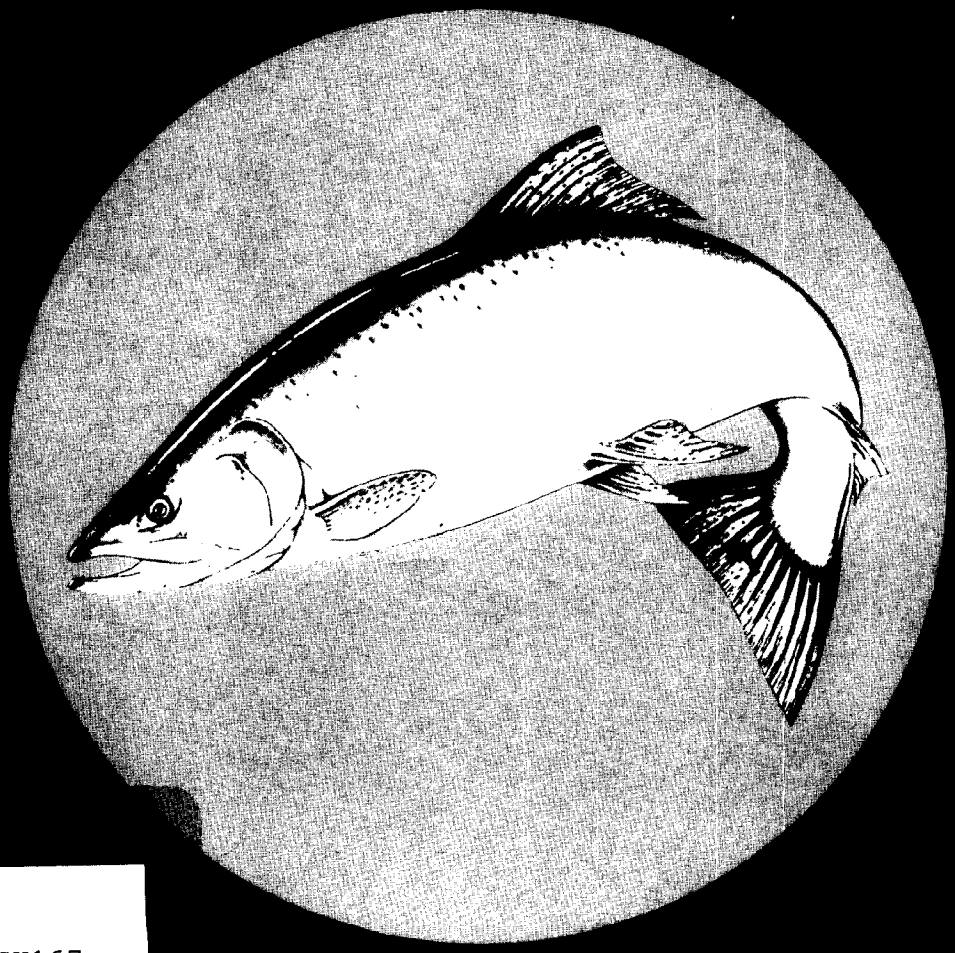
Analysis of Salmon and Steelhead Supplementation

Part 1: Emphasis on Unpublished Reports and Present Programs
Part 2: Synthesis of Published Literature
Part 3: Concepts for a Model to Evaluate Supplementation



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ANALYSIS OF SALMON AND STEELHEAD SUPPLEMENTATION

PART 1: Emphasis on Unpublished Reports and Present Programs

PART 2: Synthesis of Published Literature

PART 3: Concepts for a Model to Evaluate Supplementation

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ANALYSIS OF SALMON AND STEELHEAD SUPPLEMENTATION: EMPHASIS ON UNPUBLISHED REPORTS AND PRESENT PROGRAMS

PART 1

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PREFACE

This report was part of a Bonneville Power Administration (BPA) funded project to summarize information on supplementation of salmon and steelhead, Project No. 88-100. BPA project officer for this contract was Tom Vogel. Primary geographic area of concern was the Northwestern U.S. with special emphasis on the Columbia River Basin.

There were three reports prepared under this BPA project:

1. Analysis of Salmon and Steelhead Supplementation: Emphasis on Unpublished Reports and Present Programs by W.H. Miller, T.C. Coley, H.L. Burge and T.T. Kisanuki.

2. Supplementation of Salmon and Steelhead Stocks With Hatchery Fish: A Synthesis of Published Literature by C.R. Steward and T.C. Bjornn.

3. Concepts for a Model to Evaluate Supplementation of Natural Salmon and Steelhead Stocks With Hatchery Fish by T.C. Bjornn and C.R. Steward.

The two reports by Steward and Bjornn were contracted studies with the Idaho Cooperative Fish and Wildlife Research Unit at the University of Idaho in Moscow, Idaho. The overall objectives of the BPA funded project were: (1) summarize and evaluate past and current supplementation of salmon and steelhead; (2) develop a conceptual "model" of processes affecting the results of supplementation; and (3) make recommendations regarding future supplementation research.

ACKNOWLEDGEMENTS

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ABSTRACT

Supplementation or planting salmon and steelhead into various locations in the Columbia River drainage has occurred for over 100 years. All life stages, from eggs to adults, have been used by fishery managers in attempts to establish, rebuild, or maintain anadromous runs. This report summarizes and evaluates results of past and current supplementation of salmon and steelhead. Conclusions and recommendations are made concerning supplementation.

Hatchery rearing conditions and stocking methods can affect post release survival of hatchery fish. Stress was considered by many biologists to be a key factor in survival of stocked anadromous fish. Smolts were the most common life stage released and size of smolts correlated positively with survival. Success of hatchery stockings of eggs and pre-smolts was found to be better if they are put into productive, underseeded habitats. Stocking time, method, species stocked, and environmental conditions of the receiving waters, including other fish species present, are factors to consider in supplementation programs.

The unpublished supplementation literature was reviewed primarily by the authors of this report. Direct contact was made in person or by telephone and data compiled on a computer database. Areas covered included Oregon, Washington, Idaho, Alaska, California, British Columbia, and the New England states working with Atlantic salmon. Over 300 projects were reviewed and entered into a computer database. The database information is contained in Appendix A of this report.

Our conclusions based on the published literature and the unpublished projects reviewed are as follows:

- Examples of success at rebuilding self-sustaining anadromous fish runs with hatchery fish are scarce. We reviewed 316 projects in the unpublished and ongoing work. Only 25 were successful for supplementing natural existing runs, although many were successful at returning adult fish.
- Successes from outplanting hatchery fish were primarily in harvest augmentation, a term we use to describe stocking where the primary purpose is to return adults for sport, tribal or commercial harvest.
- Adverse impacts to wild stocks have been shown or postulated for about every type of hatchery fish introduction where the intent was to rebuild runs.
- Reestablishing runs or introductions to areas not inhabited by wild/natural populations have shown good successes.
- The stock of fish is an important factor to consider when supplementing. The closer the hatchery stock is genetically to the natural stock, the higher the chances for success.

-Chinook are one of the most difficult salmon species to supplement. A return rate, smolt or pre-smolt-to-adult, of 3-5 percent is considered good by most managers for this species.
-Salmon species with the shortest freshwater life cycle, e.g., chum and pink, have shown higher success from supplementation, than longer freshwater cycle salmon.
-Short-run stocks of salmon and steelhead have responded more positively to supplementation than longer-run stocks.
-Wild/natural fish have consistently shown a much higher smolt-to-adult survival rate than hatchery fish.
-Overstocking of hatchery fish may be a significant problem in many supplementation projects.
-The use of wild broodstock by British Columbia has shown success in their chinook and steelhead supplementation programs.
-Both Alaska and British Columbia are having some success using streamside incubation boxes and subsequent outplanting of fry.

Overall, we concluded that protection and nurturing of wild/natural runs needs to be a top management priority. There are no guarantees that hatchery supplementation can replace or consistently augment natural production. For the Columbia River system, we concluded that all hatchery fish should be marked for visual identification. This will not only permit a more precise harvest management, but also better broodstock management and supplementation evaluation. Currently only hatchery steelhead are marked to identify hatchery fish.

We recommended that supplementation efforts in the Northwest be annually summarized. There are several supplementation projects where future information will be of great benefit. All investigators are encouraged to evaluate the supplementation projects they are conducting and write up formal reports. We found a heavy bias toward not reporting negative or unsuccessful results.

INTRODUCTION

We summarized and evaluated supplementation of salmon and steelhead with special reference to the Pacific Northwest. In some cases projects were reviewed where natural runs had been extirpated and were being reestablished or where runs were being established in areas upstream of barriers. In Alaska, the term "enhancement" is used when referring to supplementation. However, the Alaska enhancement includes many fish stocking scenarios which are for increasing commercial harvest opportunities and do not address supplementing natural runs. We have termed this type of hatchery production as "harvest augmentation." Harvest augmentation occurs in many other areas including the Columbia River.

The following definitions are used in this report:

Supplementation - Planting all life stages of hatchery fish to enhance wild/natural stocks of anadromous salmonids.

Restoration - Planting hatchery products and/or improving habitat to reestablish extirpated runs or runs that are critically low in numbers.

Enhancement - A general term that describes many stocking and habitat improvement scenarios used to improve fish runs. Enhancement can include supplementation, colonization, restoration and harvest augmentation.

Colonization - Describes establishing anadromous salmonids in areas where historically the species was not endemic.

Harvest augmentation - The stocking of anadromous fish where the primary purpose is to return adults for sport, tribal or commercial harvest.

Rebuilding - Planting hatchery products to augment natural runs of salmon and steelhead. In this report used synonymously with supplementation.

Hatchery stock - Having been hatched and partially reared in a hatchery or other artificial production facility.

Wild stock - Naturally reproducing stocks of fish that have not been supplemented or augmented with hatchery fish.

Natural stock - Naturally reproducing stocks of fish that have been at one time supplemented with hatchery fish.

METHODS

The following key species are included in this report: steelhead *(Oncorhynchus mykiss)*, chinook salmon *(O. tshawytscha)*, coho salmon *(O. kisutch)*, sockeye salmon *(O. nerka)*, pink salmon *(O. gorbuscha)*, chum salmon *(O. keta)*, cutthroat trout *(O. clarki)* and Atlantic salmon *(Salmo salar)*. Of the above species, we emphasized review of work on steelhead and chinook salmon. These two species were identified as priority species for supplementation research work in the proposed Five-Year Work Plan (Supplementation Technical Work Group, 1988).

We reviewed current supplementation efforts and unpublished literature by making contact with fishery biologists throughout the study area. Agency projects and annual reports were reviewed where available. Data were recorded on a standardized form and then entered into a computerized database. Appendix A contains specific information on the individual supplementation projects we reviewed. Although we attempted to contact all the key workers involved with supplementation in the study area, we undoubtedly overlooked some individuals. In addition to project reports, research and management biologists were interviewed to determine their opinions on how to have successful supplementation.

STUDY AREA

We emphasized the Pacific Northwest in our review of the unpublished literature and ongoing supplementation work. We included work being done in Oregon, Washington, Idaho, California, Alaska, and British Columbia. Some limited information is also included from the Eastern U.S. on Atlantic salmon.

GENERAL OVERVIEW

Anadromous salmonids have been artificially propagated in the Pacific Northwest for over 100 years. Fishery managers have used hatchery production to maintain fisheries and to rebuild runs. The question for the Columbia River Basin is "How can hatchery production be used to rebuild depleted natural runs of salmon and steelhead in this large altered river system and maintain the genetic integrity of the various stocks and races of fish?"

During the past 20-30 years, salmon and steelhead hatchery propagation in the Columbia River has dramatically increased. Raymond (1988) estimated that beginning in 1970 new hatcheries were then doubling the number of smolts in the Snake River. While, in the mid-Columbia River, this doubling number was attained by 1975. Thus, after 1975 the majority of salmon and steelhead entering the Columbia River, from the Snake and Mid-Columbia, are of hatchery origin. For the Snake River Basin 80 to 90 percent of

steelhead and 90+ percent of the chinook salmon smolts passing Lower Granite Dam in recent years, (1988 and 1989), are of hatchery origin.[1] Also, during the past 20-30 years wild/natural escapement has declined.

The Columbia River Fish and Wildlife Plan of 1987 established the goal of doubling the salmon and steelhead runs from 2.5 million to 5 million. A cornerstone of this program is to fully utilize available habitat to increase wild/natural production. Although we have been producing hatchery fish for many years in the Columbia River Basin, there are still many unanswered questions concerning the use of hatchery fish for supplementation. The 1987 Columbia River Basin Fish and Wildlife Program, Section, 700 (h), recognizes this problem and stated, "Bonneville shall fund research to determine the best methods of supplementing naturally spawning stocks with hatchery fish, particularly in the upper main stem Snake and Columbia rivers." This analysis of supplementation was undertaken to assist in directing which areas of research needs to be prioritized for supplementation in the upper Columbia River. Priority species are upriver chinook salmon and steelhead. The Snake River is the drainage of highest priority.

RESULTS

General

Our review points out the importance of a potential genetic impact from supplementation with hatchery fish. The concern expressed in the published literature review (Steward and Bjornn 1990) and from interviews, indicate that hatchery fish introduction could adversely impact the natural stock.

Researchers are attempting to document any genetic impacts of supplementation. Procedures which are being used to minimize adverse genetic impacts include:

1. Using a proportion of the adults in the wild or natural run as broodstock.

2. Stocking practices should mirror the natural environment, i.e., size, timing, stocking density, and donor stock.

3. Limit the density of stocked fish to prevent displacement or competition with wild/natural fish.

There are different perceptions to which supplementation procedures work. The adequacy of supplementation procedures vary regionally. Alaska hatcheries produce and

[1]Larry Basham, Fish Passage Center, Portland, Oregon, pers. comm., March, 1989.

supplement with smolts, where appropriate. The Columbia Basin states are considering supplementing more with sub-smolts -- fry and fingerling. This can be explained to some extent by the intent of supplementation. In the Columbia River Basin, much of the supplementation effort is intended to enhance wild/natural runs. The emphasis in Alaska is to produce more adults for "harvest augmentation" while protecting wild stocks. In Alaska, they are trying to separate hatchery introductions from wild populations by time of return and release locations. Columbia Basin supplementation managers are trying to match hatchery production with the environmental constraints of wild/natural populations.

We included 316 projects in our review of the unpublished and ongoing supplementation (Appendix A). Of this number, 26 were supplementation, as defined on page 1. Twenty-five of the 26 supplementation projects we reviewed were considered successful by the principal investigator. Eighteen of the 26 projects were quantitatively evaluated. Of the 18, 14 are ongoing and four are supplementation evaluation studies. We found no evaluated projects that had rebuilt wild/natural runs to self-sustaining levels.

