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SUPPLEMENTATION IN THE COLUMBIA BASIN Part I

Rasp Summary Report Series

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SUPPLEMENTATION IN THE COLUMBIA BASIN

Part I

Rasp Summary Report Series

Background, Description, Performance Measures, Uncertainty, and Theory

Prepared For

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RASP CONTRIBUTORS

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TABLE OF CONTENTS

SUPPLEMENTATION IN THE COLUMBIA BASIN: PART I.

BACKGROUND, DESCRIPTION, PERFORMANCE MEASURES, UNCERTAINTY AND THEORY

INTRODUCTION

This progress report broadly defines the scope of supplementation plans and activities in the Columbia Basin. It provides the foundation for more detailed analysis of supplementation in subsequent reports in this series. Topics included in this report are: definition of supplementation, project diversity, objectives and performance standards, uncertainties and theory. Since this is a progress report, the content is subject to modification with new information. The supplementation theory will continue to evolve throughout the duration of RASP and beyond. The other topics in this report are essentially complete and are not expected to change significantly.

This is the first of a series of four reports which will summarize information contained in the larger, RASP progress and completion reports. Our goal is to make the findings of RASP more accessible by grouping related topics into smaller but complete narratives on important aspects of supplementation. We are planning to publish the following reports under the general title Supplementation in the Columbia River Basin: Part 1, Background, Description, Performance Measures, Uncertainty and Theory; Part 2, Theoretical Framework and Models; Part 3, Planning Guidelines; and Part 4, Regional Coordination of Research and Monitoring.

Supplementation is expected to be a major contributor to the planned increase in salmon and steelhead production in the Columbia Basin. The Fish and Wildlife Program of the Northwest Power Planning Council (NPPC) uses three approaches to protect and enhance salmon and steelhead in the Columbia Basin: 1) enhance fish production; 2) improve passage in the mainstem rivers; and 3) revise harvest management to support the rebuilding of fish runs (NPPC 1987). The fish production segment calls for a three-part approach focused on natural production, hatchery production, and supplementation. Supplementation is planned to provide over half of the total production increases. (Table 1).

Table 1. **Percent of production increases attributable to supplementation[1] in System Planning. Computed from System Planning Model output (data supplied by Duane Anderson, NPPC).**

Species/Stock	Columbia River Region: Lower	Mid	Snake	Upper	All
Late Coho	97.7%	-	-	-	97.7%
Early Coho	100.0%	100.0%	-	-	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%

[1]Supplementation projects in System Planning do not necessarily meet the RASP definition.

The Regional Assessment of Supplementation Project (RASP) was initiated as a result of a request by NPPC to address long-standing concerns about the need to coordinate supplementation research, monitoring and evaluation. Such coordination was also recommended by the Supplementation Technical Work Group.

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 addresses four principal objectives:

- provide an overview of ongoing and planned supplementation activities and identify critical uncertainties associated with supplementation,
- construct a conceptual framework and model which estimates the potential benefits and risks of supplementation and prioritizes uncertainties,
- provide guidelines for the development of supplementation projects,
- develop a plan for regional coordination of research and monitoring.

These objectives, once attained, **will** provide the technical tools fishery managers need to carry out the Council's direction to protect and enhance salmon and steelhead.

RASP has further divided the four broad objectives into 12 technical topics:

- definition of supplementation
- description of the diversity of supplementation projects
- objectives and performance standards
- identification of uncertainties
- supplementation theory
- development of a conceptual model of supplemented populations
- development of spreadsheet model of risks and benefits of supplementation

- classification of stocks, streams, and supplementation strategies
- regional design of supplementation evaluation and monitoring
- guidelines for planning supplementation projects
- application of the spreadsheet model to supplementation planning
- experimental design and decision making with uncertainty

Progress in each topic area is presented in regular progress reports which are available from the Bonneville Power Administration.

Historical Perspective

Recent supplementation initiatives in the Columbia River Basin are embedded in a larger historical context and a changing management paradigm. Policies that will guide the Council's program to rebuild salmon and steelhead populations in the Columbia Basin reflect evolving management standards. Those policies express concern over the conservation of genetic resources, the need to integrate natural and artificial propagation in the basin, a recognition of the need to address mainstem survival and harvest management, and the need to approach restoration with an integrated, system wide program within the framework of an adaptive management policy (NPPC 1987). Emphasis on conservation of genetic resources is consistent with the results of a Council-sponsored workshop which 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 the Council's policies, in particular 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 were the major tool of managers who used them to supply the fishing industry with commodity and replace production lost through habitat destruction. The early research focused on hatchery practices and the production of a healthy smolt in the hatchery. The interaction between hatchery programs and wild stock conservation was not given careful consideration.

The recent emphasis on supplementation to revitalize natural production in the basin (Table 1), the precarious status of several stocks of salmon and steelhead (Nehlsen et al. 1991), and the commitment to double total production in the basin (NPPC 1987), has reaffirmed the importance of hatcheries in the Columbia's salmon production system. Hatcheries will remain important in their traditional roles and supplementation will give them new roles. Hatchery programs, especially supplementation, will be evaluated by new performance standards which will include ecological as well as genetic criteria. 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 Anadromous Fishery Management Plan (Idaho Department of fish and Game 199 1).

The hatchery program is facing its greatest challenge since the 1940's when it became generally accepted procedure to rear salmon to full term smolts to achieve the highest survival. The transition from making fry or sac fry releases to rearing full term smolts required better understanding of nutritional requirements of salmon and disease control, prevention, and treatment. In addition, many of the early hatcheries were designed for fry release and did not have the year-round water supplies needed for smolt production (Oregon Fish Commission 1955).

The manager's new challenge is to learn how to integrate the artificial and natural salmon production systems in the Columbia Basin to produce sustainable increases in total production. 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.

These fundamental changes in management strategies are not easy to accommodate. Managers are faced with major new challenges while at the same time the conventional wisdom they relied on is challenged and weakened.

Review of Recent Work

The emphasis on supplementation as a tool to restore natural production and concern about the erosion of genetic resources has produced a rapidly growing literature. RASP has summarized selected publications using a format that makes the information relevant to supplementation readily available to the manager. The summaries give each paper's contribution to eight areas of importance to supplementation: definition of supplementation, description of project diversity, planning recommendations, performance standards, genetic uncertainties, physiological and behavioral uncertainties, research and monitoring, and recommendations (see Appendix A).

DEFINITION OF SUPPLEMENTATION

The Scientific Review Group (SRG)[2] recognized the need for a clear definition and agreement on what is meant by supplementation (SRG 1990). Current definitions of supplementation vary and are not sufficiently specific to be helpful to the development of performance standards and the design of evaluation studies. RASP agreed with the findings of the SRG and recognized the need for a clear working definition of supplementation.

RASP developed the following defmition of supplementation:

> ***"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 non-target populations within specified biological limits."**

Recent publications have used other definitions, which are presented for comparison:

- "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. 1990)

- "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 Bjomn 1990)

In its definition, RASP limited the scope of supplementation to those activities carried out with the explicit intention of maintaining or increasing natural production by means of artificial propagation. Excluded from the RASP definition is the unplanned addition of hatchery-reared fish to natural populations.

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[2] The Scientific Review Group is a panel of senior-level scientists that provides scientific and technical advice and recommendations to BPA and the Policy Review Group on implementation of the Fish and Wildlife Program.

Supplementation Is.. .

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

Supplementation encompasses a wide range of management characterized by four general objectives (SRG 1990):

- Restoration: the restoration of a native species to habitats where it has be-en extirpated.
- Introduction: planting a species into habitat where it was not native.
- Rearing Augmentation: planting fish in habitat that is under utilized.
- Harvest Augmentation: planting fish for the purpose of increasing harvest.

Within the context of those broad objectives supplementation attempts to provide a net survival benefit to the target stock. To provide that benefit, supplementation must circumvent part of the early natural mortality while preserving the natural processes that maintain long term performance of the stock and sustainability of natural production.

What distinguishes supplementation from other management activities is the assumption that artificial propagation can be used to improve the production of naturally-spawning populations without adverse genetic or ecological effects. 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. Supplementation may employ one or more of many different strategies and life stages.

Supplementation Is Not.. .

Supplementation and conventional hatchery programs differ in the goals they set for the use of returning adults. The typical goal of the conventional hatchery is to maximize adult production for harvest while assuring the collection of adequate broodstock. In the past, there has been no acceptable limitation of the impacts of hatchery programs on natural production.

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.”

DESCRIPTION OF SUPPLEMENTATION PROJECTS

A number of ongoing and planned supplementation projects in Washington, Idaho and Oregon which are called supplementation are summarized in Table 2. All the stocks/streams listed in Table 2 will be supplemented, however, in many of the supplementation projects, the associated evaluation includes unsupplemented control streams. Those streams are not included in the table, but they are included in the supplementation data base compiled by RASP.

A number of ongoing outplanting programs were excluded from Table 2 because they are intended ***primarily*** to augment harvest, not natural production. Some harvest augmentation programs will be replaced with "true" supplementation projects; in those instances, only the planned project was included.

