objectives. However, objectives are complex and multidimensional (see Section 4.). Their measurement is often difficult and costly. The outcome of some objectives can be measured directly with a great deal of confidence and others must be measured indirectly. In adaptive management when we chose to implement a given strategy we are in fact testing the various sets of hypotheses under which the objectives are met. In order to chose which strategy is most appropriate, we must identify and test those uncertainties that best discriminate among options. (Comment: Since we typically learn more from rejected hypotheses, experiments may be designed to eliminate options.)

The first step in this process is to classify the testable hypotheses into those that are judged to have little impact on the outcome of supplementation and can safely be ignored; those that are critical to the outcome and are resolvable by research;. and those that are critical and are not amendable to research. We have developed the following key to aid in the classification of testable hypotheses.

I. Based on the procedures described in the previous section and modeling exercises, prepare a list of hypotheses related to the outcome of proposed strategies.

II. Judge whether each hypotheses has significant impact on the choice of strategy or not.

A. If it has little impact, or little discriminatory value (modeling may be useful in this determination along with an assessment, from the literature, of the likely range for the population parameters involved), proceed to the next uncertainty.

B. If it is critical to the choice of strategy, determine whether it can be resolved through experimentation (it the contention here that in most cases we can judge quite well whether experimental resolution is possible).

1. If it is amenable to resolution through research, can the question be resolved as apart of a global experiment (i.e. can inferences be drawn to or from the local uncertainty?)?

a. If yes, incorporate as appropriate in global experimental design.

b. If not, this uncertainty is a candidate for priority as a part of a local experiment.

2. If not amenable to experimental resolution, can surrogate variables be identified, that indirectly indicate an unexpected response?

   a. Yes. Uncertainties involving genetics and ecological responses may tend to fall into this category. So would smolt to adult survival response especially for small populations. See discussion of risk containment in the next section.

   b. No. If significant nonremovable uncertainties remain risk containment monitoring becomes critical to the decision whether to proceed.

STEPS IN DEVELOPING EXPERIMENTAL PLANS'

This is a first attempt at identifying the steps in the M&E planning process.

Identifv Detailed Objectives

Review the ecological dimensions of supplementation objectives (section 4). Taking the dimensions explicitly into account draft a statement of specific (numeric) natural production and harvest objectives. State the genetic goals using the genetic risks as a guideline of what to avoid. In the future the Sustainability Workshop reports will give more advice useful in setting genetic goals. If, appropriate the intended distribution of spawners by,tributary may be stated as an objective. The objectives should completely describe the intent of the supplementation project, describe the trade offs among the ecological dimensions and describe performance measures used to determine success or failure.

Problem Statement

In this context a problem is an impediment. to achieving an objective: Its critical that the impediment (problem) be described as accurately as possible so the best approach to its solution can be developed. A careful definition of the problem should reveal all the relevant uncertainties.

Strategy

Describe the proposed strategy with as much detail as is available – numbers of fish planted, broodstock/rearing/release treatment etc.. If harvest is an objective, various harvest strategies should be weighed against the other objectives. Various strategies may be evaluated through the supplementation model (section 6).

Assumptions

State assumptions with respect to natural oroductivitv of target stocks and their habitat under which the objectives will be achieved. These assumptions may include but not limited to:

- life history parameters.
- habitat quantity and quality.
- passage, early marine and ocean survival.
- factors limiting current production.

The assumptions should be organized around the four ecological dimensions of:

- post release survival of planted fish.
- reproductive success of planted fish.
- genetics and long term fitness of supplemented population.
- ecological interactions.

Critical uncertainties

Identify the critical uncertainties (testable hypotheses) associated with the assumptions required to meet the objectives. Use the key from the previous section to categorize the uncertainties the three categories: safe assumptions (little impact), critical uncertainties resolvable by research and critical uncertainties that cannot be resolved by research.

Experimental Goals

Organize the critical uncertainties (resolvable by research) into experimental plan. Determine which uncertainties are specific to your project and therefore must be addressed by local experimentation and those that may have broader applicability and may be addressed in the global research design.