Oregon

Background

Oregon waters support natural populations of chinook, coho, sockeye, chum salmon, steelhead and cutthroat trout. Anadromous waters encompass 50 river and lake systems in coastal systems or tributaries flowing into the Columbia River (Anon. 1982a). There is a small run of introduced sockeye in the Willamette River and a small run of natural chum in Tillamook Bay.

Artificial production of anadromous fish began in 1877 on the Clackamas and Rogue Rivers (Anon. 1982a). There are currently 34 state fish hatcheries and 3 or 4 private anadromous hatcheries ("ocean ranchers") operating in the state. The State hatcheries produced a total of 75 million fish in release year 1988 (Table 1).

Table 1. Oregon's 1988 State hatchery releases of anadromous salmonids (excluding STEP).

Summer Steelhead	Winter Steelhead	Coho	Spring Chinook	Fall Chinook
3,906,110	3,186,256	12,674,018	11,743,330	43,395,333*

*Primarily Columbia River releases.

Oregon has recently taken a major (bold) fishery management step with the adoption of its natural production and wild fish management policy. Oregon's policy states that the maintenance of wild stocks is a biological necessity to insure the future abundance of both naturally and artificially produced runs (Anon. 1990a). Biologists believe that, despite past stocking practices, distinct stocks of wild indigenous fish are still viable. Their managers also state that prior to 1960, the majority of hatchery fish released did not live to reproduce. These failures primarily resulted from improper stocking practices, i.e., time and size at release, poor quality fish and/or stocking fish poorly adapted for the environment (Anon. 1982a).

We reviewed 51 projects in Oregon; only 2 were considered supplementation, both were successful.

Steelhead

Endemic runs of summer and winter races of steelhead occur in Oregon. Winter steelhead are primarily coastal, whereas the summer steelhead range encompasses coastal as well as interior streams.

Release size for Oregon steelhead smolts is 5-6 fish/lb (60-90 g; 200-215 mm). Oregon managers note that larger smolts produce greater adult returns. However, it was also noted that larger smolts stray at increased rates.

Hatchery philosophy in Oregon over much time (1890-1960) centered around releases of unfed fry and pre-smolts. These hatchery fish were usually superimposed on healthy stocks of natural fish in good habitat with ineffective or counterproductive results (Smith 1987). Smith (1987) also noted that outplanting unfed fry and short-fed pre-smolts probably presents the highest potential for interference with indigenous fish.

Oregon biologists are currently experimenting with sterilization of summer steelhead in the Willamette Subbasin to prevent interaction of hatchery summer steelhead with wild winter steelhead juveniles. The hatchery summers provide a sport fishery while the wild winter run rebuilds.[1]

Coho

Coho salmon in Oregon occur primarily in coastal streams and in the Columbia River (lower river tributaries). Based on historical catch records, one can easily deduce that the Columbia River once produced at least as many coho as Oregon coastal streams.

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[1]Ken Kenaston, Oregon Department of Fish and Wildlife, Corvallis, Oregon, pers. comm., April, 1990.

Oregon's hatchery releases have increased from 7.5 million in 1960 to 12 million in 1988 (excluding private releases). Coho production occurs at 18 public and 4 private hatcheries. Most natural production now occurs in coastal streams. Wild stocks comprised approximately 46 percent of the ocean harvest in 1969. They comprised only 25 percent for the period 1977-80 (Anon. 1982b). Coho produced in Oregon contributes to a number of commercial and sport fisheries.

The Oregon coho hatchery program was enlarged in the 1960s, which generated much optimism. In the late 60s, adult coho fluctuations became prevalent between years. In 1977, coho abundance dropped to the lowest level since 1962. This downward trend in adult production occurred in spite of increased hatchery production. The theories of why coho production went the opposite of predictions are numerous. After 30 years of intensive artificial production, enhancement projects have been unable to equal the historic level of natural production.

There is currently a downward trend in adult escapements of wild and hatchery stocks in a time of increasing hatchery smolt releases. Because of this, ODFW has taken actions to determine the mechanisms responsible for mortality. ODFW addressed these concerns by designing seven management objectives in their coho management plan (Anon. 1982b). Several of these include supplementation strategies. Oregon's new directive is to supplement natural runs with indigenous broodstock as per wild fish policy and to explore methods to improve hatchery fish.

Oregon recently determined that they can significantly increase densities of juvenile coho at the end of the summer rearing period in most streams. However, releases of hatchery pre-smolts has reduced the density of wild juvenile coho by 40-50 percent (Solazzi et al. 1983). Stocking hatchery pre-smolts produced a net loss for adult returns (Nickelson 1981). The results showed that hatchery pre-smolts should only be stocked in habitat that is greatly underseeded.

Release size for coho vary between 35-38 g (12-13 fish /lb) for hatcheries with survival rates less than two percent. When survival is greater than two percent Oregon managers recommend releasing 23-25 g (23-25 fish/lb) fish. Size at release becomes less critical in years with high ocean upwelling (Johnson 1982).

Chinook

Fall - The fall chinook salmon of coastal Oregon are healthy and populations are as high or higher than at anytime in the last century. The landings during 1986, 1987, and 1988 have never been higher during the 70 years that they have been activity fished in the ocean (Nicholas and Hankin 1989). The complexities of natural processes make it impossible to state for sure how this happened. However, one sure statement is that hatchery programs were not responsible. The vast majority of coastal rivers are presently supporting wild chinook populations at levels equal to anything in the past century

(Nicholas and Hankin 1989). Oregon biologists believe that the credit belongs to the natural healing, in the past three decades, in many lower main stem rivers and estuaries. The recovery of coastal chinook salmon has occurred with little or no "tweaking" from agencies. The famous Elk River study concluded that wild and hatchery systems were only weakly compatible. These data were collected over 20 years from a hatchery that was meticulously managed to mirror the wild run. This study makes the point, "hatchery and natural production systems could coexist if hatchery management practices take extraordinary care not to reduce the productive capacity of the ecosystem" (Nicholas and Downey 1989). Based on the results of the study, we conclude that coastal chinook salmon stocks are healthy and productive because they have productive habitat and have not been affected by hatcheries.

Spring - Oregon's spring chinook management primarily focuses on releases of smolts. Outplanting oversize smolts has generated excessive returns of subjacks and increased straying (Smith 1987).

The Willamette River historically produced the major portion of the run in the Columbia Basin. Dam construction and years of habitat degradation has reduced the wild run contribution to a small percentage of the spring chinook salmon return. Approximately 95 percent of the adult return are from hatchery releases. Evaluation of the status of wild stocks of spring chinook salmon in the Willamette Subbasin has not been completed.

Spring chinook salmon supplementation evaluation programs statewide are inconclusive. However, smolt (180-190 mm) releases have produced the most successful adult returns.

STEP

Oregon's Salmon Trout Enhancement Program (STEP) recruits the services of volunteer citizens to assist with habitat improvement projects, population and spawning surveys, and streamside hatch boxes. The STEP program began in 1982 and in 1988-89 the hatch box segment released a total of 2.6 million salmonid fry (Table 2).

Table 2. Total salmonid fry released in 1988-89 Oregon STEP program.

Spring Chinook	Fall Chinook	Coho	Winter Steelhead	Chum	Cutthroat
168,023	571,372	1,035,223	686,653	23,612	113,076

This program involves individuals and conservation groups throughout the state; however, coastal streams provide the major production.

Prior to STEP, Oregon biologists could not document substantial adult return from fry releases. While STEP evaluations are incomplete and difficult to document, the adult contributions are disappointing at best.

Summary

Oregon placed much emphasis on coho enhancement in the 1960s and 70s with little success. While coho was in the limelight, coastal fall chinook received little or no enhancement attention. However, coastal fall chinook rebounded to near historic levels when left to fend for themselves. Protection and healing of mainstream rivers and estuaries probably deserve most of the credit. The fact that healthy populations of fall chinook reestablished themselves when provided adequate habitat deserves a closer look by supplementation proponents.

The STEP citizen volunteer program focuses primarily on fry releases. Early evaluations have shown disappointing adult returns.

Biologists have documented that larger smolts result in greater numbers of returning adults. Also, they have documented that hatchery fish can adversely affect wild stocks.

Since there is a preponderance of evidence on the inadequacies of rebuilding runs with hatchery fish, Oregon recently established a new natural production and wild fish management plan. It is too early for the results of this program to be obvious. However, using indigenous wild/natural broodstock for hatchery programs certainly must be evaluated.

Washington

Background

Anadromous fish runs in Washington include chinook, chum, coho, sockeye, pink salmon, steelhead, and cutthroat trout. Systems that support anadromous runs include tributaries to the Columbia River, coastal systems, and Puget Sound.

Artificial production of anadromous salmonids in Washington is conducted by state, federal and tribal hatcheries. Over 340 million fish were released in Washington in 1987, (Table 3).

We reviewed 129 projects in Washington; 3 were considered true supplementation, only 1 of these was evaluated.

Table 3. Numbers of anadromous salmonids released in Washington in 1987.

Winter Steelhead	Summer Steelhead	Fall Chinook	Spring Chinook	Coho	Chum
1,803,646	3,349,917	139,359,630	17,896,634	88,363,656	90,171,973

Steelhead

The Washington Department of Wildlife (WDW) manages the steelhead runs in Washington. The WDW raises smolts almost exclusively and more than 6 million are released annually. This stocking effort is mainly to increase harvestable numbers, not to rebuild natural or wild runs. The operational procedures of WDW hatcheries have created a separation between the run timing of hatchery produced winter steelhead and naturally produced winter steelhead. They are presently managed as separate runs. The early run consists primarily of domesticated hatchery stocks and the later run primarily wild stock.

While wild steelhead broodstock are not normally used in WDW hatchery programs, some winter steelhead programs do utilize wild/natural fish. Some examples include ongoing programs on the Wynoochee and Skookumchuck Rivers (tributaries to the Chehalis system), the Nooksack River in northeastern Puget Sound and the Soleduck River on the north coast. Recently, wild/natural broodstock have also been used on the Humptulips, Satsop and Sauk Rivers. These programs have been a mixture of true supplementation and harvest augmentation. Unfortunately, the supplementation programs were not rigorously evaluated. The contribution of the hatchery supplementation to the overall return and especially to the spawning escapement was not determined. In areas where wild stock was not incorporated, the intent was to separate wild and hatchery fish.

Escapement data for wild summer steelhead is less detailed although the Toutle, Wind and Wenatchee systems have shown favorable responses.

Many WDW biologists believe that wild winter stocks are responding favorably to the current management practices. In the Kalama River, 58 percent of the total winter steelhead run consists of wild fish. The Elwha River, which is completely blocked by the Elwha Dam at River mile 5.3, averages only 14 percent wild fish in the total run.

Since 1984 marked hatchery fish are stocked in areas where the wild run is known or strongly suspected (where definitive data are unavailable) to be underescaped. In these areas fishing regulations require the release of all unmarked fish.[1]

There is mixing of wild and hatchery stocks and WDW estimates that 44 percent of the wild summer steelhead returning to the Kalama River are the direct offspring of naturally spawning hatchery fish. The WDW has also found that in the Kalama River, wild summer steelhead appear to be 8.6 times as effective as hatchery fish in producing adult returnees (Leider et al. 1989).

Survival rates for hatchery winter steelhead range from 16.9 percent for the 1984 brood year in the Quillayute River to 0.21 percent for 1980 brood year in Cook Creek, tributary to the Quinault River. An average return rate for hatchery winter steelhead is 5.3 percent (based on data on smolt return rates for nine western Washington rivers).

Salmon

The Washington Department of Fisheries (WDF) manages most of the salmon runs in Washington. State salmon programs are developing guidelines that will give the supplementation programs management direction. These guidelines will allow WDF to document, plan, coordinate, and evaluate ongoing and future activities. They are currently attempting a more focused evaluation on drainages managed as natural; i.e., Gray Harbor, Queets, Quillayute, Skagit, Snohomish, and Stillaguamish Rivers.

Hatchery management programs are conducted by the state in South Puget Sound drainages. Most of these drainages are supplemented to meet higher salmon harvest rates, maximize seeding and realize hatchery goals. These programs are primarily operational with little or no evaluation. Harvest augmentation is a management goal in many of these programs.

Within Washington, off station releases accounted for 22 percent of all releases by state and federal hatcheries in 1985 and 1986 (Anon. 1987a). This amounted to more than 154 million salmon, 60 percent coho, 26 percent chum, 13 percent fall chinook, and 0.4 percent spring chinook.

In some instances where the chinook runs have declined they are utilizing hatchery fish in an effort to rebuild runs.

Wild broodstock programs have been attempted with chinook and coho. WDF had problems with wild broodstock in hatchery production situations. Wild coho broodstock

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[1]James Nielsen, Washington Department of Wildlife, Olympia, Washington, pers. comm., August, 1990.

had low fry-to-smolt survival. The Stillaguamish River summer chinook program is currently set up to incorporate wild broodstock. The program is also shifting from fry plantings to smolt plantings with higher survival rates.

Chinook - The majority of supplementation work on chinook in Washington is being conducted by Indian tribes; outplanting approximately 9,000,000 juvenile chinook annually. The main purpose of this outplanting is to enhance or establish a fishery. Most of the fish are stocked as fingerlings (>7,000,000), with survival rates for fingerling-to-adult ranging from slightly less than 1.0 percent to 0.1 percent. Outplanted smolts have slightly higher survival rates, estimated at around 1.0 percent (Appendix A). The Yakima Enhancement Study documented survival for wild chinook smolts-to-adults at 4.4 percent in 1983, compared to only 0.05 percent for hatchery releases. Trapped outmigrating smolts had a higher survival rate for those fish that were acclimated and volitional released. However, the survival to adults was the same as those not acclimated (Fast et al. 1988).

Summer chinook salmon are managed primarily for natural production in the Wenatchee, Methow, Okanogan, and Similkameen Rivers.

One negative aspect of supplementation recently described was the "pied piper" effect of planting hatchery fish on wild fish. Hillman and Mullan (1989) found that hatchery releases of age-0 spring chinook salmon in the Wenatchee River "caused" 38 to 78 percent of wild chinook and 15 to 45 percent of wild age-0 steelhead to join hatchery migrants unless wild fish could not see them. This early migration of wild age-0 salmon and steelhead was considered a loss to production.

Chum - Most chum supplementation efforts in Washington are concentrated in South Puget Sound and its small drainages. Like chinook, a number of Indian tribes are conducting supplementation work to enhance or provide a fishery. Review of the database (Appendix A) revealed that within Washington over 20,000,000 chum fry are outplanted annually with 0.07 to 1.0 percent return to hatchery.

Coho - Coho fry are widely stocked in many small streams in Washington with no separation or differentiation made between hatchery and wild fish. Over 92,000,000 juveniles were outplanted, in 1985 and 1986 combined, to augment harvest with little or no evaluation. Releases of 395,800 yearlings to the Nisqually River has realized a 10-14 percent return to the fishery (Appendix A). Fry outplants in the Chehalis Basin are estimated to be 0.05 to 0.09 percent to catch as adults, depending upon stock.[2]

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[2]Rick Brix, Washington Department of Fisheries, Montesano, Washington, pers. comm., April, 1990.