Supplementation Data Base

A computer program ("SUPQUEST") was developed to gather data on stocks, streams and strategies for existing and planned supplementation projects. Copies of the program were distributed to project leaders for data collection. A disk containing the actual computerized questionnaire and the data base generated from it can be obtained from the Bonneville Power Administration. In addition to the questionnaire, data collected in the System Planning Process was incorporated into the supplementation data base.

Information collected to date shows that the purpose of most of the projects is to supplement spring, fall and summer chinook and summer steelhead (Figure 1). To provide a broad picture of supplementation in the basin, we have arranged the information from the questionnaire into three major categories: description of stocks to be supplemented, description of the stream and the supplementation strategies to be employed. Figures 2 - 7 display part of the information from the data base.

Table 2. 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, m	Spring Chinook	ISS-Second Generation	Planned	Yes
14	American R. SF Clearwater, m	Spring Chinook	ISS	Planned	Yes
15	Crooked R. SF Clearwater, m	Spring Chinook	ISS	Planned	Yes
16	Papoose Cr. Lochsa R., m	Spring Chinook	ISS	Planned	Yes
17	Pete King Cr. Lochsa R., m	Spring Chinook	ISS	Planned	Yes
18	Squaw Cr. Lochsa R., m	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., m	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	incomplete
26	Eldorado Cr. Clearwater R., ID	Spring Chinook	Nez Perce Tribal Program	Planned	incomplete
27	Lolo Cr. Clearwater R., ID	Spring Chinook	Nez Perce Tribal Program	Planned	incomplete
28	Yoosa Cr. Clearwater R.,ID	Spring Chinook	Nez Perce Tribal Program	Planned	incomplete
29	Newsome Cr. Clearwater R., ID	Spring Chinook	Nez Perce Tribal Program	Planned	incomplete
30	Meadow Cr. Clearwater R., ID	Spring Chinook	Nez Perce Tribal Program	Planned	incomplete
31	Mill Cr. Clearwater R., ID	Spring Chinook	Nez Perce Tribal Program	Planned	incomplete
32	Clearwater R., ID	Fall Chinook	Nez Perce Tribal Program	Planned	incomplete
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	Lookinglass 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	incomplete
52	Asotin Cr. Snake R., WA	Spring Chinook	WDF	Planned	incomplete
53	Snake R., WA	Fall Chinook	WDF	Planned	incomplete
54	Chiwawa R. Wenatchee R., WA	Spring Chinook	Rock Island Recertification	Ongoing	incomplete
55	Wenatchee R., WA	Summer Chinook	Rock Island Recertification	Ongoing	incomplete
56	Wenatchee R., WA	Sockeye	Rock Island Recertification	Ongoing	incomplete
57	Wenatchee R., WA	Summer Steelhead A-run	Rock Island Recertification	Ongoing	incomplete
58	Methow R., WA	Summer Chinook	Rock Island Recertification	Ongoing	incomplete
59	Similkameen R., WA	Summer Chinook	Rock Island Recertification	Ongoing	incomplete
60	Methow R., WA	Spring Chinook	Douglas Co. PUD	Planned	incomplete
61	Chewuk R. Wenatchee R., WA	Spring Chinook	Douglas Co., PUD	Planned	incomplete
62	Twisp R. Methow R., WA	Spring Chinook	Douglas Co., PUD	Planned	incomplete
63	Okanogan R., WA	Sockeye	Doulas Co., PUD	Planned	incomplete

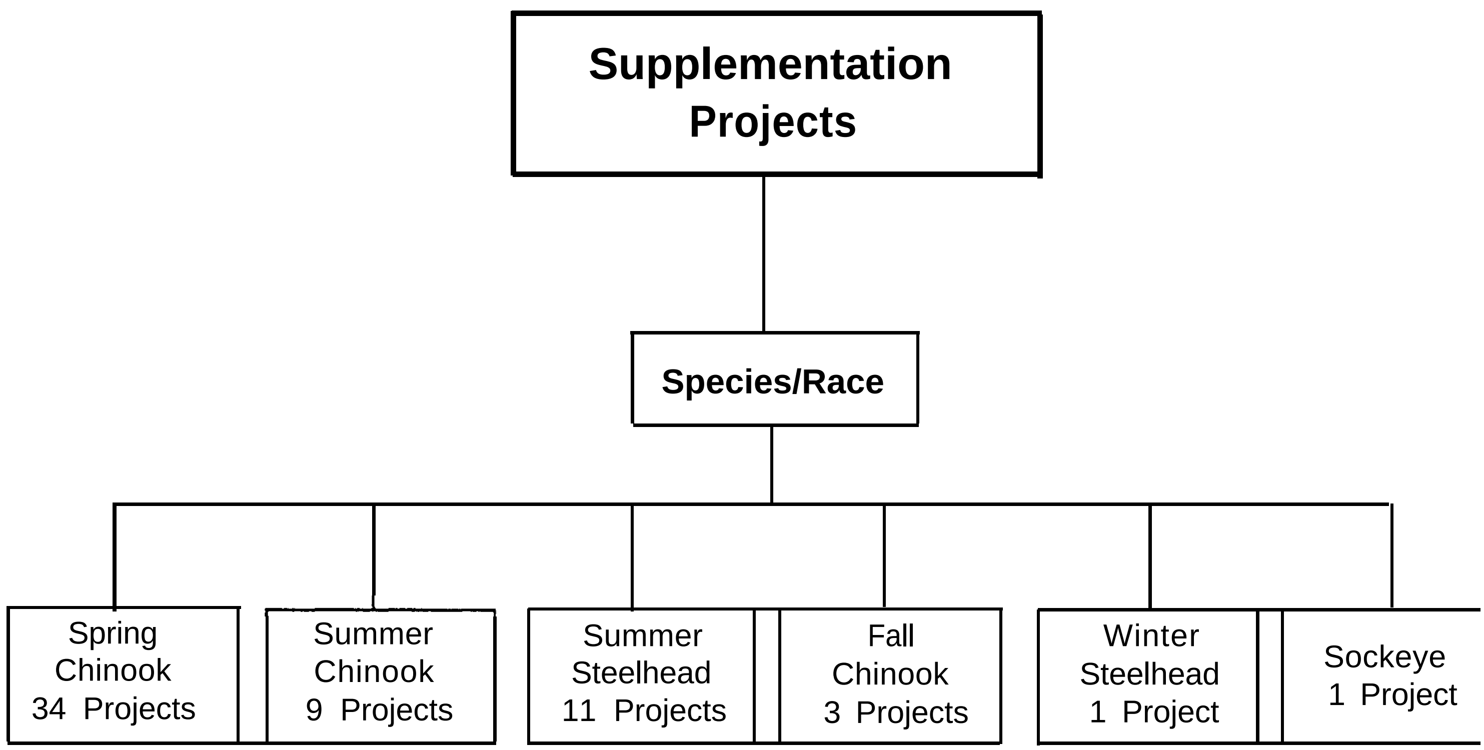

Figure 1. Distribution of supplementation projects among the species and races of salmon and steelhead.

Spring Chinook
34 Projects

Stock Characteristics

Population Trend

Trend	No. Stocks
Declining	21
Stable	4
Increasing	0
Extinct	9

Stock Status

Current prod. as % of carrying capacity	No. Stocks
< 20%	19
20-50%	4
>50%	2
Extinct	9

Smolt Survival from Release to Below Bonneville Dam

Survival	No. Stocks
10-15%	19
15-20%	5
20-25%	1
25-30%	4
30-35%	2
45-50%	1
85-90%	2

Mean Fecundity per Adult

Eggs	No. Stocks
1900-2 100	14
2100-2300	9
2300-2500	5
2500-2700	1
2700-2900	3
2900-3 100	1
3800-3900	1

Stock History

Status	No. Stocks
Native	8
Nat./Hatch	12
Introduced	5
Extinct	9

Description of Streams

Smolt Production Capacity

No. Smolts	No. Streams
<100k	7
100k to 1m	24
>1m	3

Juvenile Productivity Index. Survival to Smolt at 0 Density.

% Survival	No. Streams
6-7%	1
7-15%	1
15-17%	4
17-19%	13
19-21%	11
21-25%	2
25-27%	2

Supplementation Strategies

Life Stage Planted

Stage	No. Projects
Fry/parr	5
Pre smolts	5
Smolts	24

Brood Stock Origin

Origin	No. Projects
Wild	11
Hatchery/wild	11
Hatchery	12

Stocking Density

% Carrying Capacity	No. Projects
< 20%	4
20-50%	8
50-100%	10
>100%	12

Spawning Risks Genetic Selection

Rank (9 Low Risk, 27 High Risk)	No. Projects
9-10	4
10-12	19
12-14	11

Rearing Risk

Rank (8 Low Risk, 27 High Risk)	No. Projects
8-10	2
10-12	1
12-14	6
14-16	16
16-18	8
18-20	1

Release Risk

Rank (5 Low Risk, 15 High Risk)	No. Projects
5	7
5-7	3
7-9	18
9-11	5
11-13	1

Figure 2. Stock and stream characteristics and strategies for 34 planned and ongoing spring chinoook supplementation projects.