9. GLOBAL EXPERIMENTAL DESIGN

GENERAL CONSIDERATIONS

The global research design and risk containment monitoring are recipients of all the information developed in the previous sections of this report., Consequently completion of those two tasks must follow completion of the other work.

The concepts of system monitoring and evaluation and global experimental. design have received a great deal of attention from regional planners in recent years (n.b. the NPPC formed a technical committee (MEG) 'to develop the concepts, and technical work groups were formed to prioritize regional research needs, etc). The notion of a regional approach for research and M&E to resolve critical uncertainties about supplementation suggests that both efficiency and effectiveness would be increased through this coordination. 'Efficiency would be increased by eliminating unnecessary duplication and Improving communication of results. Effectiveness would be increased through broader and more powerful experiments. The fly 'In this ointment is the uncertainty of the extent to which the results from one subbasin can be used to draw valid inferences regarding another.

Aside from the possibility of expanding the applicability of,, results, regional coordination of research and M&E also offers the benefits provided by a sharing of theory and study methods. A regional debate on supplementation using common terminology and definitions will stimulate progressive learning. This is, in large part, what RASP set out to accomplish (see the Introduction and Approach sections).

Experimental Design Considerationg

In Section 7, uncertainties were divided into three categories: (1) first generation effects of hatchery treatment on survival and reproductive success (i.e. the effect of the artificial environment); (2) long term fitness effects of supplementation on the introgressed populations; and, (3) effects of the natural environment (habitat limitations and interactions with target and nontarget populations). These categories were also described in Section 4 as the ecological dimensions within which the objectives of supplementation are set. The dimensions provide a conceptual link among objectives, the supplementation model, uncertainties and the global design.

Conceptual relationships between these dimensions and the success of different supplementation strategies are probably similar for most stock&i& streams; i.e., a generalized model can be described that reasonably reflects our understanding of population responses. However, as concluded at a recent workshop hosted by the

YKFP on the effect of artificial rearing on salmonid post release behavior, genetic and environmental factors tend to interact suggesting a need for stock by stock studies of some questions. Uncertainties from category (3) are generally associated with local conditions and are not conducive to regional conclusions; Effects of hatchery induced behavior, physiology, and genetics may, on the other hand, follow more broadly predictable patterns especially if a model can be devised that accounts for habitat and stock specific' differences (although interaction between genetics and habitat,.do complicate the picture and may invalidate inferences).

The question of regional applicability of study results probably hinges on the significance of stock-habitat interactions. Therefore, as we proceed to identify and prioritize critical uncertainties and opportunities to resolve them, we must also keep in mind that external applicability of results cannot be taken for granted.

Adding further to the complexity of how and when supplementation might succeed is the fact that survival and abundance studies of fish. populations are notoriously imprecise. DeLibero (1986) concluded that the best one could expect from survival studies of hatchery fish is a coefficient of variation of 25%. Lichatowich and Cramer (1979) found that studies of survival and abundance may require 20 to 30 years to produce an 80% chance of detecting a 50% change. Peterman and Bradford (1987) used Monte Carlo simulations to show that "under most realistic conditions the probability of correctly detecting recruitment time trends [for English sole] may be unacceptably low".

Statistical power must be taken into consideration when making decisions based on experimental outcomes. Response variables that are more sensitive to detecting change should be pursued (such as timing of life history events, growth and size, etc.). As the RASP proceeds in developing guidelines for global design, criteria for formulating hypotheses and designing powerful and. rigorous experiments will be proposed. The importance of statistical power lies in Its capacity to minimize the potentially harmful results of decisions based on erroneous conclusions. Consequently, the use of experimental outcomes in 'decision 'making must also be considered (see below).

Decision Process

The purpose of supplementation research is to resolve critical questions affecting the choice of strategy. The rating of a question as critical is, in fact, based- on its sensitivity in the decision making process (regarding strategy). How important is the decision that hinges on this question, and what are the implications of making the wrong decision?