The WDF collected wild broodstock for rebuilding coho runs on the Quillayute, Hoh and Queets River System. They have estimated that cost per spawned female averaged $330. Juvenile fish are reared to fry, then restocked into systems that are below full seeding levels. The limited data indicates low survival from fry planting to smolt emigration. This method produced a net loss of smolt production, compared to allowing the adults to spawn naturally (Anon. 1987a).

WDF has outplanted yearling coho in Grays Harbor and Willapa Bay. This was used to reduce hatchery surplus and improve wild production. However, releases of yearlings were not cost effective and was discontinued.

Summary

Supplementation projects may detrimentally impact other anadromous and resident salmonids. A coho enhancement project in Puget Sound was at least circumstantially linked to a major decline (50 percent) in the pink salmon run in a nearby river. This evidence is substantiated by statistics that show the rest of Puget Sound pink runs increased by 38 percent for the same period (Ames 1980).

Steelhead management in Washington has benefitted from the marking of hatchery produced fish. This immediate sight identification of hatchery and wild fish allows implementation of selective fishery regulations needed to protect underescaped wild runs. Further separation of hatchery and wild fish is realized by a difference in run timing. Temporal separation allows managers to collect hatchery broodstock and limit spawning interaction between wild and hatchery fish. Return timing is also useful in commercial harvest management. Hatchery fish can be fished at a high rate without adversely impacting wild runs.

Idaho

Background

Idaho stocks of anadromous fish are in a very depressed state. Restoration more accurately describes Idaho's efforts, which focus primarily on chinook salmon and steelhead. Historically, Idaho supported runs of steelhead, sockeye and coho salmon as well as three races of chinook salmon; spring, summer and fall. Hydroelectric dams, habitat degradation, and overfishing have contributed to the decline of Idaho's anadromous fish run. Coho salmon no longer enter Idaho and can be considered extirpated from the state. The last coho to pass Lower Granite Dam was a single adult in 1986, and only two fish passed in 1985. Sockeye salmon are now being considered by the National Marine Fisheries Service for endangered or threatened species designation in the upper Snake River. In 1989, only two adult sockeye salmon passed Lower Granite Dam. Thus, sockeye may also be extinct in Idaho. Fall chinook salmon are not being

actively managed in Idaho. The Snake River, from below Hells Canyon Dam downstream to the confluence of the Clearwater River, is the only area where there are still significant numbers of fall chinook in Idaho. The Washington Department of Fisheries, who share management responsibilities on this section of the Snake River, started a monitoring program on fall chinook for this river section.

Idaho is primarily managing three groups of anadromous fishes; summer steelhead, summer chinook salmon, and spring chinook salmon. Steelhead and spring chinook salmon receive most of the management emphasis. In 1989, over 23 million hatchery fish were released above Lower Granite Dam on the Snake River. Most of these hatchery fish originated from production facilities located in Idaho. Some came from Oregon's Grande Ronde and Imnaha River systems. Of the 23+ million, 9.6 million were spring chinook and 9.9 million were steelhead -- the 2 major hatchery species reared in the state.

We reviewed 10 projects in Idaho; 2 were considered true supplementation, neither of them was evaluated.

Steelhead

The potential Snake River steelhead run, based on run strength from 1954-1967, was estimated for the Lower Snake River Compensation Plan (LSRCP) as 114,800 (Herrig 1990). In 1988, 99,714 steelhead were counted over Ice Harbor Dam. Although this number is approaching the LSRCP goal, it is estimated that 70-80 percent of the steelhead run returning to the Snake River are hatchery fish.[1]

Adult returns to the Snake River above Lower Granite in the past three years (1986-1989) have demonstrated a greater survival of wild fish over hatchery fish. Data for steelhead indicate that 20 to 34 percent of the adult fish crossing over Lower Granite Dam are wild. These returns are from an estimated 10 to 18 percent wild smolts passing Lower Granite Dam (Koski et al. 1990). This indicates as much as a two-fold survival advantage of wild/natural steelhead smolts above Lower Granite Dam.

Idaho Fish and Game's Anadromous Fish Plan (Anon. 1985) established goals of returning steelhead and salmon. Steelhead adult returns indicate that the state is nearing their goal of a smolt-to-adult survival of 2 percent for wild/natural and 1 percent for hatchery fish. However, the total number of wild/natural fish returning to Idaho is considered well below carrying capacity of the available habitat.

Idaho is in a very large hatchery program. Most of the stocking and outplanting has been done with smolts. Most smolts have been released at hatchery racks and have been

[1]Larry Basham, Fish Passage Center, Portland, Oregon, pers. comm., April, 1990.

used for mitigation, harvest augmentation, and broodstock development. Supplementation of wild/natural runs has recently been receiving more emphasis. In recent years, hatchery fish have been outplanted into streams. This program was usually the result of extra hatchery production. Evaluations are underway on some of these programs, including the South Fork of the Salmon and South Fork of the Clearwater Rivers. Evaluation entail late summer fry and yearling snorkel counts primarily.

The Pahsimeroi River was one of the earliest locations where steelhead were outplanted. This program introduced runs from the mid-Snake River to this tributary on the Salmon River. Introducing the mid-Snake River run was made necessary by the construction of three dams in the Hells Canyon section of the Snake River. These dams provide no fish passage. Returning adult steelhead are collected at the Pahsimeroi trap, but all natural fish and some hatchery fish (to total one-third of run) are released upstream for natural spawning. Adipose fin clips permit separation of hatchery fish and wild/natural fish. All hatchery steelhead are adipose fin clipped in Idaho. The Pahsimeroi River project releases approximately 900,000 smolts annually with an estimated adult return to Idaho of 1.18 percent.[2] Hatchery fish make up approximately 93 percent of the sportsman catch on the Salmon River.[3] Sport fishery regulations require that all wild/natural steelhead (those with an adipose fin) be returned to the river.

Chinook

Spring - Historically the Snake River system produced most of the spring chinook salmon in the Columbia River Basin (Fulton 1968). Today this run is only a remnant of what used to occur. The LSRCP spring-summer adult goals for the Snake River were established using the 1954-1967 counts at Ice Harbor Dam. The highest count was used as the potential production for the Snake River. For spring-summer chinook salmon, the potential run was estimated at 122,200 adults (Herrig 1990). In 1988, the spring chinook salmon returning upstream of Ice Harbor Dam, the first dam in the Snake River, totaled 34,394 (Anon. 1989a). It was estimated that up to 80 percent of these spring chinook were hatchery fish.

With very limited data, estimates were made that less than 10 percent of the chinook salmon smolts passing Lower Granite Dam are wild.[4] Data on the separation of wild/natural from hatchery fish are being collected at upriver dams on the Snake River.

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[2]Kent Ball, Idaho Department of Fish and Game, Salmon, Idaho, pers. comm., January, 1990.

[3]ibid.

[4]Basham, p. 13.

For spring chinook, the survival of wild fish may be as much as three or fourfold greater than hatchery fish. For instance, the Idaho Department of Fish and Game has estimated wild spring chinook smolt survival to adult in Marsh Creek at 1.2 percent back to Idaho with good flows at Lower Granite Dam. Rapid River Hatchery spring chinook salmon on the other hand recorded smolt-to-adult survival of 0.3 percent with good flows at the dam.[5] Hatchery returns of 0.3 percent on good flow years and 0.03 on low water years indicates that adequate flows are necessary to enhance upriver stocks.

Within the last few years, a number of satellite fish rearing stations have been established in the Clearwater and Salmon River drainages (both tributaries of the Snake River). These satellite stations are used for trapping adults and also for partial rearing of juveniles. Satellite stations are programmed to augment the wild/natural runs present in some of the tributaries. Evaluations on the effectiveness of the satellite stations in Idaho have not been determined, primarily because of the relative newness on the program. However, escapement data and snorkeling counts of yearly fish are being documented.

Summer - Supplementation of both spring and summer chinook salmon is a relatively new program in Idaho. Summer chinook salmon are supplemented primarily on the South Fork of the Salmon River. McCall Hatchery, which started releasing summer chinook smolts to the South Fork in 1980, has produced significant numbers of smolts. The goal of that facility is 1 million smolts per year. During 1988 and 1989 1,060,400 and 975,000 summer chinook smolts were released into the South Fork from McCall Fish Hatchery. The program in the South Fork entails a weir on the stream where the adults are trapped and eggs are taken. One-third of the fish are taken for hatchery production and the other two-thirds are passed upstream for natural production. Return rates from coded-wire tagged summer chinook salmon released at McCall Fish Hatchery indicate a smolt-to-adult survival of 0.80 percent for brood year (BY) 1981, 0.44 percent for BY 1982, and 0.46 percent for BY 1983 (Herrig 1990).

Idaho Department of Fish and Game removed natural barriers to allow passage of adult chinook salmon to Johnson Creek, a tributary to the East Fork of the Salmon River. Summer chinook fry were outplanted annually from 1986 to 1989. In the fall of 1889, 15 chinook redds were counted above the removed barriers. Stocking of Johnson Creek is planned to be continued until natural spawning of adults seed the area adequately.

Summary

Idaho is working to rebuild runs of summer steelhead, spring and summer chinook salmon in the Snake River Basin. Some streams are designated wild streams where no

[5]Charlie Petrosky, Idaho Department of Fish and Game, Boise, Idaho, pers. comm., February, 1990.

hatchery fish are planted. These are the Middle Fork of Salmon, South Fork of Salmon, and Selway Rivers. Outplanting is also restricted in other areas. The marking of all hatchery steelhead has aided Idaho managers in evaluating hatchery programs and in documenting the status of wild steelhead. Steelhead smolt-to-adult survival goals of 1 percent for hatchery fish and 2 percent for wild fish are being achieved. However, the numbers of wild fish are less than needed for natural habitat seeding.

Spring chinook salmon runs (hatchery and wild stocks) are very depressed in Idaho. Hatchery supplementation, to date, has not succeeded in rebuilding natural runs. Managers are not getting close to their goal of returning 0.8 percent for hatchery fish. Right now most hatchery fish returns are nearer 0.2 percent or only 25 percent of the goal.

California

Background

Anadromous salmonids native to California are chinook, coho, sockeye, pink, chum salmon, steelhead, and cutthroat trout. Historically, chinook salmon and steelhead runs were widespread and abundant throughout the state. Habitat degradation, dam construction, water developments, watershed alteration, and overfishing contributed to the decline of salmonids throughout the state.

Hatcheries were built to mitigate for these losses and are operated by the California Department of Fish and Game (CDFG) and U.S. Fish & Wildlife Service (FWS). Eggs were obtained from various California and out-of-state sources to reestablish or supplement dwindling stocks. The mixing of non-endemic stocks throughout California have likely altered the composition of distinct gene pools. Despite this, hatchery production efforts have either maintained or increased spawner escapements in many waters. Anadromous fish stocking in California is in a restoration phase. They are also in a harvest augmentation phase to provide fish for commercial, sport, and tribal harvest.

During the past two decades, private groups have become involved in habitat restoration projects. Private propagation programs have expanded, particularly in affected areas where state involvement was minimal or lacking.

The federal and state management agencies, and private groups have all focused on the importance of restoring fall chinook salmon and winter steelhead. These two species are receiving the highest attention in both habitat rehabilitation and supplementation efforts. In coastal areas where coho runs prevailed historically, interest has increased in reestablishing these stocks. The distributions and abundance of sockeye, pink, and chum salmon are so limited that propagation efforts for these species has not been practical.

Government and private efforts are attempting to rebuild salmonid runs through stock management, supplementation, and habitat rehabilitation programs. Although efforts are ongoing to restore wild spawning populations, the major emphasis is the production of hatchery fish for harvest augmentation. With this emphasis, the rebuilding of wild stocks may be limited to some coastal waters and a few subbasin streams within California's major river systems.

The role of supplementation may become more crucial in California if wild runs of chinook salmon, coho salmon, and steelhead continue their statewide declining trends.

We reviewed 75 projects in California; 6 were considered true supplementation, only 3 were evaluated.

Steelhead

Steelhead are widely distributed throughout California. The majority of California's stocks from the larger river systems (Sacramento, Klamath/Trinity) are augmented or sustained by hatchery operations. Within these basins and in other coastal streams, numerous waters have remnant or depressed runs of wild winter steelhead. The winter run is the dominant form in California. The Middle Fork of Eel River has the only native run of summer steelhead in the state. This native stock is not supplemented. A Washougal River (Washington) stock of summer steelhead was introduced into the Mad River and has been established as a small naturally spawning run. In some years these adult fish enter the Mad River Hatchery and are propagated independently from winter steelhead.

Steelhead propagation ranks second to the chinook salmon for all anadromous salmonid releases. The CDFG and FWS are the main producers of steelhead. The Indian tribes do not propagate steelhead.

Coleman National Fish Hatchery (NFH) raises about one million winter steelhead annually. These fish are released as yearlings on-site and off-site (downstream or estuarine). Contribution rates for on-site releases ranged from 0.10 percent to 0.25 percent, and 0.10 percent to 0.50 percent for off-site releases.[1] The Forest Service operates two spawning channels, Kelsey and Indian Creek. Although intended primarily for fall chinook salmon, these channels are also utilized by steelhead and coho salmon.

Except for the Merced River Fish Facility, winter steelhead are raised in every CDFG anadromous hatchery. The estimated annual production is about 4.5 million from these facilities. The steelhead are released as yearling smolts. Release strategies vary by

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[1]Gene Forbes, U.S. Fish and Wildlife Service, Anderson, California, pers. comm., March, 1990.

facility and also in response to the continuing drought. In wet years, in the Sacramento River system steelhead are trucked to the San Francisco Bay estuary. The on-site steelhead releases from Mokelumne River Fish Hatchery also serve as put-and-take fishery, while the off-site releases are trucked to Rio Vista (delta area) or the estuary. Reliable return rates to the Sacramento River Basin hatcheries were not available. However, based on results achieved with chinook salmon, off-site (downstream or estuarine) releases are assumed to yield higher ocean and inland returns.

Private programs (includes county and local projects) produced 338,089 steelhead in 1989. The largest programs were (average annual production): Rowdy Creek Fish Hatchery, 75,000; the Mendocino County Fish & Game Commission, 70,000; Monterey Bay Salmon and Trout Project, 45,000; and Gualala River Steelhead Project, 30,000.

Chinook

Winter chinook salmon are known only to the upper Sacramento River and this race is a federally listed threatened species. Coleman NFH represents the only entity propagating winter chinook. Only one adult pair was spawned at Coleman in 1989.[2]

Spring chinook salmon are native in the Klamath and Sacramento River Basins and are represented by hatchery and wild stocks. The status of the wild stocks are not well-known and may be tenuous. The South Fork Trinity River spring chinook salmon abundance has declined and this geographical stock may become a candidate for state listing as a threatened species.