Summer Chinook
9 Projects

Stock Characteristics

Population Trend

Trend	No. Stocks
Declining	4
Stable	2
Increasing	0
Extinct	

Stock Status

Current prod. as % of carrying capacity	No. Stocks
< 20%	6
20-50%	1
>50%	1
Extinct	1

Smolt Survival from Release to Below Bonneville Dam

Survival	No. Stocks
12-15%	2
15-I 8%	2
21-24%	1
24-27%	2
30-33%	2

Mean Fecundity per Adult

Eggs	No.Stocks
1600-I 700	2
1700-I 800	2
2000-2100	1
2100-2200	1
2400-2500	2
2700-2800	1

Stock History

Status	No. Stocks
Native	1
Nat./Hatch	7
Introduced	0
Extinct	1

Description of Streams

Smolt Production Capacity

No. Smolts	No. Streams
<100k	0
100k to Im	4
>1m	5

Juvenile Productivity Index. Survival to Smolt at 0 Density.

% Survival	Io. Streams
15-16%	2
20-21%	3
24-25%	1
31-32%	1
47-48%	1
50%	1

Supplementation Strategies

Life Stage Planted

Stage	No. Projects
Fry/parr	
Pre smolts	
Smolts	9

Brood Stock Origin

Origin	No. Projects
Wild	2
Hatchery/wild	5
Hatchery	2

Stocking Density

% Carrying Capacity	No. Projects
< 20%	1
20-50%	5
50-100%	2
>100%	1

Spawning Risks Genetic Selection

Rank 9 Low Risk 27 High Risk	No. Projects
11	2
12	3
13	2
14	2

Rearing Risk

Rank 8 Low Risk 27 High Risk	No. Projects
9	1
16	2
17	4
18	2

Release Risk

Rank 5 Low Risk 15 High Risk	No. Projects
9	6
10	2
12	1

Figure 3. Stock and stream characteristics and strategies for 9 planned and ongoing summer chinook supplementation projects.

Fall Chinook
3 'Projects

Stock Characteristics

Population Trend

Trend	No. Stocks
Declining	0
Stable	2
Increasing	0
Extinct	1

Stock Status

Current prod. as % of carrying capacity	No. Stocks
< 20%	0
20-50%	2
>50%	0
Extinct	1

Smolt Survival from Release to Below Bonneville Dam

Survival	No. Stocks
13%	1
20%	1
27%	1

Mean Fecundity per Adult

Eggs	No.Stocks
532	1
1595	1
2851	1

Stock History

Status	No. Stocks
Native	2
Nat./Hatch	0
Introduced	0
Extinct	1

Description of Streams

Smolt Production Capacity

No. Smolts	No. Streams
<100k	0
100k to 1m	0
>1m	3

Juvenile Productivity Index. Survival to Smolt at 0 Density.

% Survival	No. Streams
42%	2
50%	1

Supplementation Strategies

Life Stage Planted

Stage	No. Projects
Fry/parr	0
Pre smolts	0
Smolts	3

Brood Stock Origin

Origin	No. Projects
Wild	2
Hatchery/wild	0
Hatchery	1

Stocking Density

% Carrying Capacity	No. Projects
< 20%	0
20-50%	0
50-100%	1
>100%	2

Spawning Risks Genetic Selection

Rank 9 Low Risk 27 High Risk	No. Projects
11	1
14	2

Rearing Risk

Rank 8 Low Risk 27 High Risk	No. Projects
9	2
15	1

Release Risk

Rank 5 Low Risk I5 High Risk	No. Projects
5	2
11	1

Figure 4. Stock and stream characteristics and strategies for 3 planned and ongoing fall chinook supplementation projects.

Summer Steelhead

11 Projects

Stock Characteristics

Population Trend

Trend	No. Stocks
Declining	9
Stable	2
Increasing	0
Extinct	

Stock Status

Current prod. as %% of carrying c capacity	No. Stocks
< 20%	3
20-50%	8
> 50%	0
Extinct	0

Smolt Survival from Release to Below Bonneville Dam

Survival	No. Stocks
24-26%	2
26-28%	4
28-30%	1
30-3 2%	1
4446%	1
8486%	2

Mean Fecundity per Adult

Eggs	No.Stocks
2054	1
2412	1
2526	4
2753	1
2965	1
4200	3

Stock History

Status	No. Stocks
Native	3
Nat./Hatch	8
Introduced	0
Extinct	0

Description of Streams

Smolt Production Capacity

No. Smolts	No. Streams
< 100k	7
100k to Im	3
> 1m	1

Juvenile Productivity Index. Survival to Smolt at 0 Density.

% Survival	No. Streams
2.5%	1
3.5 %	1
4.0 %	2
5 %	6
7 %	1

Supplementation Strategies

Life Stage Planted

Stage	No. Projects
Fry/parr	
Pre smolts	
Smolts	11

Brood Stock Origin

Origin	No. Projects
Wild	4
Hatchery/wild	7
Hatchery	0

Stocking Density

% Carrying Capacity	No. Projects
< 20%	0
20-50%	0
50-100%	5
> 100%	6

Spawning Risks Genetic Selection

Rank 9 Low Risk 27 High Risk	No. Projects
11	5
12	1
13	1
14	4

Rearing Risk

Rank 8 Low Risk 27 High Risk	No. Projects
9	1
13	4
14	3
15	1
17	2

Release Risk

Rank 5 Low Risk 15 High Risk	No. Projects
5	1
7	3
11	2
12	1
13	4

Figure 5. Stock and stream characteristics and strategies for 11 planned and ongoing summer steelhead supplementation projects.

Winter Steelhead

1 Project

Stock Characteristics

Population Trend

Trend	No. Stocks
Declining	1
Stable	
Increasing	
Extinct	

Stock Status

Current prod. as % of carrying capacity	No. Stocks
< 20%	
20-50%	1
>50%	
Extinct	

Smolt Survival from Release to Below Bonneville Dam

Survival	No. Stocks
78%	1

Mean Fecundity per Adult

Eggs	No. Stocks
2574	1

Stock History

Status	No. Stocks
Native	
Nat./Hatch	1
Introduced	
Extinct	

Description of Streams

Smolt Production Capacity

No. Smolts	No. Streams
<100k	1
100k to 1m	
>1m	

Juvenile Productivity Index. Survival to Smolt at 0 Density.

% Survival	No. Streams
.54%	

Supplementation Strategies

Life Stage Planted

Stage	No. Projects
Fry/parr	
Pre smolts	
Smolts	1

Brood Stock Origin

Origin	No. Projects
Wild	
Hatchery/wild	1
Hatchery	

Stocking Density

% Carrying Capacity	No. Projects
< 20%	
20-50%	
50-100%	
>100%	1

Spawning Risks Genetic Selection

Rank 9 Low Risk 27 High Risk	No. Projects
13	1

Rearing Risk

Rank 8 Low Risk 27 High Risk	No. Projects
16	1

Release Risk

Rank 5 Low Risk 15 High Risk	No. Projects
13	1

Figure 6. Stock and stream characteristics and strategies for 1 planned winter steelhead supplementation project.