Implicit in every choice of supplementation strategy is a set of postulated hypotheses that supports that choice. When these hypotheses are true, the decision is correct in the sense that the desired objectives would be met (benefits achieved within acceptable levels of risk). Also associated with every decision is: a) a chance that one or more of the supporting hypotheses is false; and, b) a consequence or cost of making that decision when the hypotheses in fact do not support the decision. The product of a) and b) describe an'expected loss function. When the uncertainty about the hypothesis is high and the decision cost is high, the expected loss may be unacceptable, and the hypothesis should be labeled critical. Thus the choice of critical supplementation questions (hypotheses) and the power (sample sizes, numbers of replicates, duration, etc.) of the experiments to resolve them are affected by the rules of the decision making process.:

One purpose of this discussion under the lofty label of global experimental design is to propose some guidelines for integrating ongoing and proposed studies in a manner that best supports effective decision making about supplementation in the Columbia Basin. In order to do this some assumptions have to be made about the decision making process. The adaptive management policy adopted by the NPPC implies a decision making process that acknowledges the inevitability of uncertainty about the outcome of management decisions. The literature on adaptive management stresses the importance of statistical power (controlling experimental error) and the application of statistical decision theory [cit.]. While it is clear that decisions will not, and should not, be made solely on the basis of technical information, it is also clear that any technical information brought forward should be accurately and completely represented.

As this section is further developed, we will discuss how research questions should be framed to assure that the technical conclusions offer clear insight to both resource opportunities and risks, even when studies are incomplete or inconclusive. Protocols for scientific decision making using qualitative information are needed and will be explored as the RASP Project continues.

Figure 9.1 illustrates the notion of reducing the sphere of uncertainty through global research design.