Fall chinook salmon are the dominant anadromous salmonid in California. The CDFG and FWS are the largest producers of fall chinook salmon, annually releasing approximately 30 million and 16 million juveniles, respectively. The U.S. Forest Service, U.S. Bureau of Indian Affairs, various Indian tribes, and private groups also propagate fall chinook salmon. Private groups produce over 1 million fall chinook annually (Table 4).

Federal and state hatcheries commonly truck their releases, particularly in the Sacramento River system. Trucking reduces fish loss at numerous water pumping stations and diversions. Sacramento River fish are usually trucked to San Francisco Bay or the river delta. Another outplanting technique used to enhance survival is to divide release groups and plant into adjacent drainages or different locations within the same drainage. Outplanted and trucked release chinook groups have exhibited higher survival than those released on-site. Private programs have also experienced higher ocean contribution rates and inland return success from yearling-sized releases rather than fingerling releases.

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[2]ibid.

Table 4. Estimated releases of anadromous salmonids from private California projects (permit and contract categories) during 1989.

	Fall Chinook	Coho	Winter Steelhead	Cutthroat
Rearing				
Independent production	186,350	77,225	76,310	500
Eggs from CDFG	163,000	-	13,999	-
Ocean Pen-rearing	51,082	-	-	-
Natal stocks				
Yearlings	246,189	188,956	247,780	14,000
Smolts	479,712	-	-	-
TOTALS	**1,126,333**	**266,181**	**338,089**	**14,500**

Natal stocks releases are progeny of broodstock taken from natural populations.

A late fall chinook population occurs in the upper Sacramento River and is propagated at Coleman NFH. This late fall population may be declining in abundance.

Coho

Coho salmon utilize coastal streams for spawning. They are native to the Russian, Klamath, and Eel Rivers, and other coastal streams. In contrast to the known historical status and distribution, the present wild populations are remnant. The status of some stocks are uncertain.

Coho are propagated by CDFG and private groups. Federal agencies and Indian Nations are not propagating coho salmon in California. In recent years, CDFG has annually released about 1 million coho yearlings into state waters. The CDFG operates the Noyo River Egg Collection Station on the South Fork Noyo River. Eggs taken from this station have been used to supplement or reestablish coho runs to other coastal waters.

Prairie Creek Fish Hatchery (PCFH) releases about 100,000 coho annually and represents the largest level of production from a non-CDFG agency. Recent adult return rates to PCFH for coho salmon was 3 percent.[3] The city of Arcata rears coho salmon and steelhead in a wastewater marsh aquaculture project. The yearlings are then

[3]Steve Sanders, Humboldt County, Orick, California, pers. comm., February, 1990.

released into a stream adjacent to the marsh. Coho releases average 5,000 annually and adult returns range from about 0.1 percent to 0.3 percent.[4]

The 1989 coho salmon production from private projects (including county and local programs) contributed 266,181 yearlings to California waters. The Humboldt Fish Action Council (HFAC), and the Monterey Bay Salmon and Steelhead Project are the two largest private coho producers, releasing about 25,000, and 23,000 yearlings annually, respectively. The HFAC's coho releases contributed an estimated 0.2 percent to the 1989 ocean fishery, the inland recovery rate was also 0.2 percent.[5]

Coastal Cutthroat Trout

The coastal cutthroat trout occurs in coastal waters from the Eel River drainage and northward. The present range may be identical to the known historical distribution. However, while their abundance has declined considerably, existing populations are believed to be stable. There are about 120 streams with cutthroat, comprising about 700 miles of habitat (Gerstung 1981). Although cutthroat trout are not as popular as other anadromous species, increasing harvest pressure on the other species may elevate the importance of cutthroat as a sport fish.

The Fisheries Department of Humboldt State University (HSU) has begun propagating anadromous coastal cutthroat to enhance sport fishing in local Humboldt County lagoons. The first release of 14,000 juveniles is scheduled for the spring of 1990. They are reared at the HSU hatchery then trucked to release sites. Humboldt County and HSU are the only entities propagating coastal cutthroat in California. About 500 cutthroat trout are released annually by Humboldt County. These cutthroat are released as yearlings and will hopefully contribute to the local inland sport fisheries.

Summary

There is considerable interest in supplementation, especially among private groups. Consensus among private groups expressed a need for additional programs, to rehabilitate waters which formerly produced salmonids. They also voiced the need to work together with the state to meet common objectives. The majority of the state personnel interviewed were in agreement with the private faction.

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[4]David Hull, City of Arcata, Dept. of Public Works, Arcata, California, pers. comm., February, 1990.

[5]Jud Ellinwood, Humboldt Fish Action Council, Eureka, California, pers. comm., March, 1990.

One concern that was apparent among virtually all groups contacted was the issue of inter-basin transfers of salmonid stocks. Although most people were aware of the biological implications, some felt that inter-basin transfers were necessary to attain their goals. Others expressed a need to end all inter-basin transfers of all life stages. Although CDFG has a formal policy against inter-basin transfer of stocks, this supplementation review indicated that the practice is common and widespread. The CDFG has transferred stocks for restoration purposes to establish and maintain runs. Some private programs have received both endemic and non-endemic eggs from CDFG, particularly in waters with depressed or extirpated stocks.

The state's intent has been to supplement and expand dwindling or geographically extinct wild stocks. However, a formally organized statewide active program to increase wild stocks (through supplementation) was not apparent from the state personnel interviewed. Maintaining high production levels is the driving force within the hatchery management system. Many personnel from all sectors expressed concern about the proper levels (density) of stocking. Additionally, various measures to promote the survival and return of hatchery stocks (such as trucking juveniles downstream) have been successful. However, there is little done to aid natural production.

Although private projects are also motivated to maximizing their production, they have not deviated from their grass-roots objectives of rebuilding local remnant stocks. The private projects are limited by economics; the materials, personnel, technology, and funding necessary to define the capability and nature of these projects. California's private sector has the potential to increase present levels of supplementation with additional funding.

Guidelines among public agencies and private groups on the biologically appropriate levels of production and supplementation are lacking. This problem needs to be addressed to promote an organized and scientifically sound approach to rebuilding salmonid stocks.

Alaska

Background

Alaska has two entities doing enhancement of salmon and steelhead, private non-profit (PNP) hatcheries and the Alaska Department of Fish and Game, Fisheries Rehabilitation Enhancement and Development (FRED) Division hatcheries. PNP hatchery programs provide a structure for fishermen to be involved with the commercial fisheries programs. The PNP hatcheries are supported by Regional Aquaculture Associations and produce fish for commercial harvest. There are seven regional aquaculture associations in Alaska. The PNP rear pink, chum, coho, chinook and sockeye salmon at their hatcheries. In 1988, PNP hatcheries took more than 1 billion

eggs and released 819 million fry and smolts (Holland 1989). Most releases were pink and chum salmon fry, approximately 626 million pink fry and 186 million chum fry. In 1988, there were 22 PNP hatcheries in Alaska. The Regional Aquaculture Associations are supported by a tax on the commercial salmon harvest (landing fee). They also market excess fish returning to the PNP hatcheries.

Alaska's FRED Division focuses on the development of new enhancement technology, hatchery production, technical services, permitting, and habitat restoration and rehabilitation. The PNP hatchery program is administered by FRED under a permitting system.

The FRED system operates 16 hatcheries and several ancillary hatchery facilities. In 1988, FRED hatcheries released 412.6 million fry and smolts of which 407 million were salmon and steelhead (Holland 1989). Of the total release (1989) 320 million were pink and chum salmon (Table 5).

Most of PNP hatcheries produce pink and chum salmon with some sockeye, coho, and chinook. Plans are moving forward to produce more sockeye smolts at some PNP and FRED operated facilities.

Table 5. Releases of fry and smolts, salmon and steelhead, from Public Non-profit (PNP) and Alaska Department of Fish and Game, FRED Division hatcheries, 1988. (Holland 1989).

PNP Hatcheries		FRED Division Hatcheries	
Species	Number (x1,000)	Species	Number (x1,000)
Chum	186,050	Chum	106,531
Pink	625,820	Pink	213,580
Sockeye	1,000	Sockeye	68,142
Coho	4,720	Coho	14,441
Chinook	2,210	Chinook	4,115
		Steelhead	271
TOTAL	**819,800**	**TOTAL**	**407,080**

Biologists are attempting to rebuild or supplement some wild/natural runs of salmon and steelhead. However, most of the hatchery effort is to increase runs for harvest augmentation. Fish are released directly from the hatchery or introduced to areas where the adults can be harvested while wild stocks are managed for escapement. Efforts are underway to introduce salmon to unutilized production areas where barriers or other factors have restricted access to fish. New programs will examine means to bring fish

back to areas just for a specific type of harvest - sport, commercial or subsistence. Fry, fingerling, and smolts are released directly into ocean bays, small streams, lakes or rivers to key adults back to a terminal fishery.

Alaska's hatchery program is rated quite successful because it is providing more stability in the commercial fisheries program. In 1987, roughly 25 percent of the total statewide salmon harvest was from salmon produced by public programs (FRED & PNP). In 1988, this figure was 24 percent (Hartman et al. 1988). To separate wild from hatchery stocks in a mixed stock fishery, many hatchery fish are marked with coded-wire tags (CWT). In some fisheries, hatchery fish are separated by timing into a fishery area and by location of return. Overall, fisheries management in Alaska is directed primarily for wild fish escapement with hatchery releases directed for harvest augmentation.[1]

We reviewed 24 projects in Alaska; 2 were considered true supplementation, both were evaluated.

Steelhead

Very little steelhead supplementation has occurred in Alaska. No specific evaluation information was found.

Chinook

Hatchery chinook salmon programs have not been as successful as some of the other hatchery programs in Alaska. When comparing adult returns with the Columbia River system, Alaska does as well or better. Chinook salmon adult returns in the 2-4 percent range from smolt plants have been common (Dudiak and Boyle 1988). Alaska biologists expect to get 3 percent or better adult returns for smolt releases of chinook, coho, and sockeye salmon. Programs to build fisheries in selected areas for chinook salmon harvest has worked quite well in Alaska. Chinook salmon smolt releases in Prince William Sound return in the 4-5 percent range.[2]

Alaskan biologists use indigenous broodstock almost exclusively for supplementation. Fry, fingerling and smolts have been outplanted to natural areas. In the Kasilof River, biologists have stocked chinook salmon smolts into areas with wild stock and noted no impacts on wild stocks. They did note that survival of hatchery fish was about one-half of what they thought it should be (Kyle and Litchfield 1989).

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[1]Keith Pratt, FRED Divisions, Alaska Department of Fish and Game, Anchorage, Alaska, pers. comm., February, 1990.

[2]Bruce Suzumota, Prince William Sound Aquaculture Association, pers. comm., February, 1990.

Managers in Alaska are doing some lake rearing of chinook with fish from the Gulkana Hatchery, a Copper River stock. Fed fry are taken out by plane and planted into lakes in the upper Copper River. This pilot study has just started so no data on survival is available at this time.

Sockeye

Sockeye salmon are the premier commercial fish with outstanding market value. Therefore, production has increased in PNP and FRED hatcheries. Early hatchery programs suffered from chronic losses to IHN disease; however, techniques for managing around IHN have now been improved. Also, techniques of both lake fertilization and lake production modelling have progressed so managers can strive for maximum production from rearing waters.

Sockeye salmon in Alaska are planted into barren lakes or lakes with adult barriers and to supplement existing stocks. Lakes are usually only a few miles from salt water. A program of lake fertilization is done following a liminological study to identify needed fertilizers. Again, natural broodstock are used where possible. Excellent adult returns have been realized with smolt releases. Adult returns as high as 35 percent were documented at Big Lake. Biologists are expanding sockeye smolt releases because of the phenomenal successes.

Following are survival rates of various stocking techniques:

> Sockeye stockings of unfed fry into lakes; expecting a greater than 1 percent survival in the Gulkana River area. Sockeye stocked in Summit Lake of the Gulkana drainage as unfed fry have returned at 0.8 percent as adults.[3]
>
> Some sockeye smolt stocking into Big Lake have adult returns at a rate as high as 35 percent.
>
> Planting eyed eggs in upper Thumb River, a tributary of Karluk Lake, has increased adult returns to Karluk Lake and spawners to upper Thumb River. Eyed egg survival to fry is reported as exceeding survivals commonly obtained from natural spawners (White 1986).
>
> Fingerling sockeye released into Hidden Lake built up the production for the lake. It was believed spawning area was the limiting factor. Fingerling-to-smolt survival averaged about 20 percent and smolt-to-adult survival averaged around 15 percent (Litchfield and Flagg 1988).

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[3]Ken Roberson, Alaska Department of Fish and Game, Glennallen, Alaska, pers. comm., January, 1990.

Streamside hatching facilities at Gulkana for sockeye and chinook salmon also appear to be working exceptionally well. Groundwater from the stream is directed through large units of Kitoi egg boxes loaded with sockeye and chinook eggs. As fry hatch, they are washed into a trapping and enumeration area and from there outplanted. Fry hatch at a similar time as natural spawned eggs. This is a low technology, low cost method of salmon fry production.

Coho

Coho salmon are stocked into lakes, streams, and net pens for enhancement purposes. Stocking and enhancement procedures in lakes are similar to the sockeye salmon supplementation effort. Some limited success has been achieved with coho lake stocking, but this program is still in the evaluation stage. Also, some coho work is being done with net pens in the inlets and salt water areas. PNP reports of 15 to 20 percent adult survival for some coho salmon smolt releases.[4]

Examples of coho salmon adult returns from hatchery releases follows:

Fingerling-to-adult from Seldovia Lake approximately 1 percent (Dudiak and Boyle 1988).

Fingerling-to-adult from Caribou Lake approximately 2-3 percent (Dudiak and Boyle 1988).

Up to 4 percent return from smolts on Homer spit (Dudiak and Boyle 1988).

In the Yukon River hatchery fingerling produced adult returns of 4.0-8.5 percent and 13.4 percent for wild fish (Raymond 1986).

Smolts released from net pens in Prince William Sound returned at a rate in the 15-20 percent range.[5]

Pink and Chum

Pink and chum salmon are released as fry (fed or unfed) and go directly to the ocean. Releases can occur directly from hatcheries or from other sites where fish migrate directly to the ocean. Some net pens are used with feeding programs and match release of fry with plankton peaks. The key to success is to get fish to the estuary at peak plankton production.

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[4]ibid.

[5]Suzumota, p. 23.

In Tutka Bay, Boyle and Dudiak (1986) recorded survival rates of hatchery released pink salmon fry at 12.5 percent for fed fry and 14.5 percent for unfed fry. Most other releases have shown a higher return for fed fry. Lower rates near 1-3 percent for unfed fry are common for both pink and chum fry releases (Kohler 1984; McDaniel et al. 1984). Feeding fry a few weeks and releasing with plankton peaks contribute to higher survival. Survival as high as 14 percent were seen, with several groups returning at 8 percent.