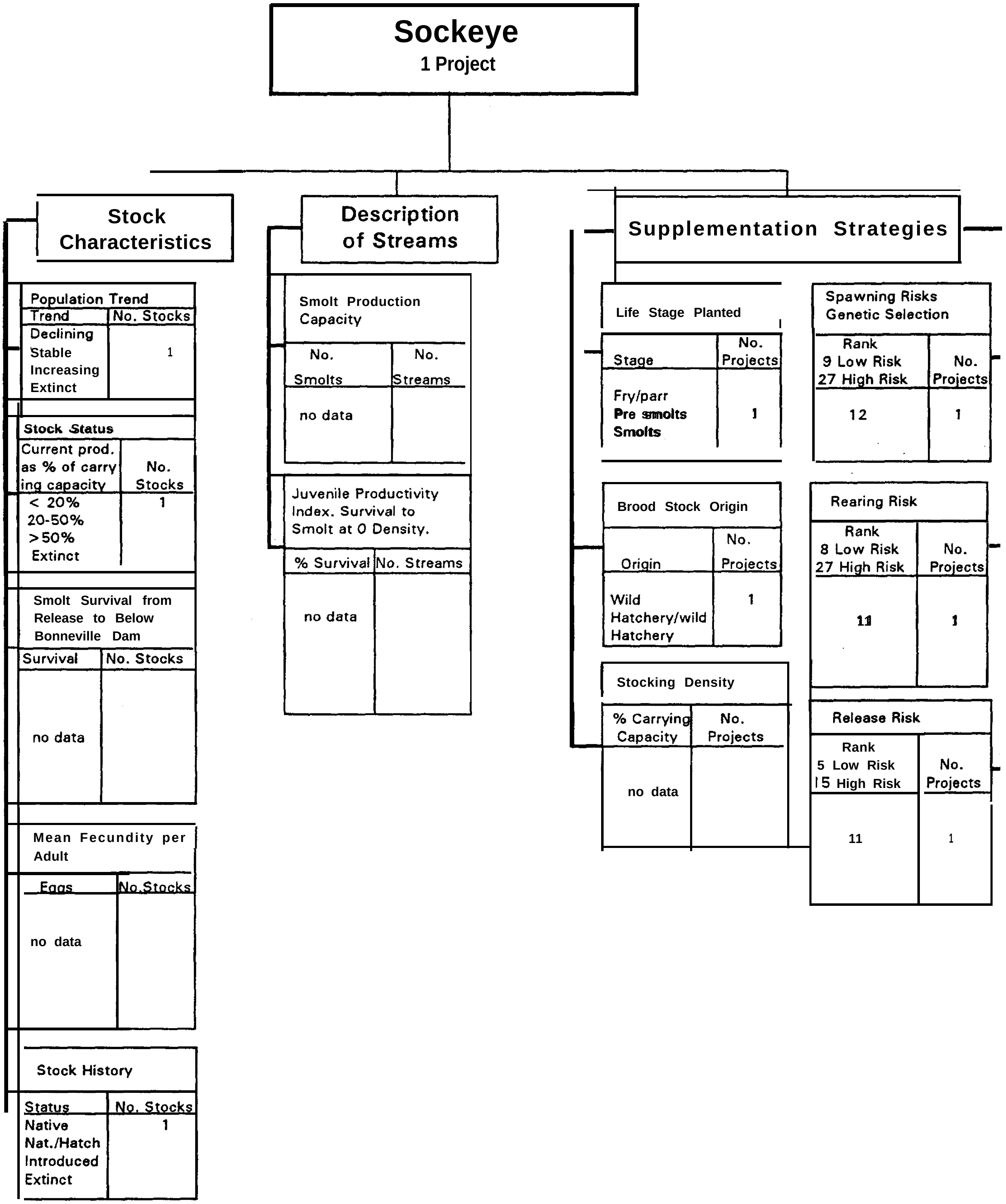

Figure 7. Stock and stream characteristics and strategies for 1 planned sockeye supplementation project.

OBJECTIVES AND PERFORMANCE STANDARDS

This section describes the objectives of supplementation and how progress toward the objectives will be measured. Supplementation planning must produce objectives that are socially useful and technically sound, and they must be stated in a way that permits measurement of performance and progress. Performance standards should provide insight into the mechanisms that determine success or failure. Performance standards therefore must reflect biological or ecological significance as well as economic and social benefit.

Supplementation is relatively new. It is a largely untested means of integrating natural and artificial production to achieve sustainable increases in productivity (CBFWA 1991). Since fishery managers do not have extensive experience in the implementation and evaluation of supplementation, project planning, in particular the development of objectives and performance standards, assumes increased importance.

The four general objectives of supplementation (restoration, introduction, rearing augmentation, and harvest augmentation) are useful in discriminating projects at a gross level, for example, in an overall survey of the types of supplementation projects in the basin. Objectives have another more important function: to define specific targets against which performance of the program can be measured. Objectives of hatchery programs have traditionally been limited to production targets - pounds of fish reared and released, contribution to fisheries, etc. Those targets are important, but the definition of supplementation adopted by RASP implies that other measures of performance must also be included in the objectives. RASP has proposed the routine addition of four new performance standards in all supplementation projects: post-release survival, reproductive success, long-term reproductive performance, and ecological interactions.

Post-Release Survival

Post-release survival is measured from the time of release to the time adults return to the subbasin or are harvested in a fishery. The system planning model discounts the contribution of hatchery fish by 50% to account for differential survival between wild and hatchery smolts (Monitoring and Evaluation Group 1989). Given the magnitude of the discount applied to hatchery fish, improving post-release performance can make a large contribution to the success of a supplementation project. To improve post-release survival, evaluation projects should focus on learned behavior in the hatchery, physiological state of the hatchery fish, ecological factors such as predation and competition, and environmental factors such as flow and temperature patterns.

Reproductive Success

Reproductive success measures how well supplemented fish reproduce in the natural environment. It is limited to those changes in the natural reproductive process induced by the hatchery experience but that do not persist into the next generation. Reproductive success is broadly defined as the number of offspring produced per spawner and it is influenced by:

- changes in average fecundity of the stock
- pre-spawning mortality
- large- and small-scale spawning distribution (homing to appropriate drainage or selection of quality spawning bed)
- spawning effectiveness (mate acquisition, redd digging capability, spawning timing, and egg retention)
- survival of progeny of hatchery-reared fish across significant life history stages (egg-to-fry, fry-to-presmolt, and presmolt-to-smelt survival and recruit per spawner ratios).

Long-Term Performance

Long-term performance is defined as the capacity of a population to persist in the face of environmental variability while undergoing natural genetic change. Ultimately, long-term performance is demonstrated by the simple fact that a population has maintained its productivity over a long period of time. Long-term performance of a stock might be indexed by changes in the ratio of recruits to spawners, overall egg to adult survival and survival between life history stages, gene frequencies as measured by electrophoresis, by changes in life history patterns. Long-term performance is a relatively new approach to the evaluation of artificial propagation, hence new tools and methodologies are needed. Standards designed to measure long-term performance must consider the four genetic risks associated with supplementation: extinction, loss of within-population variability, loss of between-population variability and domestication (Busack 1990).

Ecological Interactions

Hatchery fish released into the natural stream immediately become a part of the ecological matrix comprised of the physical habitat and its biota, including predators and competitors. Hatchery-reared fish both affect and are affected by the ecological matrix of the stream. For example, one of the most controversial biotic effects is the impact of a successful supplementation program on non-target species or races. The inter- and intra-specific trade-offs implicit in any supplementation program and the performance standards used to measure those trade-offs must be made explicit. Performance standards designed to measure the interaction between ecological factors and supplementation may be derived from:

- 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 critical habitat parameters (e.g., adult passage at dams and other obstructions; effectiveness of screening and bypass systems for irrigation diversions; adequate in-stream flows for spawning, rearing, and outmigration; and water quality, especially as impacted by such human activities as logging and grazing
- competitive and genetic interactions between resident @e-existing) and anadromous trout (supplemented)
- interactions between pre-existing resident trout and other anadromous species
- interactions among supplemented and natural anadromous salmonids themselves (e.g., competition, predation, "pied piper" effects, and residualism).
- 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

UNCERTAINTIES

This section describes uncertainties associated with supplementation. In supplementation planning, as in other activities where a biological resource is to be manipulated, what we don't know is at least as important in shaping the program as what we do know and can control. This is because our ignorance often outweighs our knowledge about ecological systems.

The uncertainties associated with a supplementation project result from a combination of three factors: the productive processes in the stream ecosystem, or our perception of them; the supplementation strategies; and the objectives (performance targets) of the project (Figure 8).

Management decisions, whether to initiate programs or to take no actions, are often made with uncertainty. The presence of uncertainty automatically presents the manager with risk - risk of failure, risk of unintended impacts (genetic or ecological), and risk of future surprise outcomes. Uncertainty and risk are inseparable elements in fisheries programs: where you find one you will always find the other.

Risk can be estimated and assessed through models that substitute assumptions for the critical uncertainties. The accuracy of risk measured in this way depends on the accuracy of assumptions. Lesser uncertainties are usually ignored in the models. Risks can also be assessed by listing and reviewing of critical uncertainties. The nature of those uncertainties and the potential importance of their effect can be estimated qualitatively through experience and a review of the literature. This method cannot deal effectively with cumulative or synergistic interactions among uncertainties, but models can be designed to handle those kinds of interactions.

Uncertainties also play an important role in the design of monitoring and evaluation programs. One way to reduce risk to acceptable levels is to monitor the appropriate parameters in a way that gives early warning of a problem. RASP calls this "risk containment monitoring."

Since uncertainties are the product of factors that will vary from project to project, they must be evaluated on a case-by-case basis. However there is utility in displaying uncertainties that are generally applicable to supplementation. A general list of uncertainties and matrices that can be used to generate potential uncertainties are presented in the next two sections.

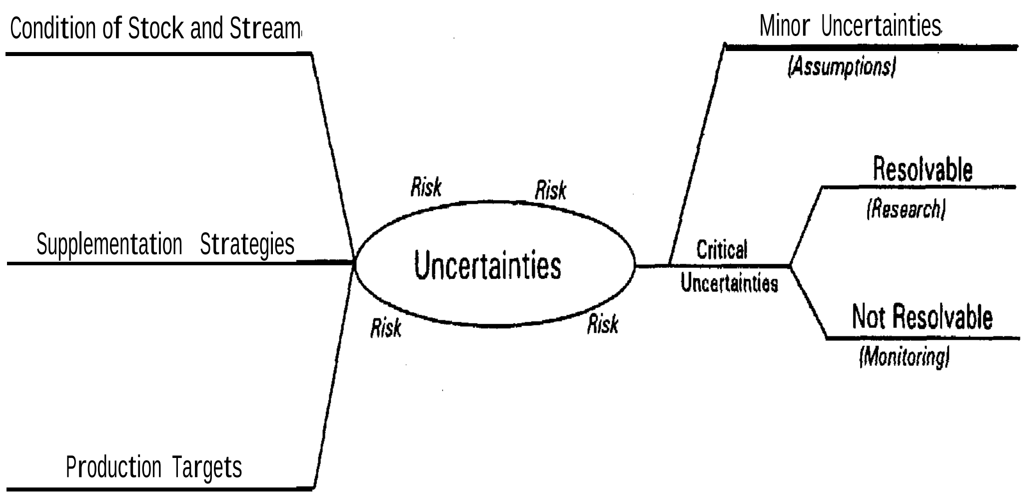

Figure **8. Schematic representation of the origin and treatment of supplementation uncertainties.**

General Uncertainties

The SRG (1990) identified the central uncertainty or question regarding supplementation as: " Under what set of conditions will supplementation of natural and wild production with hatchery production add to the total production of salmon, steelhead or other targeted fishes over the long term?" All of the more specific uncertainties are related to that question. One source of the more specific uncertainties is the literature review by Steward and Bjomn (1990). The list presented below is our interpretation of the major uncertainties contained in that report. An exhaustive review is not intended: the original document should be consulted for details.