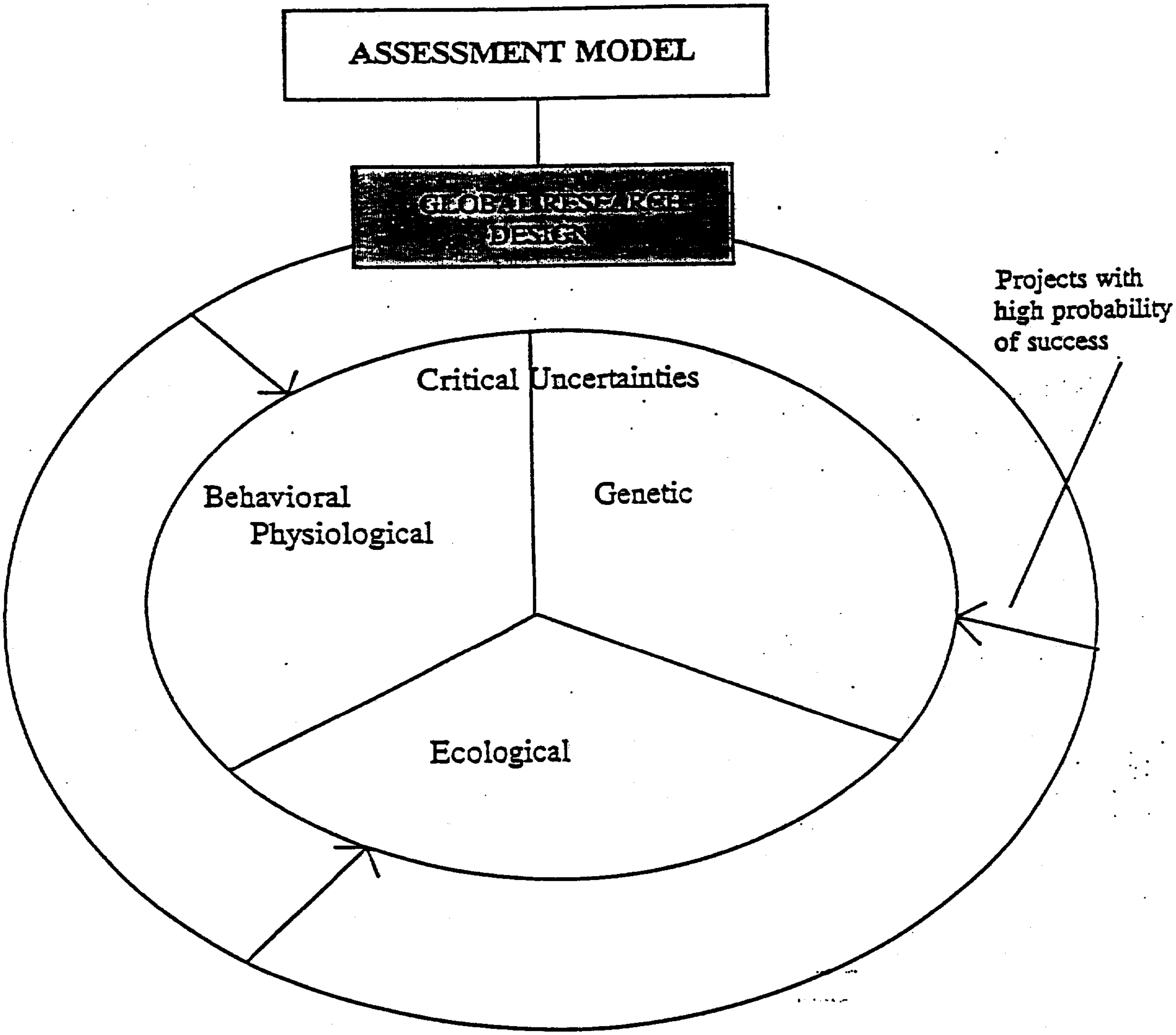


Figure 9.1 **Schematic showing the "Supplementation Universe", with a "Shrinking Sphere of Uncertainty".**

Intearation of Planned and Onaoina Proiects into the Global Desian

Table 9.1 illustrates how the critical questions will be tied to opportunities to resolve them in ongoing and planned supplementation projects. Those questions not adequately addressable by these projects would also be identified.

Table 9.1

FACTORS	COMMENTS
Critical Uncertainties	Listing of uncertainties identified and ranked in sections 7 and 8
Applicability	Supplementation objectives for which the listed uncertainty is critical. This is discussed in section 8.
Rank	Relative importance of the listed uncertainty. Sensitivity of the uncertainty can be evaluated through the supplementation model(section 6).
Hypotheses	Specific hypotheses and subhypotheses under which the affected supplementation objective will succeed (See section 8).
Feasibility	Feasibility of resolving uncertainty: ability to control/explain variability, baseline data needs, practical constraints etc (Part of the global design section 9).
Statistical Requirements	Statistical power and accuracy requirements, duration of study (part of sections 8 and 9).
Scope	Species, stocks, strategies and subbasins for which the listed question is critical (part of section 5).
Risks	Biological risks associated with experiments to resolve uncertainty (part of section 5 supplementation model).
Opportunities	List of planned and ongoing projects that offer opportunities to address the question (part of sections 5 and 9).
Remaining needs	Questions and information needs not expected to or unlikely to be met under current plans.

REFERENCES

Bjornn, T.C. and CR. Steward. 1990. Concepts for a model to evaluate supplementation of natural salmon and steelhead stocks with hatchery fish, Technical Report 90-2, Bonneville Power Administration, Portland, OR. '30 pages.

Busack, C. 1990. Yakima/Klickitat production project genetic risk assessment. Manuscript. Genetics Unit, Washington Department of Fisheries, Olympia, WA. 21 pages.

Chilcote, M.W., S.A. Leider, and J.L. Loch. 1986. Differential reproductive success of hatchery and wild summer-run steelhead under natural conditions. Trans. *Am. Fish. Society.* 115:726-735.

Columbia Basin Fish and Wildlife Authority. 1991. Integrated system plan. Portland, OR. 527pp.

Cuenco, M.L. 1991. Examples where supplementation has successfully resulted in increasing naturally reproducing fish populations. Manuscript Columbia River Inter-Tribal Fish Commission. Portland, OR.