Summary

Supplementation in Alaska is primarily what we have classified as harvest augmentation. Their management scheme is to manage for wild stock escapement and use supplementation to increase salmon runs for commercial fisheries. In a few cases, natural sockeye stocks have been rebuilt. Most of the impetus for this rebuilding was for harvest.

Separating hatchery stocks from wild stocks has occurred by bringing salmon back to areas where no natural population exist and by separating time of run return.

Ideas that apply to supplementation in the Columbia River Basin include: (a) streamside spawning and incubation units, Kiotoi boxes, and outplanting of fry, (b) lake fertilization and fry planting schemes for sockeye, (c) separating hatchery stocks from wild stocks by place and time of return, and (d) managing for wild stock escapement with hatcheries keyed to harvest augmentation.

British Columbia

Background

British Columbia (BC) probably comes closer to true supplementation than any area in the Northwest. Their Fraser River Basin is similar to our Columbia River Basin. However, BC does not have as many dams and associated fish passage problems. BC's Salmonid Enhancement Program (SEP) began in 1977 to double their salmonid production. SEP's responsibilities are divided between two agencies. The Federal Department of Fisheries and Oceans manages the five species of Pacific salmon. Steelhead and cutthroat trout are managed by the Provincial Ministry of the Environment.

SEP supplements natural production by the most natural means and thereby reduces cost. Currently SEP has a moratorium on new hatchery construction. They concentrate primarily on using existing hatcheries to incubate gametes from indigenous broodstock. They employ streamside upwelling incubation units and groundwater fed side channels to produce rearing habitat. They also utilize spawning channels to extend the amount of spawning area available. These channels are of particular value for sockeye, pink, and

chum salmon. The spawning channels also provide rearing habitat for other species such as chinook and coho salmon.

In the late 1970s, SEP, in its infancy, developed facility targets in a piecemeal fashion. The present system evolved by dividing the geographic regions into management units. Each unit reviewed the individual stocks as to the status, ability to manage and capacity for additional production potential. There are three area planning committees that develop recommendations, the South Coast Division, Fraser River - Yukon Division, and the North Coast Division. When a project shows promise, the management unit outlines the expected economic and social benefits and submits it to the Treasury Board. For allocation of construction and operating dollars, the project has a goal of 1.5:1 benefit/cost ratio (Hurst and Blackman 1988). Each project uses estimated survival rates for each type of enhancement strategy and is sized accordingly.

Federal fisheries biologists have increased productivity of lakes and streams by the application of fertilizers. This technique is used in situations when there are sufficient sockeye salmon spawners and suitable habitat is available. The fertilization promotes increased growth of the basic components of the salmonid food chain. SEP also concentrates on habitat improvements for enhancing salmonid productivity by some basic stream improvements. These improvements may require physical cleanup, placement of boulders, planting of streamside vegetation, flow control, and eliminate possible pollution sources.

We reviewed 18 projects in BC; 9 were considered true supplementation, 8 were evaluated. One of these projects was considered not successful in contributing to natural production.

Steelhead

BC's total steelhead hatchery production for 1989 was only 2.4 million fish. These were planted into 28 systems. Steelhead are released at three life history stages: smolt, parr, and fry. The strategy of the smolt programs is to grow the smolts as large as possible (60-100 g or 190-220 mm), then outplant during late April to late May. The smolt-to-adult survival varied from 1 percent for small smolts to almost 10 percent for 60 g smolts (BC's program released 800,000 smolts in 1987). They determined that they could gain 30-40 percent smolt-to-adult survival by lower river releases, i.e., tide water. They had much lower survival for groups released only 10 km upstream. BC's major limitation in steelhead research is returning adult enumeration.

Parr - BC released 355,000 parr from brood year 1987. They use two strategies for parr releases, both with 15 g fish (30/lb). This program began in 1987 and the return data for the Coquihalla River demonstrated a parr-to-adult survival of 2.6 percent. They expected 3.2 percent parr-to-adult survival. Based on cost comparisons to produce 100

adults BC concluded that if you have the habitat, parr are more cost effective over fry or smolts.

Fry - BC stocks steelhead fry for two primary reasons: colonization - defined as releasing fry above anadromous barriers, and supplementation - stocking fry in underseeded stream reaches.

From the 1987 brood year BC released 1.2 million; 2.0 g fry (200/lb) into 28 systems. A typical release method is by helicopter to enhance dispersal. BC fry stocking began in the early 1980s. Criteria used for survival of fry-to-smolt are largely dependent on: 1. age at smolting, 2. amount of physically suitable habitat for all life history stages, 3. size of fish released, 4. productivity of different streams, (i.e., total alkalinity can very from 4 to 200 mg/l), and 5. presence of competitors or predators. Biologists we interviewed stated that in the early fry programs they overstocked. They used no prescribed stocking formula in these early programs and the results were disappointing. BC biologists went back to streams, developed site specific biostandards for stocking densities, and now release fish at more conservative stocking densities. Now they consider total usable area rather than the older method of total wetted area. They cite many examples of overstocking resulting in decreases in growth performance of both hatchery and wild juveniles. The results from the Coquihalla River are encouraging with fry-to-adult survival ranging from 0.4 to 1.3 percent. Expected survival was estimated at 1.3 percent (Ptolemy 1986). They measured a fourfold increase in standing crop of juveniles following the fry released.

Salmon

In release year 1988, the Department of Fisheries and Oceans (DFO) recorded releases of approximately 530 million pink, chum, coho, sockeye, and chinook salmon (Table 6). DFO biologists use indigenous broodstock to ensure against stocking maladapted fish. They release the progeny from wild fish into the parent watershed after adipose clipping.

Broodstock are spawned (streamside) 1:1 male/female ratio and gametes taken to hatcheries. Biologists verify carrying capacities of life stage to be stocked in terms of usable habitat before outplanting progeny.

Chinook

In 1988, DFO released 63.6 million chinook salmon of various life stages. Production of chinook salmon (stream and ocean types) for stocking is primarily through hatchery operations (federal, provincial, and community economic development programs). These hatcheries do not recycle broodstock. DFO biologists also develop groundwater side channels with upwelling incubation for chinook production. These groundwater channels also provide critical rearing habitat.

Table 6. British Columbia's salmonid production from SEP facilities, 1988 release year.

Species	Juveniles Released	Expected Adults	Canadian Catch
Pink	62,713,919	1,325,423	727,357
Chum	213,391,888	2,535,674	1,163,013
Coho	18,470,120	1,099,881	707,648
Sockeye	171,988,081	2,063,346	812,754
Chinook	63,624,513	895,503	483,376
Cutthroat	238,680	20,584	13,792
Steelhead	2,371,647	45,407	26,944
TOTAL	**532,798,848**	**7,985,818**	**3,934,884**

From SEP 1988-89 update booklet.

Sockeye, Chum, and Pink

Spawning channels, lake fertilization, barrier removal, and habitat improvements are the primary enhancement methods for sockeye, pink, and chum salmon. DFO biologists recently constructed a new spawning channel at Glendale Cove on Knight Inlet that will potentially produce 1 million adult pink salmon annually. Channel production has realized an egg-to-fry survival of 81 percent (Anon. 1989b). The channel addresses natural low flow problems by drawing water through a pipeline from Tom Browne Lake.

Lake fertilization increases production in the enhancement of sockeye, pink, and chum salmon. Fertilization takes the place of the thousands of carcasses from spawned out adults that once fertilized these lakes.

Coho

Biologists from DFO primarily use natural and semi-natural enhancement and secondary hatchery production to supplement coho salmon stocks. We visited a new construction site on the Englishman River (Vancouver Island). The Englishman River utilizes side channel production for the lower river and coho salmon colonization for the inaccessible reaches. Spawning and rearing channels built in 1988 use groundwater and infiltration galleries to provide water flows. In areas not accessible to spawners, coho salmon fry obtained from a nearby hatchery were stocked. For succeeding years, wild stocks from the Englishman River are the preferred donor stocks.

Eight streams that empty into Baynes Sound have been the traditional backbone of the Georgia Strait coho sports fishery. However, commercial fisheries and an aggressive sport fishery targeting on these runs have led to depressed stocks through overfishing. They became the focus of rebuilding in 1988. It became impractical to manage the eight streams separately because of extreme exploitation. Biologists now manage them as one unit with stocks treated as a single gene pool. BC biologists believe the small genetic differences do not justify managing each stream separately. Also, too few fish return to attempt separate stock management for each stream. Thirty pairs of wild adults, collected from the eight streams, provide smolt production. All outplanted smolts are adipose clipped to facilitate wild broodstock collection in subsequent years using this management strategy. Fry are never more than one generation removed from wild stock. The use of wild broodstock each generation in SEP supplementation more than pays for the additional labor. We believe this procedure may be of benefit in the Columbia Basin where possible to implement.

Public Participation

BC provides an opportunity for many citizens to volunteer their time in enhancing salmonids. The SEP sponsors one of the most unique public participation program in North America. This program provides community advisors, stationed throughout the province, to give technical and financial assistance. Individuals, clubs, schools, service organizations, and community groups may apply for this program.

Opportunities for such participation lie in maintaining, restoring, and improving the stream habitat essential to salmonid production. Through public participation, enhancement projects also offer a unique opportunity to develop a greater awareness of the salmonid resource and man's influence on the stream environment.

Summary

In the 13 years since the SEP began, BC biologists have recorded real progress toward meeting their goals of doubling the runs. Their total budget for 1988/89 was approximately $42 million. They de-emphasize recycling hatchery broodstock and placed a moratorium on new hatchery construction. They developed objectives and goals to utilize natural production and semi-natural production in supplementing their stocks.

It would be tempting at this juncture to dismiss SEP's objectives as unrealistic in the Columbia Basin. However, their upper Fraser and Thompson River stocks of steelhead and chinook salmon migrate hundreds of miles inland to spawning grounds. SEP biologists still practice the same sound genetic principles as with coastal stocks. The Whitehorse Rapids Hatchery on the Yukon River continues to collect wild broodstock in view of adult immigrations of 3520 Km (2200 miles). We believe the judicious use of wild broodstock for BC supplementation work has been a positive factor in their successes.

We, in the Columbia Basin, should be envious of their management predicament. Biologists only have to coordinate between two agencies, the Department of Fisheries and Oceans and the Ministry of Environment, to manage supplementation in BC. The provincial government manages steelhead and DFO oversees salmon management. They do not have to run the gauntlet of countless agencies and committees that currently exert management authority in the Columbia Basin. It appears that BC's bureaucracy may be down to fighting weight.

New England

Atlantic Salmon Program

This information was obtained from the New England Atlantic Salmon Program Annual Progress Reports for 1987 and 1988 and the 1989 Annual Report of the U.S. Atlantic Salmon Assessment Committee (Anon. 1987b, 1988, 1990b). Telephone conversations with the various program coordinators also clarified overall direction.

Background

Historically, Atlantic salmon thrived in rivers from Maine to Connecticut, with major runs found in the Connecticut, Merrimack and Penobscot Rivers. By the late 18th Century, the Atlantic salmon was essentially extirpated from these areas due to the Industrial Revolution and overfishing. While the Atlantic salmon was never totally eliminated from all Maine Rivers, their numbers were severely depressed, and by 1872 the federal government began stocking rivers in Maine. During the period 1872-1959, more than 63,340,000 juvenile Atlantic salmon were released into drainages throughout Maine.

Today's program receives much of its direction from the Atlantic Sea-Run Salmon Commission, which was formed in 1947. The overall goal of the program is to restore a self-sustaining population of Atlantic salmon by the year 2021. The Atlantic Salmon Program is divided into four major programs involving state and federal agencies, private industry and conservation organizations. Collectively, about 5.5 million juvenile Atlantic salmon were released into 15 New England rivers in 1989. The Maine program received 36 percent of the releases, 34 percent went to the Connecticut River program, 23 percent to the Merrimack River program and 7 percent to the Pawcatuck River program. The stocking summary for 1989 is shown in Table 7. From 1980 through 1988, almost 27 million juvenile salmon had been stocked into New England rivers. Almost 50 percent of the fish released were fry and about 25 percent were age-1 smolts. During this same 9-year-period, 33,486 adult Atlantic salmon have returned to 16 rivers in New England.

Of these returns, 80 percent has been to the Penobscot River in Maine. Ten percent of the returns to the Penobscot River are from natural production.[1]

Table 7. Atlantic salmon stocking summary by program in 1989.

Program	Fry	0+Parr	1Parr	1Smolt	2Smolt	Total
Maine						
USA	580,000	430,500	282,200	524,300	80,200	1,897,200
Canada	66,000	-	-	-	10,300	76,300
Merrimack River	1,033,000	60,000	88,600	58,200	-	1,239,800
Pawcatuck River	-	379,900	35,900	6,400	-	422,200
Connecticut River	1,242,000	272,900	116,300	221,000	-	1,852,200
TOTAL	**2,921,000**	**1,143,300**	**523,000**	**809,900**	**90,500**	**5,487,700**

Atlantic salmon cannot be harvested in the Connecticut or Pawcatuck Rivers. Fishing is allowed in parts of the Merrimack watershed. However, there were no reported catches in 1989. Total catch of Atlantic salmon in Maine was reported at 1,007 fish in 1989, 520 of those were released. The Penobscot River produced 86 percent of the total catch. An exploitation rate of 10 percent was set to help accelerate the restoration of the Penobscot salmon run.

In Maine, the Dennys, E. Machias, Machias, and Narraguagus Rivers are designated "wild" but still receive releases of fry, parr, and smolts. In 1989, they were supplemented with 270,800 juvenile salmon. Returns to these rivers are believed to be mostly of wild origin, primarily from natural reproduction, with very few originating from fry releases. In New England "wild" generally refers not only to fish produced naturally, but also to fish produced from fry stockings.

While all of the programs receive various life stages of Atlantic salmon, each of the four programs has a different emphasis. The Maine program is mainly a smolt stocking program while the Merrimack River receives mainly fry. The Connecticut River program

[1]Jerry Marancik, U.S. Fish and Wildlife Service, Orland, Maine, pers. comm., February, 1990.

receives a combination of fry and smolts and the Pawcatuck River has a parr stocking program.

We reviewed nine projects in the New England states; two were considered true supplementation, both were evaluated.

Fry Stocking

Restoration in the Merrimack River relies mainly on fry that are scatter planted into nearly all suitable rearing habitat. Roughly 250 miles of stream are presently included in the program. In 1989 and 1988, over 1.0 million and 1.7 million fry respectively were released in the river basin. The fry stocking goal for the Merrimack River Basin is 1.8 million.

The majority of returning salmon are trapped and held to be used for spawning. Domesticated captive broodstock and reconditioned kelts are also used to obtain the number of eggs desired for the program. All fry stocked into Merrimack drainages in 1987 were of Merrimack River origin.