Genetic Uncertainties

1) Biochemical techniques for stock separation are not always conclusive and the genetic basis for the observed variability in stocks of Pacific salmon is not well documented.

2) It is not known whether some species or races of salmon or life histories within species are better suited to supplementation than others.

3) It is not known whether domestication and loss of performance in the wild is an inevitable consequence of artificial propagation. The kinds of hatchery environments and practices that preserve natural adaptations in hatchery-reared fish are unknown.

4) The impact of the use of foreign or distant broodstock on smolt-to-adult survival and fitness is unknown. A closely related uncertainty is the magnitude of outbreeding depression and the consequences of losing co-adapted gene complexes in wild stocks when exogenous stocks are used.

5) The amount of information on genetics, life history, ecological characteristics and interactions of hatchery and wild stocks necessary to employ artificial selection safely and beneficially in supplementation is unknown. Put another way, can "remedial selection" in a hatchery ever be safely employed on stocks that have already lost genetic variability or are poorly adapted to a modem environment?

6) The rate at which hatchery-reared fish adapt to natural environments is unknown. A related uncertainty with major implications for supplementation is the number of natural generations required before offspring of hatchery-reared parents achieve the fitness of the wild stock.

7) The conditions under which ***beneficial*** gene flow from hatchery to wild stocks occurs are unknown.

8) The maximum ratio of hatchery to wild spawners to ensure minimal deleterious genetic impacts is unknown. The minimum effective population size for hatchery breeding and natural spawning is unknown.

9) The environmental conditions (dam mortality, habitat degradation, etc.) under which supplementation will fail to achieve its goals - even when hatchery fish are genetically equivalent to wild fish - are unknown.

Ecological Uncertainties

10) The effects of hatchery practices on survival and production are unknown. For example, the combinations of release size, time, and density which stimulate natural production without displacing wild fish are unknown; the life stage and season of stocking that minimize hatchery-induced impairment of predator avoidance and feeding efficiency are unknown; the degree to which behavior learned in the hatchery predisposes hatchery fish to higher rates of predation, lower feeding efficiency, or suboptimal habitat use is not known; and the degree to which improved hatchery practices (size and time of release, disease prophylaxis, and reduced rearing density, etc.) can improve early marine survival is unknown.

11) It is not known whether interspecific competition or predation can prevent a depressed target population from responding to supplementation. A related uncertainty concerns the impacts of multiple stability regions. Assuming that multiple stock-recruitment stability regions exist, and that some populations are "trapped" in a lower region because of interspecific competition or predation, what combinations of hatchery release numbers and reductions of competitor or predator populations will allow the target population to regain its higher equilibrium level?

12) It is not known whether the magnitude or strategies employed by particular supplementation projects could *attract* predators and exacerbate predatory losses of wild fish.

13) The incidence of vertical transmission of disease from hatchery to wild fish is unknown, as is the impact such transmission has on wild stocks.

14) The conditions under which successful supplementation might selectively increase harvest of wild fish in a mixed population have not been determined.

Identifying Supplementation Uncertainties

This section describes potential sources of uncertainties related to supplementation. These are intended to provide guidance for identification of relevant uncertainties for specific supplementation projects. The section considers sources in the hatchery environment. and from ecological interactions.

Hatcherv Environment

The survival of first generation hatchery fish is influenced by the culture practices, the environmental conditions in the hatchery, the compatibility of the stock, and the size and time of release to the natural environment. Certain behavioral and physiological characteristics of fish, and in some cases genetically related traits, are apparently altered within the first generation of hatchery experience. Such changes explain why hatchery fish produced from wild parents exhibit significantly lower survival than natural fish in the same river system for the same life history phases. These changes in a fish's condition or characteristics, referred to here as its ***attributes,*** apparently cause the poor performance within the natural environment.

RASP identified 19 attributes of salmonids potentially altered by hatchery practices within the first generation of hatchery experience (Table 3). Each attribute can affect survival and therefore contribute to the differential in performance of hatchery and wild fish. RASP also developed a schematic model to illustrate the link between an attribute and survival during a particular life stage (Figure 9).

Figure 9 lists six potential fates, of hatchery produced fish that die before spawning. Clearly, death may be caused by several of these modes, acting in concert. For example, starvation, stress, and disease could all be contributors to a fish's demise. However, for descriptive purposes, it is useful to link attributes and fates as though they act independently (Table 4).

Figure 9 also illustrates that the life stage being supplemented is an important factor. The relative influence of a particular attribute on survival of hatchery produced fish differs between fish released as fry and fish released as smolts. Sorting out these life history effects will increase the complexity of the task significantly.

Numerous hatchery practices or treatments can potentially alter survival-related attributes. We focused our attention on 22 treatments considered of greatest importance (Table 5). This list will be modified as RASP continues its assessment. A very brief description of each treatment is provided in Table 5.

Many of the same hatchery practices that create the first generation effects identified in Tables 3-5 can also cause changes in the diversity or distribution of genetic information in

Table 3. Survival-related attributes of salmonids potentially altered by hatchery practices within the fii 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 aelection	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.
Frey recognition	Ability to locate suitable prey items.
size	Length and associated condition factor of fish at time or age.
Smohification	Timing and degree of physiological tmnsformation in prepamtion for seaward migration/entry.
Saltwater transfer efficiency	Effectiveneaa 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, hieranhial associations, and schooling.
Catchability	Effectiveness, or lack thereof, at avoiding capture by a fishery.

Table 4. Potential fates, or modes of death, of hatchery produced salmonids unsuccessful at surviving to spawn and attributes which can contribution to a particular fate.

Predation	Starvation	Disease	Environmental Impacts	Fishery	Stress
predator recognition	health	health	habitat selection	dispersiveness	health
swimming ability	feeding behavior	disease resistance	swimming ability	emigmtion pattern	amount of body fat
size	dispersiveness	smoltification	emigmtion pattern	immigmtion pattern	rmoltitication
dispersiveness	emigmtion pattern	emigmtion pattern	immigmtion pattern	homing/straying	aggressiveness
feeding behavior	social intemction	immigmtion pattern	homing/straying	rmoltification	dispersiveness
emigmtion pattern	prey recognition	aggressiveness	rmoltification	size	social intemction
habitat selection	amount of body fat	dispersiveness	size	aggressiveness	habitat selection
smoltification	aggressiveness	social interaction		prey recognition	
	smoltification	amount of body fit		catchability	
	saltwater transfer efficiency	saltwater transfer efficiency		matumtion	
				feeding behavior	

Table 5. List of hatchery treatments potentially affecting survival-related attributes of sahnonids within the first generation of hatchery experience.

Hatchery treatment	Component of treatment of potential concern
Broodstock origin	Indigenous natural stock or imported stock (hatchery or natural and source)
Broodstock capture/holding methods	Repmscntivcness of timing and ages obtained by capture/holding methods
Mating practices	Random vs. non-random, representation by age classes, male-per-female mtio, etc.
Incubator type and substrate	Degree of intemction between substrate and alevin; emergence or removal
Diet	Type of food: dry vs. wet, buoyant vs. sinking, natural vs. manufactured
Growth schedule	Rate of desired growth and size projected; ration adjusted to meet schedule
Feeding method	Automatic feeders. demand feeders, broadcasting by humans, etc.
Rearing density	Density
Grading	Consolidation of sizes in mating with or without culling of undesirable fish
Predation exposure	Extent of experience with natural predators: birds, otters, fish
Structural complexity	Exposure to variable habitat structure: overhanging cover, visual sepamtors, etc.
Container design	Size, shape and depth of rearing unit: mceway vs. pond, meander vs. straight
How	Quantity and velocity of flow through tearing unit
Water temperature	Range of temperatures during either incubation or rearing compared to nature
Disease control	Extent of exposure to pathogens and treatments applied
Hygiene	Rearing vessel cleaning practices (frequency and methods)
Size of release	Number of fish released
Release method	Volitional vs. forced, degree of acclimation, mode of transportation
Release location	Distance from hatchery, single point release vs. multiple release sites, etc.
Release tinting	Means of selecting date for release; relationship to natural tinting