DeLibero, F.E. 1986. A statistical assessment of the use of the coded wire tag for chinook (*Oncorhynchus tschawytscha*) and coho (*O. kisutch*) stud&&. Ph.D. Dissertation, Univ. of Wash., Seattle, WA 227pp.

Fisher, R.A. 1958. The genetical theory of natural selection. Second Revised Edition. Dover Publications, Inc., New York. 291pp.

Lee, D.C. and J.B. Hyman. 1991. Stoctiastic life-cycle model (SLCM): A tool for simulating the population dynamics of anadromous salmonids. '-Resources for the Future, Washington, D.C. 22 pages.

Lichatowich, J. and S. Cramer. 1979. Parameter selection and sample sizes in studies of anadromous salmonids. Oregon Dept. of Fish and Wildlife Information Report Series, Fisheries Number 80-1, Portland, OR. 25pp.

McIntyre, J.D., R.R. Reisenbichler, J.M. Emlin and R.L. Wilmont. 1988. Predation of Karluk River sockeye salmon by coho salmon and char. Fishery B&tin Vol. 36: 611-616.

Miller, W.H., T.C. Coley, H.L. Burge and T. T. Kisanuki. 1990. Analysis of salmon and steelhead supplementation: emphasis on unpublished reports and present programs. U. S. Department of Energy Bonneville Power Administration project No. 88-100.

Nehlsen, W., J.E. Williams and J. Lichatowich. 1991. Pacific salmon at the crossroads: stocks at risk from California, Oregon, Idaho and Washington. *Fisheries* 16: 4-21.

Nickelson, T.E., M.F. Solazzi, and S.L. Johnson. 1986. Use of hatchery coho salmon (*Oncorhynchus kisutch*) presmolts to rebuild wild populations in Oregon coastal streams. *Can. J. Fish. Aquat. Sci., 43:* 12 2443-2449.

Northwest Power Planning Council. 1989. Salmon and steelhead systems planning and documentation. Monitoring and Evaluation Group. Northwest Power Planning Council. Portland, OR.

Northwest Power Planning Council. 1987. Columbia River Basin Fish and Wildlife Program (Amended). Portland, OR.

Oregon Department of Fish and Wildlife. 1986. The impact of Oregon Aqua-Foods operation on the wild coho salmon in the Yaquina River. Staff Rep., Fish Division, Portland OR.

Oregon Fish Commission. 1955. Biennial report of the Fish Commission of the State of Oregon to the Governor and the Forty-eighth Legislative Assembly. pp. 28.

Peterman, R.M. 1977. A simple mechanism that causes collapsing-stability regions in exploited salmonid populations. *J. Fish. Res. Board Can.* 34:1134-l 142.

Peterman, R.M. and M.J. Bradford. 1987. Statistical power of trends in fish abundance. *Can. J. Fish. Aguat. Sci. 44:* 1879-1889.

Reisenbichler, R.R. and J.D. McIntyre. 1977. Genetic differences in growth and survival of juvenile hatchery and wild steelhead trout, *Salmon gairdneri. J. Fish. Res. Board. Can. 34: 123-l* 28.

Ricklefs, R.E. 1973. Ecology. Chiron Press, Portland, OR 861pp.

Riggs, L. 1990. Principals for genetic conservation and production quality. Northwest Power Planning Council Contract C 90-005. Portland, OR.

Scientific Review Group. 1991. Review of fisheries supplementation in the context of activities related to the Columbia River Basin Fish and Wildlife plan. Memorandum to Wally Steucke, IPP Coordinator, Portland, OR. 7pp.

Skud, E. B. 1982. Dominance in fishes: the relation between environment and abundance. *Science 216:* 144-149.

Smith, E. M., B. A. Miller, J. D. Rodgers and M. A. Buckman. 1985. Outplanting anadromous salmonids – a literature survey. U. S. Department of Energy, Bonneville Power Administration Project No. 85-68. Portland, OR.

Steward, C. R. and T. C. Bjornn 1990. Supplementation of salmon and steelhead stocks with hatchery fish: A synthesis of published literature. U.S. Department of Energy, Bonneville Power Administration Project 88 -100. Portland, OR.