Fry are stocked at 20 to 50 fry per 100 square meter unit depending on the quality of habitat, etc. Seven index sites are then monitored for growth and survival, condition factors and water quality.

Since 1982, roughly 40 percent of the adult returns to the Merrimack River have originated from the fry stocking program. Seventy-four percent of these fry emigrate as two-year-old smolts. The contribution of the fry program was 66 percent of returns in 1988 and 67 percent in 1989. It should be noted that total fish for 1988 and 1989 was 65 and 84, respectively. These are the first and second lowest full-season totals since salmon returns to the river were first documented in 1982. The range of adult returns to the Merrimack for 1983 to 1987 is 103 to 214 with a mean of 137. Total return through 1989 numbers 860. The adult return rate for 1984 fry plants surviving to 1+ parr was estimated at 0.04 percent. Total return fry-to-adult was 0.005 percent for 1984 releases. Of the adults returning to the Merrimack, 78 percent return as 2-sea-winters, 18 percent as 1-sea-winters and 4 percent as 3-sea-winters.

The Connecticut River program utilizes fry releases in its restoration efforts with a stocking goal of 2.0 million fry. In 1989 and 1988, over 1.2 million and 1.3 million fry, respectively, were released in the river basin. Minta et al. (1987) found the survival of "wild" smolts (smolts produced from fry releases)-to-adults was nearly 10 times greater than hatchery smolt-to-adult return rates for a Connecticut River tributary in 1984. These "wild" fish comprised 36 percent of the total run. Y. Cote, a Quebec biologist, found that flow for 30 to 40 days after stocking is a critical factor in fry survival.

Parr Stocking

While Atlantic salmon parr are stocked in a number of locations in New England, they are mostly incidental by-products that are graded out of one year smolt programs. The Pawcatuck River program in Rhode Island is an exception in that parr are stocked almost exclusively. The Pawcatuck program is unique in a number of other ways also. The watershed is near the southern extent of the range of Atlantic salmon; therefore, it is not a typical cold water river, as found farther north. Furthermore, predator species, abundant in this drainage, exact a heavy loss on salmon fry. The Pawcatuck program is also the smallest of the four Atlantic salmon programs, hence the smallest budget. For these reasons, the program has decided that parr stockings are the most cost effective method of developing their salmon program.[2] Further problems have developed from the parental source of these parr. The program currently uses only domesticated captive broodstock (fish that have never gone to sea) as their egg source. There is evidence that this strain is inferior to sea run parents (Gibson 1989); thus producing poor return rates in the progeny. Return rates for the program range from 0.0 percent to 0.009 percent with a mean of 0.003 percent. Releases in 1989 numbered over 400,000 parr, which is the largest number of fish stocked into this system since the program began in 1979.

Smolt Stocking

The smolt program is the most successful of the various programs. The Penobscot River in Maine received over 416,000 smolts in 1989 (47 percent of the smolts released). Overall adult returns to the Penobscot have ranged from 0.23 percent to 1.32 percent with a mean of 0.71 percent. In 1989, 2719 fish returned to traps in the Penobscot, 813 were 1-sea-winter fish, 1,864 were 2-sea-winter fish, 4 were 3-sea-winter fish, and 38 were previous spawners. The Maine stocking program utilizes returning salmon and domesticated captive broodstock for egg takes. Additionally, returning adults not needed for egg takes are released to spawn naturally. In 1988, this amounted to 2,141 out of 2,688 fish trapped in the Penobscot River.

The long-term objectives for the Penobscot River are:

1. Achieve an annual production of 185,000 wild smolts.
2. Ensure a minimum of 6,000 adults will be available for spawning annually.
3. Provide a minimum of 2,000 adult salmon for sport harvest annually.

The Connecticut River program also utilizes smolts in its restoration effort with 10 to 32 percent of total releases being smolts. This program released 221,000 and 395,300 smolts in 1989 and 1988, respectively. The smolt stocking goal for the Connecticut program is

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[2]Mark Gibson, Rhode Island Division of Fish and Wildlife, W. Kingston, Rhode Island, pers. comm., March, 1990.

590,000. Smolt-to-adult return rates for hatchery smolts released in the Connecticut River Basin ranges from 0.006 to 0.159 percent depending upon year and location.

Smolts in Connecticut are generally stocked from hatchery trucks via "quick release" hoses or netted off trucks directly into ponds. In 1989, one lot of coded-wire tagged smolts (22,500 fish) was placed into a 15-by-15 meter net pen in the lower Connecticut River. The net pen was towed two kilometers into Long Island Sound where the smolts were released. The primary purpose of this project is to compare return rates of salmon that were not subjected to river related mortality. Data on the success of this technique will not be available for a few years.

Tagged Atlantic salmon smolts and parr are used to help determine the contribution of the New England Atlantic salmon programs to the ocean harvest. Tagging also allows sight identification and a method to ascertain the contribution of various life stages to the run.

Summary

While adult return rates are generally low for the Atlantic salmon program, it should be remembered that the program is a restoration effort because of degraded river systems. Furthermore, the program does not base its success in terms of adult returns, but on what is learned and the directions then taken. While the progress is slow, it is continuing to move forward. Wild fry or smolts were found to survive to adults at a much higher rate than hatchery smolts.

The reuse of kelts for egg taking was a new procedure we have not considered for steelhead in the Columbia Basin.

River flow at time of fry release seemed to be a factor to consider in the success of fry plants.

Broodstock that has never gone to the ocean produced inferior results when compared to sea run broodstock. Again, the genetics of the broodstock should be a factor when implementing supplementation programs.

Releases of smolts returned more adults than releases of other life stages in the Atlantic salmon program. The average smolt-to-adult return rate for the Penobscot River is 0.71 percent. However, the ability to establish self-sustaining runs is still being evaluated for all the programs.

CONCLUSIONS

Supplementation has provided positive results in the following:

a) BC is having success with chinook, coho, and steelhead by using only wild broodstock and scatter planting the hatchery produced fish through the supplemented area.
b) BC also concluded that in some instances parr stocking of steelhead was more cost effective than either fry or smolts.
c) Alaska and BC are having success using streamside incubation boxes with stream water diverted through boxes. Fry are scatter planted and spot planted from these stream incubator systems.

However, when we consider the overall anadromous fish programs we reviewed, examples of successes at rebuilding self-sustaining fish runs with hatchery fish are scarce. The successes we recorded in the unpublished literature were mainly in harvest augmentation, not rebuilding runs.

In an earlier review of supplementation, Beck (1987) makes it clear that the supplementation strategies most often used are not necessarily related to success. Most supplementation projects we reviewed were poorly evaluated and documented, especially projects that were failures. Many well meaning evaluations remain in file cabinets as raw data. Smith et al. (1985) certainly did a commendable literature review (published and gray). We concur with his conclusions and cannot shed much new light on supplementation. We turned over scores of gray literature stones without finding any significant new evidence that supplementation can consistently enhance natural populations.

A few studies we reviewed demonstrated adverse impacts to wild/natural stocks from hatchery stocking. However, when hatchery fish were released into virgin areas; barren lakes, above falls or barriers, in new geographic areas, directly into estuaries or coves, they performed quite well. In these cases, managers usually were not attempting to build a self-perpetuating run, but merely producing adult fish for augmenting harvest. When managers attempt to introduce hatchery fish on top of an existing population to build or rebuild the run to "historic" levels of production or to "full seeding" levels of production, problems seem to develop. The hatchery fish do not perform as well as the wild/natural fish and adverse impacts to the wild/natural stocks have been indicated and demonstrated (Reisenbichler and McIntyre 1977; Chilcote et al. 1986).

Based on our review of the data and from recent interviews, we believe that hatchery production needs to be divided into two distinct categories. These would be: (1) hatchery production for "harvest augmentation," and (2) supplementation which is "natural production augmentation." We believe this separation does in fact now exist but that success has mainly been in number (1), production for harvest augmentation.

Time, effort, and knowledge needed to accomplish harvest augmentation is much less than that needed for natural production supplementation. In order to supplement natural production, managers need to know several factors. They need to know the ecology of the area, the factors limiting present production, the unique qualities of the stock of fish to be supplemented, and the most efficient means for supplementation. The time frames for determining success stretches into multiple life cycles for natural production supplementation while for harvest augmentation we can determine success in one generation.

Fishery agencies have been stocking anadromous fish for many years in the Pacific Northwest. There have been reports of increasing adult returns from various types of planting strategies. Outplantings of smolts return the highest percentage of adults for both salmon and steelhead. However, there are mixed results on the ability to rebuild or increase natural runs by supplementing with hatchery fish. A few examples suggest that it is possible to supplement natural runs with hatchery fish without adverse effects. For instance - in Oregon, the Elk River run of fall chinook has been supplemented for approximately 20 years. Although no major adverse effects have been noted from this highly controlled supplementation program, the natural run of fall chinook did not significantly increase either. Managers believed the Elk River wild run was at carrying capacity prior to supplementation.

In Idaho, plants of steelhead fry in some upper Salmon River drainages is believed to have contributed to the building up of natural spawning fish in a few of the drainages. Streams with no apparent spawning were planted with excess fry and in subsequent years spawning adults were noted. No numerical information is available for these observations, and straying can not be ruled out. In BC, Coquihalla River biologists, supplementing with hatchery fry, have documented steelhead fry-to-adult survival as high as 1.3 percent and parr-to-adult survival of 2.6 percent for hatchery fish. After releasing hatchery fry, a fourfold increase in standing crop of the stream was noted. Long range build-up of natural production was not shown because of the continuous annual stocking programs. In New England, work with Atlantic salmon demonstrates how difficult it is to rebuild and reestablish anadromous fish runs. Stockings of fry and smolts have both returned adults but natural production has not really taken off.

Following are conclusions we arrived at based on our review of supplementation:

-Chinook salmon, particularly upriver stocks, are the most difficult to supplement successfully with hatchery fish. This is because of the greater distance from the ocean and the longer freshwater life cycle.
-The stock of fish is an important factor to consider when supplementing. The closer the hatchery stock is to the supplemented stock or original natural stock, the better chances are for success. Ideally, the hatchery supplementation brood fish should be taken from the natural stock that is to be supplemented.

-Salmon species with shorter freshwater life cycle have shown a higher success rate from hatchery supplementation. They also have less negative impacts on wild/natural populations. Pink and chum salmon supplementation projects in Alaska and BC are examples of this success.

-Short-run stocks of salmon and steelhead have responded more positively to supplementation than longer-run stocks. In some cases, it was shown that introducing hatchery stock to a river system a few kilometers closer to the estuary significantly increased rate of adult returns.

-Wild/natural fish have higher survival rates than hatchery fish. This has been demonstrated with pink salmon in Alaska, Atlantic salmon in Maine, coho salmon on the coast, and upriver chinook salmon in the Columbia. Where tests were made to compare survival to adult, wild/natural produced fish had higher survival rates than associated hatchery produced fish.

-Overstocking of hatchery fish may be a significant problem in a lot of supplementation projects. If hatchery fish are overstocked in a system, the result is decreased performance of both hatchery and wild/natural fish.

-Scattering or distributing the supplemented hatchery stock is more successful than single spot techniques which tend to overstock areas of planting and leave unplanted areas understocked.

-There is a need to evaluate more supplementation programs. We found 18 projects that were all or partially evaluated out of 26 projects classified as supplementation. In order to do hatchery evaluation work or compare survival, hatchery fish need to be identified uniquely from wild/natural stock. There is a need to have a unique visual mark for hatchery produced chinook salmon in the Columbia River.

-Successful techniques for establishing, rebuilding, and supplementing sockeye salmon populations have been developed in Alaska and BC. Most of these programs integrate lake fertilization with fry plantings of appropriate stocks. Some of these techniques may prove useful in rebuilding Columbia River sockeye populations.

-Hatchery broodstock management for supplementation needs to be stressed. The "Summary of Recommendations Regarding Hatchery Production Principles" in draft form, June 6, 1989, System Planning Oversight Committee, reflect many of the concerns with hatchery broodstock management for supplementation.

-Genetic considerations should be an initial concern of all supplementation efforts aimed at rebuilding existing runs of anadromous fish.

-Interpretation of genetic studies of hatchery/wild interaction will be difficult, and long-term in order to obtain the necessary second and third generation data - maybe 15 to 20 years. Also, the opportunity for documenting the genetic "identity" of many native stocks is already lost.

-Overall, conclusions from our review of supplementation show that there are many documented cases of introduced hatchery fish returning as adults to a specific area. However, little data were found on the capability or probability of supplemented hatchery fish building up and sustaining wild/natural populations. Figure 1 summarizes some of the factors mentioned relative to supplementation success.

Figure 1. General success of supplementation with hatchery fish to returning adult.

```
Good
Success -->-------------------->-------------------->-------------------> Poor  Success
              Increasing length of freshwater residency

Good
Success -->-------------------->-------------------->-------------------> Poor  Success
                 Increasing distance from ocean

Good
Success -->-------------------->-------------------->-------------------> Poor  Success
              Increasing distance between stocks used

Good
Success -->-------------------->-------------------->-------------------> Poor  Success
           Lake rearing   Main river rearing   Stream rearing
```

Introduced hatchery fish will augment the number of returning adults to a particular area, but if the factors which originally caused the natural runs to decline are not corrected, production will not significantly change. In fact, in some cases the presence of additional hatchery adults can lead to increased exploitation; thus decreasing the natural production even faster. In some studies, wild/natural stocks were shown to be more viable than hatchery stocks. Thus, replacing wild/natural fish with hatchery fish, and cross breeding wild/natural and hatchery fish, can result in less viable production. (Bjornn and Steward 1990).

If supplementation is ever going to be successful with hatchery fish, we must make major changes in hatchery management. We must make the fish as compatible with the environment (outplanting site) as possible. The hatchery mind-set works against fish-environment compatibility. Changes that appear insignificant at the hatchery, e.g., rearing program, outplant timing, and marking etc., can seriously affect the success of supplementation. However, when hatchery experts were questioned, 53 percent responded that fish culture decisions are based primarily on human efficiency not resource concerns (Diggs 1984).

Does supplementation of anadromous fish work? We believe that it can work, although success varies dramatically by (1) species, (2) stock, (3) area, and (4) method or type of supplementation. Also, success depends on goals we are trying to achieve. If we look at natural production, we have very few successful examples. The two basic questions asked in the supplementation "Proposed Five-Year Work Plan", prepared by the Supplementation Technical Work Group (1988), are considered still quite valid. "What

are the best techniques for supplementing wild/natural stocks and what are the effects of supplementation on endemic populations?" We consider the information presented in Smith et al. (1985) in their "Outplanting Anadromous Salmonids - A Literature Survey" to be very pertinent. The survey does in fact contain representative information we have found to be substantiated in our own literature work and interviews.

We concur with Smith et al. (1985) that no supplementation procedures should be attempted in wild/natural fish only streams. These streams are best enhanced by habitat protection and harvest control.