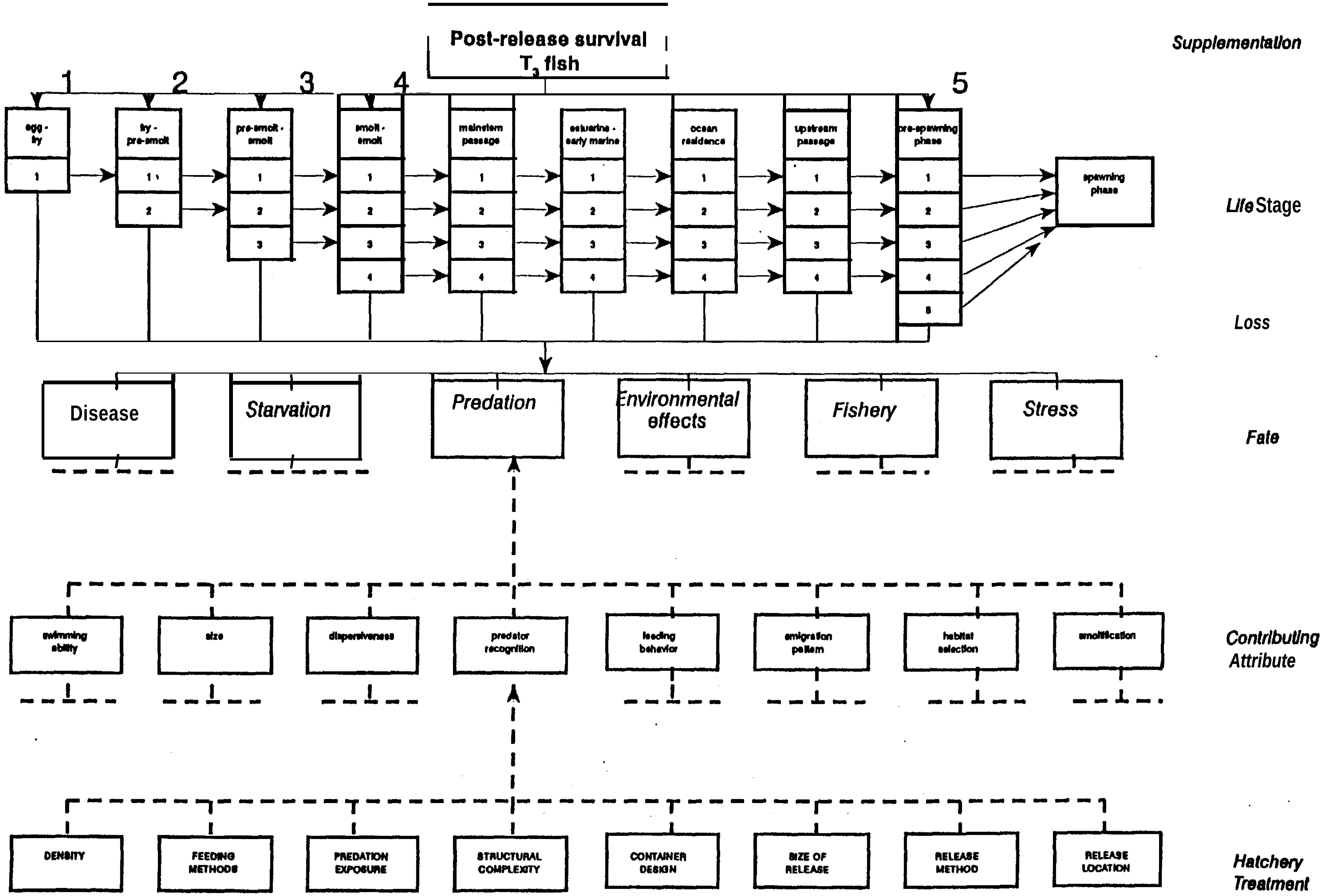

Figure 9. Schematic of effects of hatchery treatment on survival related attributes of first generation hatchery fish outplanted at different life stages.

the population and thus cause changes in the long-term performance. For example, all the attributes listed in Table 3 probably have a genetic, as well as an environmental component. The genetic component can be altered through selection exerted by hatchery treatments shown in Table 5.

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. Table 6 displays the hatchery practices that can contribute to uncertainties associated with each type of genetic risk.

Ecological Interactions

Juvenile salmon and steelhead released into a stream as part of a supplementation project are expected to return to the stream, to spawn, and to contribute to natural production unless they are harvested. The rate at which they return (survive) is determined largely by their physiological state, their behavior (especially maladaptive behavior learned in the hatchery environment), their genetic fitness, the mainstem passage mortality and the ecological interactions between them and the physical and biological habitat. The last category is probably the one about which we know the least. Many of the first generation effects and genetic changes are expressed as reduced survival; however, the proximate cause of mortality in many of these cases is probably some type of "ecological interaction".

Ecological interactions are partitioned into three general types: interaction between salmonids and their habitat, biotic interactions that impact target species, and biotic interactions that impact non-target species/races (Table 7).

Habitat. Production may be severely limited by a suite of factors in the target stream which act at one or two specific life stages (production "bottlenecks"). Such production bottlenecks and mainstem passage mortality may have to be substantially reduced before the supplementation objectives can be met. For example, streams with headwater impoundments and regulated flows may have a seasonal hydrograph and temperature regime that severely compromises the performance of a targeted species. If the timing of life history events is entrained to natural rhythms of flow or temperature, critical events such as emergence, outmigration, and spawning will be disrupted and production will be reduced dramatically.

Table 6. Hatchery treatment and critical uncertainties associated with four genetic risks.[1]

Genetic Risk	Hatchery Treatment/Uncertainty
Extinction	• Donor population reduced below MVP by removal of hatchery broodstock • Supplemented population has different genetic makeup, life history or rearing environment than the hatchery stock • Hatchery stock strays into non-target spawning areas • Mixed stock fisheries reduce target or non-target population below MVP
Loss of Within-Population Variability	• Hatchery broodstock less than the minimum effective population size (N_e) • Mating design and fertilization protocol reduces N_e below minimum • Hatchery practices increase natural variation in family size • Non-random selection of brood fish from the donor population • Mixed-stock fisheries reduces non-target population below N_e • Failure to recognize and compensate (during brood selection) for the impact of a selective fishery
Loss of Between-Population Variability	• Occurrence and magnitude of outbreeding depression • Hatchery broodstock is taken from a genetically distant donor stock • Scale of the supplementation program causes excessive strays into non-target streams • Hatchery practices cause abnormal rates of straying into non-target streams • Failure to identify the smallest group of interbreeding individuals of evolutionary significance in a subbasin
Domestication	• Hatchery brood stock not collected from all portions of the run • Grading, ponding, outplanting or other hatchery practice causes non-random mortality • Broodstock not selected randomly among age classes and life histories • Rearing and release strategy is not consistent with natural life history pattern

[1]Adopted from Kapuscinski, A. R., C. R. Steward, M. L. Goodman, C.C. Krueger, J. Holt Williamson, E. Bowles and R. Carmichael (1991).

Table 7. Interaction uncertainties partitioned by habitat, target species, and non-target 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 temperatures not compatible with life history (juvenile and adult) Mainstem passage mortality Altered habitat better suited to non-target species
Target Population	Habitat previously used by target species colonized by non-target species/race which: • Preys on target species • Competes with target species • Forces target population into a lower stability region Supplementation strategy attracts predators
Non-Target Population	Successful supplementation displaces non-target species or race of economic or recreational value Resident, non-target species or race vulnerable to predators attracted by supplementation strategy

Non-Target Species. One cannot assume that a stream with a depleted salmon population has vacant habitat equivalent to the difference between the past and present population sizes. Depletion of an abundant and productive salmon population generally doesn't create production vacuums. In oligotrophic waters, the loss of salmon carcasses might result in a reduced productivity and production of potential prey. In more productive waters, vacant habitat will, in many cases, be colonized by another species/race. Consequently successful supplementation may displace a population of another species or a resident population of the same species (e.g. steelhead may displace resident rainbow trout). The displacement can have biological, economic and political consequences.

Target Species. The effect of ecological interactions on target species can be expressed by several uncertainties. For example, one set of uncertainties arise from the existence of multiple stability points in the stock-recruitment relationship. Managers proposing supplementation should be especially concerned when colonizing species compete with and/or prey on the supplemented species with sufficient intensity to lock the latter 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 sockeye population of Karluk Lake, Alaska.

Shifts in dominance following the collapse of a dominate species have also been observed in marine populations. For example, the northern anchovy became dominant after the collapse of California sardine populations and Atlantic herring dominated 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 a lower 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.

ELEMENTS OF A SUPPLEMENTATION THEORY

The expectation that we can increase total production by adding artificially propagated fish to natural habitats, is based on our understanding of the artificial and natural production systems. Realizing the expected increases in production depends on how well the two systems are integrated. Supplementation theory is an attempt to generalize our understanding of natural and artificial production and to establish guidelines for integrating the two. Theory gives managers the tools needed to build conceptual models of supplemented stream/stock systems. The models permit managers to deduce hypotheses about the expectations (benefits and risks) of supplementation. The hypotheses are also the basis for performance evaluation and subsequent refinement of both theory and supplementation strategies (adaptive management).

A supplementation theory should describe the basis for assessing potential benefits, risks, applications and uncertainties of supplementation. Developing a supplementation theory is important to: narrow the range of potential risks, applications and uncertainties; track the rational for assessment of those parameters; and provide common ground from which discussions of supplementation can take place.

Consistent with the overall purpose of this report - to provide a general introduction to supplementation in the Columbia Basin and broadly describe the scope of the program - the purpose of this discussion of supplementation theory is limited to general concepts. More detailed development of theory and examples of its use will be discussed in later reports in this series.