We believe that plans to double anadromous fish runs in the Columbia River Basin, as stated in the Northwest Power Planning and Conservation Act, may be placing too much emphasis on hatchery production. This effort may continue to erode the genetic integrity of wild stock. We believe that the only way to "double the runs" in the Columbia Basin is to provide optimum habitat for natural producing stocks with limited hatchery supplementation. Equally important is the need to improve mainstream passage conditions by providing adequate flows and reducing losses at the dams. In addition, some hatchery programs should probably divert their efforts at "harvest augmentation" with no or minimal impacts to natural production. If hatchery production, as we know it today, could solve the production problem in the Columbia Basin, we would have doubled the runs 50 years ago.

We may have created an "environmental predicament" where "man's ability to modify the environment increases faster than his ability to foresee the effects of his activities" (Bella and Overton 1972). We must make every effort to reduce the genetic consequences of large scale outplanting. We believe that in many instances anadromous fish could do a better job of rebuilding if we would place a moratorium on "helping" them for several generations. We need to refocus our efforts to protect and enhance habitat. We have tried for 100 years "to have our cake and eat it too," the time is ripe for more innovative methods of hatchery outplanting.

Again, we may need to look at what factors caused the runs to decrease in the first place. If we have not ameliorated the problems which caused the runs to decrease, we will not be able to build up natural runs by just planting hatchery fish. Also, if harvest management is not linked with supplementation, the increased harvest on supplemented fish may in fact put increased harvest pressure on natural stocks. Thus, the overall result would be a negative impact to natural production.

RECOMMENDATIONS

1. A means needs to be established for annually summarizing and updating supplementation efforts by geographic area. Many supplementation projects are underway or planned throughout the northwest. Since supplementation projects normally span a number of years, it is important to update our information base annually. A state-by-state annual summary based on the format of the New England Atlantic salmon program annual reports is suggested.

2. A means of identifying hatchery salmon from wild/natural salmon needs to be instituted for the Columbia River Basin. A visual mark is needed so hatchery and wild/natural escapement and production can be monitored and runs managed separately.

3. Factors related to hatchery fish survival need to be studied. Hatchery spring chinook salmon were found to be the least successful species to supplement. We believe from our discussion with workers in the Basin that BKD is a major factor contributing to this poor success. Therefore, BKD research on spring chinook salmon should be a high priority.

Recommended Research

1. Assessment of factors limiting wild/natural production by area and species in association with carrying capacity.

2. Impact of hatchery smolt releases on wild/natural smolt production and migration.

3. Develop a hatchery rearing broodstock program for stock rebuilding that minimizes adverse genetic impacts to wild/natural stocks. Explore use of wild/natural stocks. Sperm cryopreservation and other innovations could be used to direct hatchery production to a more compatible product. Using kelts for wild steelhead production could be investigated.

4. Need to determine natural production parameters for stocks to be supplemented.

5. Need to develop a means of identifying hatchery from wild/natural fish for salmon in Columbia River Basin.

6. Need to explore use of streamside upwelling incubation boxes or systems to match natural production timing.

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APPENDIX A

APPENDIX A

PART 1

Table of the 26 projects considered true supplementation (for codes used in data entry and reporting see Part 3 of Appendix A).

SUPPLEMENTATION REPORT

#	SPECIES	RACE	STOCK	LIFE STAGE	MAJOR DRAINAGE	SUB DRAINAGE	EVAL	AGENCY	PRINCIPAL CONTACT	PHONE	#/YEAR RELEASED	PURPOSE OF PROJECT
6.	AS		MIXED	SM,FY,PR	MC		QN	FWS	JERRY MARANCIK	(207)469-6701	1900000	SUPPLEMENTATION, RESTORATION
7.	AS		MIXED	SM,FY,PR	MC		QN	MSRSC	ED BAUM	(207)941-4452	1900000	SUPPLEMENTATION, RESTORATION
10.	CH			AD	BC		QN	ABREC	J. FEE		2150	SUPPLEMENTATION EVALUATION STUDY
11.	CH			FY	BC		QN	CFSO	GORDON BEREZAY	(604)666-2600	125000	SUPPLEMENTATION
14.	CH		BR	FY,SM	BC		QN	CFSO	GORDON BEREZAY	(604)666-2600	107344	SUPPLEMENTATION, ENHANCE RUNS
26.	CH		MT	PS,FN	CC	18010108	QN	MWSSG	GARY PETERSON	(707)629-3514	30000	SUPPLEMENTATION, ENHANCE WILD STOCKS
36.	CH	FAL	CH	EG,FY,SM	OC	17100306	QN	ODFW	JAY NICHOLAS	(503)737-4431	400000	SUPPLEMENTATION, ENHANCE RUNS
50.	CH	FAL	HR	YR	CC	18010112	QN	PCFFA	MITCH FARRO	(707)839-5664	30000	SUPPLEMENTATION, ENHANCE RUNS
52.	CH	FAL	LR	SM	CC	18010108	QN	PCFFA	MITCH FARRO	(707)839-5664	50000	SUPPLEMENTATION, ENHANCE RUNS
73.	CH	SPR		FN,SM	CR			FWS	BILL MILLER	(208)476-7242	200000	SUPPLEMENTATION, ENHANCE RUNS
94.	CH	SUM	ST	FN	PS	17110008	QA	STIL	KIP KILLEBREW	(206)435-8770	81093	SUPPLEMENTATION, ENHANCE RUNS
120.	CO			FY	BC		QN	CFSO	ROBERT HURST	(604)756-7296	9500	SUPPLEMENTATION, STOCK EVALUATION
161.	CO		MT	YR,SM	CC	18010108	QN	MWSSG	GARY PETERSON	(707)629-3514	8000	SUPPLEMENTATION, ENHANCE WILD STOCKS
180.	CO		TM	PS,SM	OC	17100304	QN	ODFW	PAUL REIMERS	(503)888-5515	180000	SUPPLEMENTATION, ENHANCE WILD STOCKS
182.	CO		TR	FY	BC		QN	CFSO	ROBERT HURST	(604)756-7296	7500	SUPPLEMENTATION
210.	CU	SEA	RW	YR	CC	18010102	QA	HBCO	STEVE SANDERS	(707)488-2253	500	SUPPLEMENTATION, ENHANCE WILD STOCKS
219.	SH			FY	BC		QN	MEBC	JEREMY HUME	(604)660-1812	0	SUPPLEMENTATION
234.	SH		KR	SM	BC		QN	MEBC	BRUCE WARD	(604)660-1812	20000	SUPPLEMENTATION
238.	SH		NP	YR	CC	18050002	QN	NRS	GEORGE CARL	(707)252-1440	7000	SUPPLEMENTATION, ENHANCE RUNS
248.	SH		YK,SK,RI,PR	SM,FY	CR	17030002	QA	WDW	JIM CUMMINS	(509)575-2740	0	SUPPLEMENTATION, ENHANCE WILD STOCKS
251.	SH	SUM		AD,FY,SM	CR		QA	FWS	BILL MILLER	(208)476-7242	1000000	SUPPLEMENTATION, ENHANCE RUNS
256.	SH	SUM	NR	FY	BC		QN	MEBC	BRAIN BLACKMAN	(604)565-6413	23550	SUPPLEMENTATION, ENHANCE PRODUCTION
257.	SH	SUM	SC	FY	BC		QN		BOB GRIFFITH	(604)387-3660	11400	SUPPLEMENTATION
288.	SH	WIN	CH,BG	SM,FY	WC	17100101	QN	WDW	BILL FREYMOND	(206)533-9335	171711	SUPPLEMENTATION, ENHANCE WILD STOCKS
312.	SO			FN	AC		QN	ADFG	DAVID LITCHFIELD	(907)262-9369	1400000	SUPPLEMENTATION, ENHANCE RUN
313.	SO			EG	AC		QN	ADFG	LORNE WHITE	(907)486-4791	6000000	SUPPLEMENTATION, ENHANCE NATURAL RUN

APPENDIX A

PART 2

Summary of the 26 projects considered true supplementation (for codes used in data entry and reporting see Part 3 of Appendix A).

6. SPECIES: AS RACE: STOCK(S): MIXED
MAJOR DRAINAGE: MC SUB DRAINAGE: 15 RIVERS IN MAINE
CONTACT: JERRY MARANCIK PHONE: (207)469-6701
AGENCY: FWS ADDRESS: GRAIG BROOK NFH, E. ORLAND, ME 04431
PROJECT: MAINE ATLANTIC SALMON PROGRAM
PURPOSE: SUPPLEMENTATION, RESTORATION ONGOING: Y
EVALUATION: QN : 26,790 FISH HAVE RETURNED TO MAINE RIVERS
SURVIVAL: SEE PROJECT # 7
STOCKING DETAILS:
ACCLIMATION DETAILS:
OTHER PRE STOCKING INFO:
IMPACTS; RESEARCH: 10% OF RETURNS TO THE PENOBSCOT R. IS FROM NATURAL PRODUCTION
IMPACTS; OPINION:
CONTROL DETAILS:
OTHER COMMENTS: 2,141 OUT OF 2,688 FISH (IN 1988) ALLOWED TO SPAWN NATURALLY

7. SPECIES: AS RACE: STOCK(S): MIXED
MAJOR DRAINAGE: MC SUB DRAINAGE: 15 RIVERS IN MAINE
CONTACT: ED BAUM PHONE: (207)941-4452
AGENCY: MSRSC ADDRESS: P.O. BOX 1298, BANGOR, ME 04401
PROJECT: MAINE ATLANTIC SALMON PROGRAM
PURPOSE: SUPPLEMENTATION, RESTORATION ONGOING: Y
EVALUATION: QN :
SURVIVAL: ADULT RETURNS RANGE FROM .23 TO 1.32%, MEAN = .71%
STOCKING DETAILS: MAINLY SMOLT STOCKING
ACCLIMATION DETAILS:
OTHER PRE STOCKING INFO: 47% OF RELEASES TO THE PENOBSCOT RIVER
IMPACTS; RESEARCH: FISH UNNEEDED FOR EGG TAKES ARE ALLOWED TO SPAWN NATURALLY
IMPACTS; OPINION: RETURNS TO "WILD" RIVERS ARE PRIMARILT OF WILD ORIGIN
CONTROL DETAILS:
OTHER COMMENTS: MAINE PRODUCED ALL OF THE SPORT CATCH IN 1989, 86% OF THAT FROM THE PENOBSCOT RIVER

10. SPECIES: CH RACE: STOCK(S):
MAJOR DRAINAGE: BC SUB DRAINAGE: SHUSWAP RIVER
CONTACT: J. FEE PHONE:
AGENCY: ABREC ADDRESS: VICTORIA, B.C.
PROJECT: EVALUATION OF CHINOOK & COHO OUTPLANTING OPPORTINUITY, SHUSWAP RIVER
PURPOSE: SUPPLEMENTATION EVALUATION STUDY ONGOING: N
EVALUATION: QN : POSSIBLE RETURN OF 240-430 FISH
SURVIVAL: PRE-SUPPLEMENTATION WORK (SEE COMMENTS)
STOCKING DETAILS: NEED TO STOCK TO DENSITIES OF 3.0 AND 6.0 G/SQ. METER
ACCLIMATION DETAILS:
OTHER PRE STOCKING INFO: WOULD FULLY SEED USUABLE REARING HABITATS
IMPACTS; RESEARCH:
IMPACTS; OPINION:
CONTROL DETAILS:
OTHER COMMENTS: BC DOES RECONNAISSANCE REPORTS ON ALL STREAMS BEFORE SUPPLEMENTATION TO DETERMINE OPPORTUNITIES FOR RESTORATION & ENHANCEMENT OF ENDIMICS

11. SPECIES: CH RACE: STOCK(S):
MAJOR DRAINAGE: BC SUB DRAINAGE: UPPER FRASER RIVER
CONTACT: GORDON BEREZAY PHONE: (604)666-2600
AGENCY: CFSO ADDRESS: 555 W HASTINGS ST., VANCOUVER, BC V6B 5G3
PROJECT: PENNY CHINOOK PILOT HATCHERY, OPERATIONAL HISTORY, 1980-83
PURPOSE: SUPPLEMENTATION ONGOING: Y
EVALUATION: QN :
SURVIVAL: EGGS TO FRY = 74-90%, FRY TO ADULT = 0 -.10%
STOCKING DETAILS: VIA HELICOPTER IN OXYGENATED 360 LITER TANKS
ACCLIMATION DETAILS: BROODSTOCK COLL. FROM & FRY TRANSPORTED TO NATAL STREAMS
OTHER PRE STOCKING INFO: FRY TAGGED @ 1-2 G
IMPACTS; RESEARCH: LOW SUR. TO ADULT INDICATES THE PROD. STRATEGY SHOULD BE REASSESSED
IMPACTS; OPINION: MODIFY PROGRAM TO INCREASE POST-RELEASE SURVIVAL
CONTROL DETAILS:
OTHER COMMENTS: OPERATION RESULTED IN SUCCESSFUL REARING OF CHINOOK FRY IN COLD WATER 1-5 oC

14. SPECIES: CH RACE: STOCK(S): BR
MAJOR DRAINAGE: BC SUB DRAINAGE: HARRISON RIVER
CONTACT: GORDON BEREZAY PHONE: (604)666-2600
AGENCY: CFSO ADDRESS: 555 W. HASTINGS ST., VANCOUVER, BC V6B 5G3
PROJECT: BIRKENHEAD RIVER CHINOOK HATCHERY OPERATIONAL HISTORY 1977-86
PURPOSE: SUPPLEMENTATION, ENHANCE RUNS ONGOING: Y
EVALUATION: QN : LOW RETURNS INDICATE VERY POOR MARINE SURVIVAL
SURVIVAL: LOW TAG RETURNS FOR 77-81 BROODS 0-0.3%
STOCKING DETAILS: FRY RELEASED 2-4G BY 1984 AND 5-7G LATER
ACCLIMATION DETAILS:
OTHER PRE STOCKING INFO:
IMPACTS; RESEARCH: BIRKENHEAD HATCHERY UNABLE TO MEET GOALS DUE TO LOW ESCAPEMENT
IMPACTS; OPINION: PROBLEM AGGRAVATED BY HIGH EXPLOTATION RATE IN INDIAN FISHERY
CONTROL DETAILS: LOW TAG RETURNS MAY BE RESULT OF INSUFICIENT TAGGED FISH
OTHER COMMENTS: LIMITED COHO & STEELHEAD PRODUCTION