Supplementation Concepts

Supplementation theory rests on three concepts:

- capacity: each stream/stock system has a capacity to produce salmon and steelhead determined by the interaction of abiotic and biotic factors operating through the stock's life history

- performance: performance of a stream/stock is that part of the capacity realized in any given time interval

- stock-recruit relationship: there is a relationship between the quality and quantity of a spawning population and recruitment of the adult progeny.

Capacity

The geomorphic setting, vegetation, climate and stock life histories determine the capacity of the system to produce salmon. Capacity is the product of the interaction of the biotic and abiotic factors and the stock life histories, therefore, it can rarely be measured directly as a fixed quantity. Capacity of a stock/stream system is not necessarily determined in the spawning or freshwater rearing habitats because capacity incorporates all life stages and associated habitats. For example, the ability of a stream system to produce emigrants may never be realized because of factors limiting capacity during the smolt to adult stage.

Supplementation introduces another determinate of capacity -- the physical size and operational practices of the hatchery. Hatcheries have a physical capacity to produce juvenile salmon. Because hatcheries circumvent much of the freshwater incubation and rearing mortality, they may be considered analogous to a super tributary from the standpoint of smolt production. Hatchery practices that alter long term fitness or life histories will change the interaction between the stock and its habitat and therefore influence capacity.

Performance

That part of a stream's capacity realized over a specified period is its performance and it is usually measured as the production of target species and races. Production is comprised of measures of abundance, post-release survival, reproductive success, long-term performance, and ecological interactions. Following supplementation, the performance of a stream /stock system is determined by the fitness of the supplemented stock and the density-dependent regulation of the combined natural/artificial population. Factors outside the subbasin such as mainstem passage mortality also influence performance. The goal of supplementation is to improve performance and increase natural production, but before supplementation can be considered an appropriate management strategy, the manager must conclude that the capacity of the system is greater than its current performance. However, a difference between capacity and performance does not automatically lead to supplementation. For example, if the difference between capacity and production is due to degradation of spawning, rearing and migrational habitat, supplementation may not improve performance without concurrent habitat improvement.

Stock-Recruit Relationshin

Salmon mangers generally accept the existence of a relationship between the quantity and quality of spawners and recruitment in the next generation. In addition to biotic and abiotic components of the habitat and life history of the native stock, the performance of a stream/stock system is influenced by density-dependent population regulation. The stock-recruit model has served for 40 years as the primary tool for evaluating the nature of the density-dependent influence of stock size on subsequent recruitment and production. Various types of stock-production models have been proposed for salmon, including the Ricker (1954) and Beverton and Holt (1957) models and the more complex forms proposed by Paulik (1973). Families of stock-recruitment curves may be used to show the range of performance levels of a stock/stream system.

In addition, salmon and steelhead typically exhibit discrete life history stages (egg to fry, fry to emigrant, emigrant to smolt, and smolt to adult). Specific productivity curves illustrating the performance relationship within each life history can be useful in evaluating the overall stock-recruitment relationship.

Stock-Recruitment Models

Stock-recruitment models of salmon populations have received extensive treatment since Ricker's (1954) treatise on the subject. However, the debate, refinement and use of the stock-recruitment models have focused on questions related to harvest management. Among the exceptions are Junge's (1970) use of stock-production models to determine the relative impact of smolt, adult and racial mortalities in freshwater on overall production. Ginzburg (1990) used a stock-recruit model to assess the effect of density-dependence on the risks of extinction. Reisenbichler and McIntyre (1977) illustrated the impact on production of interbreeding between hatchery and wild steelhead through hypothetical stock-recruit models. Reisenbichler (1984) used the stock-recruit model to show the theoretical response of a wild population to supplementation and the loss of fitness through the introduction of a maladapted allele.

In the development of a supplementation theory, we will assume that the shape of the stock-production curve describes the density-dependent regulation of numbers, that this regulation takes place predominately in freshwater, and therefore it reflects important constraints on production which supplementation must address. A criticism of the use of stock-production models to characterize salmonid populations is that they contain little or no allowance for evolutionary or other complex biological mechanisms (Slobodkin 1973). Also, changes in habitat can alter the relationship between stock size and subsequent production (Moussalli and Hilbom 1986). Some of these concerns can be addressed through modifications of the basic model.

Paulik (1973) and Peterman (1977) illustrated how stock-production relationships can have multiple stability regions. Paulik (1973) and Moussalli (1984) described ways of partitioning a stock-production relationship into life stages to address some of the complexities that arise in models based on full generations. The potential for multiple stability regions has important implications to the scale of supplementation projects. Use of multiple life stages can permit greater diversity of experimental approaches and designs.

Clinical Model

For descriptive purposes, the concepts of capacity and performance are embedded in a broader clinical model of the target stream and stock. The basic elements of the clinical model[3] are: Template, the healthy stream/stock system; patient, the current condition of the stream/stock in need of restoration; diagnosis, the comparison of template and patient that leads to identification of limiting factors; and treatment, the specific strategies to remove or circumvent the limiting factors.

A description of the stream/stock's capacity is a template against which proposed future states of system habitat and stock life histories are compared. The template is a historical reconstruction of the habitat and life histories in the healthy system. Because it is a historical reconstruction, the template analysis will often employ indirect evidence or findings from other streams reported in the literature. The template serves as a guide, a model or a pattern, to assist in planning the reconstruction of a degraded stream/stock system.

The current performance of the stream/stock system is analogous to a patient in the clinical model. In many cases only fragments of the template will remain in the patient stream/stock. Life histories and their associated habitats may be missing entirely or severely degraded. A comparison of the template with the patient leads to a diagnosis of not only the proximate causes of observed performance, but it suggests potential treatments that are likely to increase performance. The comparison of template and patient will also identify treatments that might decrease performance, for example, selection of a stock for supplementation that exhibits maladapted life histories for the target habitat.

When constructing the template and patient descriptions, it is important to include all life history stages including those that take place outside of the spawning and juvenile rearing habitats. This is particularly important where the patient's condition is primarily determined outside the subbasin where spawning takes place.

Summary

The stock-recruit model and the concepts of capacity and performance are the basis for a supplementation theory. Those concepts employed in a clinical model result in a description of the production process in a stream/stock system in a way that permits rational development of biologically appropriate treatments and the formulation of hypotheses that permit critical evaluation and adaptive management of the supplementation program.

[3]The clinical model is described in greater detail in the third report in this series dealing with planning guidelines

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APPENDIX A

SUMMARY OF SELECTED SUPPLEMENTATION LITERATURE

Table A.l. Information contained in recent report relevant to supplementation: Definition, Classification, and Planning

REPORTS (See Literature Cited for reference)	DEFINITION OF SUPPLEMENTATION	CLASSIFICATION OF PROJECT DIVERSITY	PLANNING RECOMMENDATIONS
Miller, W.H., et al. 1990 **Analysis** of Salmon and Steelhcad **Supplementation: Emphasis** on **Unpublished Reports** and **Present** Programs	Planting **all** life **stages** of hatchery fib to enhance wild/natural **stocks** of **anadromous salmonids**	No **stratification** or classification of **projects** other than **the separation** between supplementation and non-ntpplementalion **projects.** Provides a summary of 3 16 projects	**Planning recommendations** can be extracted from the report's **conclusions.** Recommends looking for **factors** that caused decline before supplementation
Kapuscinski, A.R., at **al.** 1991 Genetic Conservation Guidelines for Salmon and Steelhead Supplementation	The **use** of artificial propagation while conserving genetic **resources,** for the goal of **restoring** or augmenting **self-sustaining populations.** Broken into broad **categories** of restoration and augmentation	No **classification** other than the distinction found in definition between **restoration** and augmentation	**Lists** five **steps** in planning **a** supplementation project: **set goals,** present **status,** feasibility, propagation options, **evaluate genetic risks. Lists five** general **steps** in planning a management program: **goals, objectives,** identity problem, **implement,** and evaluate **actions**
Currens, K.P., et **al.** 1991 A Hierarchical Approach to Conservation **Genetics** and Production of **Anadromous Salmonids** in tbe Columbii River Bain	NOM	None	**Recommends seven principals** for **designing** genetic **resources** reserves: 1) must **address** regional, local human **concerns;** 2) hierarchy of **reserves must** parallel the hierarchy of **genetic organizations;** 3) maintain demographic atability; 4) identify and protect **habitats corresponding** to life history; 5) protect and **restore** historical complexity of migratory **patterns;** 6) **harvest** management **must** protect genetic **reserves; 7) management goals** and objectives must clearly define **risks.** Presents **a** schematic of the implementation **steps**

Table A.1 (cont'd).

REPORTS (See Literature Cited)	DEFINITION OF SUPPLEMRNTATION	CLASSIFICATION OF PROJECT DIVERSITY	PLANNING RECOMMENDATIONS
Columbia Basin Fish and Wildlife Authority 1991 Integrated System Plan. Chapter C Supplementation	The stocking of fish into the natural habitat to increase the abundance of naturally producing fish populations. Adjuncts to tbir definition included in the report are: [supplementation] is oriented toward maintaining natural biological characteristics of the population and reliance on rearing capabilities of the natural habitat. The report giver three uses of supplementation: seed barren habitat, provide survival advantage to depressed stocks, and speed rebuilding to carrying capacity	No formal classification but life cycle analysis of a supplemented population, supplementation technology and guidelines (Table 57) could be used as a basis for classification	Gives planning guidelines or recommendations for several aspects of supplementation: Life cycle analysis of limiting factors, prerequisites for supplementation (sufficient habitat, suitable stock and appropriate technology), level of technology, hatchery practices, genetic risks and stock status
Smith, E., B. Miller, J. Rodgers, and M. Buckman 1985 Outplanting Anadromous Salmonids: A Literature Survey	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. The authors referred to this activity as out-planting, however, it appears to be close to the concept of supplementation	The literature review did not classify individual projects but summarized the information from different projects under the categories: density, survival, genetics, competition and carrying capacity models	The report goes through several planning steps in the design of a supplementation project for the Willamette River. The planning steps used by the authors were: 1) estimate adult returns and reproductive success, 2) identify underseeded streams and reservoirs 3) set criteria for selecting hatchery stocks, 4) evaluate the use of an ● ttificial spawning channel, 5) evaluate harvest benefits, 6) describe design of evaluation, 7) sensitivity analysis, 8) describe sampling methods and budget
Scientific Review Group 1990 Review of Fisheries Supplementation in the Context of Activities Related to the Columbia River Basin Fish and Wildlife Plan	The report does not offer a formal definition but recognizes the need for a clear definition using specific terminology. Development of useful objectives and evaluation prioritiea arc hampered by lack of clear definition of supplementation	Does not review specific projects but suggests that supplementation objectives could include: restoration, intmduction, tearing augmentation, and habitat augmentation	The report recommended the following steps when developing a supplementation project: 1) clearly state hypotheses and objectives, 2) specify performance measures, 3) establish baseline knowledge of target stock, 4) use treatment and control streams to determine changes, 5) analyze seasonal habitat conditions, utilization, and carrying capacity
Riggs, L. 1990 Principals for Genetic Conservation and Production Quality	None. The report focuses on genetic conservation with reference to all management activities (harvest, passage, habitat and production) although hatcheries are given emphasis	None. The report doer list management opportunities which is a general form of classification of the stream/stock subject to management action. The opportunities are stated here as objectives: 1) conserve native populations, 2) facilitate natural population productivity, 3) maintain natural stock identity and productivity, 4) impmve hatchery stock naturalization, 5) increase hatchery stock productivity, and 6) introduce and test a new stock	The report describes seven steps in implementation to ensure production quality: 1) assess existing stock or population status, 2) identify production alternatives, 3) assess genetic impacts, 4) develop operational plans, 5) conduct monitoring and evaluation, 6) identify important research needs, and 7) facilitate information transfer

Table A.2. **Information contained in recent reports relevant to supplementation: Performance Standards, Identification of Genetic Risks, and Behavioral Risk**

REPORT (See Literature Cited)	PERFORMANCE STANDARDS	IDENTIFICATION OF GENETIC RISKS	IDENTIFICATION OF PHYSIOLOGICAL/BEHAVIORAL RISKS
Miller	Performance standards against which projects were evaluated were not clearly stated. For example, no genetic or natural production standards, although they did recognize genetic risks	Recognized general concept. Listed three ways to reduce genetic risks: 1) use some wild fish in brood stock, 2) stock in a way that mimics natural, and 3) limit density	Acknowledged presence and recommend research in this area
Kapuscinski	Does not explicitly state performance standards, but are inferred in the text especially conclusion section. For example, error on the side of caution, maintain life history patterns, maxirnii effective population size	Identified four genetic risks: 1) extinction, 2) loss of within-population diversity, 3) loss of between-population diversity (identity), 4) domestication divided into brood selection and differences in hatchery and natural environment that result in selection. Environmental components of traits negatively altered by the hatchery could increase genetic risks. Lists hatchery activity and genetic process involved in the four genetic risks	Recognized the impact of environmentally modified traits that could hamper survival, and inflict genetic risks. Hatchery fish should be qualitatively similar to wild
Currens	Monitoring and evaluation and, by implication, performance standards should be based on a program's specific objectives. Performance standards are implied in the text	Lists genetic risks associated with artificial production as: 1) loss of genetic diversity due to founder effects, genetic drift and hybridization, 2) selection of traits disadvantageous in nature, 3) removal of stimulus for habitat protection, 4) implementing programs with no definable end point, 5) financial uncertainty, 6) changing social values	None

Table A.2 (cont'd).

REPORT (See Literature Cited)	PERFORMANCE STANDARDS	IDENTIFICATION OF GENETIC RISKS	IDENTIFICATION OF PHYSIOLOGICAL & BEHAVIORAL RISKS
Columbia Basin Fish and Wildlife Authority	**Performance standards should be identified for each objective. Some possible performance** standards are indicated indirectly throughout the report (see spawning protocols for example). No specific list of performance standards	**Recognizes four genetic risks: extirpation, loss of genetic variability** between and within populations and genetic risks of other activities such as habitat degradation. The report gives **detailed** descriptions of each risk	**Indirectly through general rearing and release guidelines**
Smith	**Adult returns in treatment streams compared to control streams appeared to be the measure of success of outplanting**	**The report reviewed selected literature on genetic interactions between wild and hatchery fish**	**None**
Scientific Review **Group**	Recognized the need to develop **perfor**mance measures consistent with objectives	Recognizes the need to **detect** and measure **genetic** change and recommends focusing attention on life history characteristics	None
Riggs	No specific performance measures	The entire report addresses genetic risks. However, it identifies three specific risks: 1) extinction, 2) loss of within-population genetic diversity, and 3) loss of **between**-population diversity	None

Table A.3. Information contained in recent reports relevant to supplementation: Research and Recommendations

REPORT (See Literature Cited)	RECOMMENDED RESEARCH/MONITORING	RECOMMENDATIONS
Miller	**Recommend R&D and monitoring listed specific research areas**	GENERAL • Annual review of supplementation projects • Identify (mark) hatchery salmon • Factors related to survival need study R & D • Identify limiting factors for wild production • Impact of hatchery smolts on wild production & migration • Develop broodstock compatible with wild fish • Identify natural production parameters for supplementation stock • Explore use of streamside egg boxes
Kapuscinski	Favored the use of adaptive management. Other R&D identified: 1) causes of population decline, 2) population status, 3) proper mixes of hatchery and wild in the hatchery broodstock and natural spawning, 4) role of genetics and environment in life history, 5) several hatchery studies. Risks due to selection and environmentally altered fish. Rearing release and marking strategies, genetic risk of increased variance in family size. No overall global design	Supplementation should only be used with the goal of maintaining genetic resources as first priority. Gives detailed recommendations on choice of donor population (need to maintain similar genetic resources, life history patterns and nature of originating environments). Gives priorities for selecting target populations. Mating methods - life history, effective populations. Hatchery rearing - simulate natural incubation, simulate natural rearing, acclimate hatchery fish, monitor for fitness, resolve uncertainty. Release strategies - reduce stress, match natural age/dynamics, match size/time with natural, stocking densities. Handling returning adults
Currens	Recommend research on: theory of genetic population structure of the Columbia River salmon; develop tools for Population Viability Analysis, describing genetic diversity and addressing polygenetic variation. Also, need tools for describing historic genetic variation, studies of local and regional cultures to design education programs	Identify conservation units and set up genetic reserves

Table A.3 (cont'd).

REPORT **(See Literature Cited)**	**RECOMMENDED RESEARCH & MONITORING**	**RECOMMENDATIONS**
Columbia Basin Fish and Wildlife Authority	**Discusses the importance of research and monitoring and gives seven steps: clearly define objective, identify, and develop experimental** design, collect data, interpret results, make adjustments in program. The report also lists 11 genetic research areas	**The entire report gives recommendations on several aspects of supplementation**
Smith	**Recommended research on outplanting but did not identify general topics**	**Listed recommendations obtained from the literature. The authors' own** recommendations are: 1. In streams managed for wild fish, adding hatchery **fish** to streams to supplement natural production without affecting wild stocks may not be possible. However, these guidelines will improve the chance of success: a) use native or closely related stock, b) keep planting density within stream carrying capacity, c) introduce **fish** using methods that minimize hatchery-wild interactions, d) coordinate introductions of various life stages with existing wild populations, e) operate the hatchery to ensure genetic quality of the fish. 2. In streams managed for hatchery **fish** smolt releases can quickly increase adult abundance
Scientific Review Group	**Does not list specific research priorities but strongly recommends** timely organization of coordinated research on existing projects Stream classification and modelling are recommended as aids to supplementation planning and evaluation	**The report posses the central question regarding supplementation: "Under what** set of conditions will supplementation of natural and wild production with hatchery production add to total production of salmon, **steelhead** or other target fishes over the long term?" Recommends research to answer the question
Riggs	Identifies the need for research but does not list specific research needs	The central recommendation of the report is to modify the Council's production (doubling) goal to include: maintaining the genetic **resources** of salmon and steelhead in native, naturalized and **artificially** propagated populations, with no avoidable and irreversible loss of genetic diversity resulting from management interventions or interactions