26. SPECIES: CH RACE: STOCK(S): MT
MAJOR DRAINAGE: CC SUB DRAINAGE: MATTOLE RIVER
CONTACT: GARY PETERSON PHONE: (707)629-3514
AGENCY: MWSSG ADDRESS: P.O.BOX 188, PETROLIA, CA 95538
PROJECT: MATTOLE WATERSHED SALMON SUPPORT GROUP
PURPOSE: SUPPLEMENTATION, ENHANCE WILD STOCKS ONGOING: Y
EVALUATION: QN : CWT PROGRAM(2 YEARS);JUVENILE TRAPPING; SPAWNING SURVEYS
SURVIVAL: POPULATIONS STATIC
STOCKING DETAILS: DUSK OR EVENING RELEASE WITH NEW MOON PHASE
ACCLIMATION DETAILS: TEMPERATURE ACCLIMATION
OTHER PRE STOCKING INFO: FISH TAKEN OFF FEED AND SALTED PRIOR TO STOCKING
IMPACTS; RESEARCH:
IMPACTS; OPINION: POPULATIONS ARE STATIC- NO INCREASE OR DECREASE
CONTROL DETAILS:
OTHER COMMENTS: STOCKS MAY BE STATIC DUE TO JUVENILE BOTTLENECK IN ESTUARY

36. SPECIES: CH RACE: FAL STOCK(S): CH
MAJOR DRAINAGE: OC SUB DRAINAGE: ELK RIVER, CHETCO RIVER
CONTACT: JAY NICHOLAS PHONE: (503)737-4431
AGENCY: ODFW ADDRESS: 28655 HWY 34, CORVALLIS, OR 97330
PROJECT: ELK RIVER STUDY
PURPOSE: SUPPLEMENTATION, ENHANCE RUNS ONGOING: Y
EVALUATION: QN : EST. SURVIVAL RATE DOES NOT INCLUDE OCEAN CATCH
SURVIVAL: MEAN ADULT = 2.42% RETURN TO ELK RIVER (MOUTH) (68-78 BROOD)
STOCKING DETAILS: TRUCK SMOLTS AND FRY, USE HATCH BOXES
ACCLIMATION DETAILS:
OTHER PRE STOCKING INFO: PRE HATCHERY EVALUATION WAS COMPLETED
IMPACTS; RESEARCH: BROODSTOCK SEINED FROM CHETCO R., 25,000 CWT STOCK ASSESSMENT
IMPACTS; OPINION: FEEL THAT IT STABALIZES RUN
CONTROL DETAILS: N/A
OTHER COMMENTS: PUBLIC HAS INFLUENCED ALLOCATION INCREASES TO THE CHETCO, AS WELL AS INCREASES IN MARKING AND EVALUATION

50. SPECIES: CH RACE: FAL STOCK(S): HR
MAJOR DRAINAGE: CC SUB DRAINAGE: TRINITY RIVER
CONTACT: MITCH FARRO PHONE: (707)839-5664
AGENCY: PCFFA ADDRESS: 216 H ST., EUREKA, CA 95501
PROJECT: KLAMATH-TRINITY FALL CHINOOK ENHANCEMENT PROJECT
PURPOSE: SUPPLEMENTATION, ENHANCE RUNS ONGOING: Y
EVALUATION: QN : USDI SPAWNING SURVEYS SINCE 1981; CWT PROGRAM
SURVIVAL: N/A
STOCKING DETAILS: FISH NOT HANDLED DURING RELEASE; RELEASED AFTER 1ST STORMS
ACCLIMATION DETAILS:
OTHER PRE STOCKING INFO: FOREST SERVICE HAS ESTIMATED CARRYING CAPACITY
IMPACTS; RESEARCH: MARK RETURNS INDICATE PROGRAM IS SUCCESSFUL
IMPACTS; OPINION:
CONTROL DETAILS:
OTHER COMMENTS:

52. SPECIES: CH RACE: FAL STOCK(S): LR
MAJOR DRAINAGE: CC SUB DRAINAGE: LITTLE RIVER
CONTACT: MITCH FARRO PHONE: (707)839-5664
AGENCY: PCFFA ADDRESS: P.O.BOX 291, TRINIDAD, CA 95570
PROJECT: LITTLE RIVER FALL CHINOOK ENHANCEMENT PROGRAM
PURPOSE: SUPPLEMENTATION, ENHANCE RUNS ONGOING: Y
EVALUATION: QN : CWT PROGRAM; SPAWNING GROUND SURVEYS SINCE 1985
SURVIVAL: N/A
STOCKING DETAILS: 100% CWT; TRUCKED; LATE EVENING RELEASES WITH LUNAR PHASE
ACCLIMATION DETAILS: TEMPERATURE ACCLIMATION
OTHER PRE STOCKING INFO:
IMPACTS; RESEARCH: FIRST RETURNS CAME IN 1988,SHOWS PROJECT HAS CONTRIBUTED TO RUNS
IMPACTS; OPINION:
CONTROL DETAILS: SPLIT RELEASE STRATEGY (LOWER VS. UPPER RIVER)
OTHER COMMENTS: LAND USE PRACTICES CAN IMPACT PROJECT; ADULT MALES USED ONLY ONCE; ONLY MARKED FISH ARE SPAWNED

73. SPECIES: CH RACE: SPR STOCK(S):
MAJOR DRAINAGE: CR SUB DRAINAGE: LOCHSA RIVER
CONTACT: BILL MILLER PHONE: (208)476-7242
AGENCY: FWS ADDRESS: P.O. BOX 18, AHSAHKA, ID 83520
PROJECT: UPPER LOCHSA ON THE CLEARWATER RIVER
PURPOSE: SUPPLEMENTATION, ENHANCE RUNS ONGOING: Y
EVALUATION: : STATE RUN WIER FIRST OPERATED IN 1989, NO PAST EVALUATION
SURVIVAL: IDAHO DEPT. OF FISH & GAME OPERATES WIER
STOCKING DETAILS: TRUCKED FROM DWORSHAK NFH TO POWELL & RELEASED
ACCLIMATION DETAILS: RAISED ON NF CLEARWATER R., CURRENTLY RAISED AT POWELL
OTHER PRE STOCKING INFO: CHINOOK CWTed IN 1989, 60,000 OUT OF 200,000 RELEASED
IMPACTS; RESEARCH:
IMPACTS; OPINION:
CONTROL DETAILS:
OTHER COMMENTS: MAY HAVE HAD 1 OCEAN RETURNS IN 1989 BUT WEIR WAS NOT OPERATED DUE TO CONSTRUCTION

94. SPECIES: CH RACE: SUM STOCK(S): ST
MAJOR DRAINAGE: PS SUB DRAINAGE: STILLAGUAMISH RIVER
CONTACT: KIP KILLEBREW PHONE: (206)435-8770
AGENCY: STIL ADDRESS: 3439 STOLUCKQUAMISH LN, ARLINGTON, WA 98223
PROJECT: STILLAGUAMISH CHINOOK
PURPOSE: SUPPLEMENTATION, ENHANCE RUNS ONGOING: Y
EVALUATION: QA : SPAWNING SURVEYS DONE ANNUALLY
SURVIVAL: RELATIVE SURVIVAL RATES TO BE EVALUATED
STOCKING DETAILS: DUMP PLANTED INTO MAINSTEM & MOUTHS OF TRIBS
ACCLIMATION DETAILS: 41,115 FN AT FORTSON POND FOR 16 DAYS AVG. IN 89
OTHER PRE STOCKING INFO: TRY TO MATCH PLANTINGS TO TIME & SIZE OF WILD OUTMIGR
IMPACTS; RESEARCH:
IMPACTS; OPINION: ANY INCREASE IS A BENEFIT, RUN IS SLOWLY INCREASING
CONTROL DETAILS: 405,998 FISH TAGGED WITH CWT
OTHER COMMENTS: ADDL. STREAMS: ARMSTRONG,HARVEY,CANYON,BEAVER,PERRY,& PALMER

120. SPECIES: CO RACE: STOCK(S):
MAJOR DRAINAGE: BC SUB DRAINAGE: CRAIG CREEK
CONTACT: ROBERT HURST PHONE: (604)756-7296
AGENCY: CFSO ADDRESS: 3225 STEPHENSON PT RD, NANAIMO, BC V9T 4P7
PROJECT: CRAIG CREEK
PURPOSE: SUPPLEMENTATION, STOCK EVALUATION ONGOING: Y
EVALUATION: QN : WILD BROODSTOCK COLLECTED FROM CRAIG CK & REARED IN HATCHERY
SURVIVAL: WILD=4.2%, HATCHERY=3.2%
STOCKING DETAILS: STOCKS DIFFERENTLY MARKED & RELEASED INTO CRAIG CK HEADWATER
ACCLIMATION DETAILS:
OTHER PRE STOCKING INFO: WILD FRY .2 G LARGER THAN HATCHERY FRY
IMPACTS; RESEARCH: SURVIVAL OF WILD FISH SIG HIGHER THAN HATCHERY
IMPACTS; OPINION: STOCKING DENSITIES WERE EXCESSIVE, RESULTING IN LOW SURVIVAL
CONTROL DETAILS:
OTHER COMMENTS: OBJECTIVES: (1)DETERMINE DECLINE IN FRY TO SMOLT SURVIVAL RATE (2)PROVIDE ADDITIONAL INFO ON OPTIMUM STOCKING DENSITIES FOR COHO

161. SPECIES: CO RACE: STOCK(S): MT
MAJOR DRAINAGE: CC SUB DRAINAGE: MATTOLE RIVER
CONTACT: GARY PETERSON PHONE: (707)629-3514
AGENCY: MWSSG ADDRESS: P.O.BOX 188, PETROLIA, CA 95538
PROJECT: MATTOLE WATERSHED SALMON SUPPORT GROUP
PURPOSE: SUPPLEMENTATION, ENHANCE WILD STOCKS ONGOING: Y
EVALUATION: QN : CWT PROGRAM(2 YEARS); JUVENILE TRAPPING; SPAWNING SURVEYS
SURVIVAL: POPULATIONS STATIC
STOCKING DETAILS: DUSK OR EVENING RELEASES WITH NEW MOON PHASE
ACCLIMATION DETAILS: TEMPERATURE ACCLIMATION
OTHER PRE STOCKING INFO: FISH TAKEN OFF FEED AND SALTED PRIOR TO STOCKING
IMPACTS; RESEARCH:
IMPACTS; OPINION: POPULATIONS ARE STATIC- NO INCREASE OR DECREASE
CONTROL DETAILS:
OTHER COMMENTS: PROJECT HAS ESTABLISHED RUNS IN DIFFERENT TRIBUTARIES

180. SPECIES: CO RACE: STOCK(S): TM
MAJOR DRAINAGE: OC SUB DRAINAGE: EEL LAKE
CONTACT: PAUL REIMERS PHONE: (503)888-5515
AGENCY: ODFW ADDRESS: P.O.BOX 5430, CHARLESTON, OR 97420
PROJECT: EEL LAKE COHO STUDIES
PURPOSE: SUPPLEMENTATION, ENHANCE WILD STOCKS ONGOING: Y
EVALUATION: QN : CWT PROGRAM; SURVIVAL BASED ON CONTRIBUTION AND RETURNING ADULTS
SURVIVAL: 1.17% TO ADULTS
STOCKING DETAILS: STOCK AFTER THE BASS ACTIVITY SLOWS DOWN
ACCLIMATION DETAILS:
OTHER PRE STOCKING INFO:
IMPACTS; RESEARCH: FISH GET PHENOMENAL GROWTH WHEN REARED IN THE LAKE
IMPACTS; OPINION:
CONTROL DETAILS:
OTHER COMMENTS: THIS PROGRAM UTILIZES EEL LAKE AS A REARING AREA; WILD FISH ARE CONTINUALLY FUSED INTO THIS PROGRAM TO MAINTAIN THE GENETICS

182. SPECIES: CO RACE: STOCK(S): TR
MAJOR DRAINAGE: BC SUB DRAINAGE: TRENT RIVER, CANADA
CONTACT: ROBERT HURST PHONE: (604)756-7296
AGENCY: CFSO ADDRESS: 3225 STEPHENSON PT RD, NAMAIMO, BC V9T 4P7
PROJECT: TRENT RIVER - COLONIZATION
PURPOSE: SUPPLEMENTATION ONGOING: Y
EVALUATION: QN : DOWN STREAM SMOLT TRAP ON BRADLEY LK
SURVIVAL: BRADLEY LK FRY TO SMOLT=19%, OUTPLANTED FRY IN TRENT R=5.4%
STOCKING DETAILS: STOCKED FORM 81-86 ONLY EVALUATED IN 86
ACCLIMATION DETAILS: N/A
OTHER PRE STOCKING INFO:
IMPACTS; RESEARCH: BRADLEY L HAS GOOD SMOLT PROD. POTENTIAL & PRODUCED LARGER SMOLTS
IMPACTS; OPINION: 2-2.5 G COHO FRY DO WELL IN LAKES W/ FEW PREDATORS & LOW GRADIENT STS
CONTROL DETAILS: N/A
OTHER COMMENTS:

210. SPECIES: CU RACE: SEA STOCK(S): RW
MAJOR DRAINAGE: CC SUB DRAINAGE: REDWOOD CREEK
CONTACT: STEVE SANDERS PHONE: (707)488-2253
AGENCY: HBCO ADDRESS: PRARIE CREEK FISH HATCHERY, ORICK, CA 95555
PROJECT: PRARIE CREEK FISH HATCHERY
PURPOSE: SUPPLEMENTATION, ENHANCE WILD STOCKS ONGOING: Y
EVALUATION: QA :
SURVIVAL: INCREASE IN CUTTHROATS IN LOST MAN CREEK
STOCKING DETAILS: RELEASE WITH NEW MOON PHASE
ACCLIMATION DETAILS:
OTHER PRE STOCKING INFO:
IMPACTS; RESEARCH:
IMPACTS; OPINION: INCREASE IN ABUNDANCE OF COASTAL CUTTHROAT IN LOST MAN CREEK
CONTROL DETAILS:
OTHER COMMENTS:

219. SPECIES: SH RACE: STOCK(S):
MAJOR DRAINAGE: BC SUB DRAINAGE: VANCOUVER, ISLAND & MAINLAND
CONTACT: JEREMY HUME PHONE: (604)660-1812
AGENCY: MEBC ADDRESS: 2204 MAIN MALL, UNIV. OF B.C., VANCOUVER, B.C. V6T 1W5
PROJECT: EFFECTS OF VAR. STOCKING STRATEGIES & GROWTH OF HEADWATER STOCKED SH
PURPOSE: SUPPLEMENTATION ONGOING: N
EVALUATION: QN :
SURVIVAL: SURVIVAL TO 2+ SMOLTS WAS HIGHER FOR LATER REL & LARGER FRY
STOCKING DETAILS: STOCK ABOUT 0.1 FRY/SQ METER
ACCLIMATION DETAILS:
OTHER PRE STOCKING INFO: ABOVE 0.7 FRY/SQ M. THERE WILL BE NO INCREASE IN PROD.
IMPACTS; RESEARCH: FRY FROM HIGH DENSITY GROUPS SMALLER THAN THOSE IN LOW, MED GROUPS
IMPACTS; OPINION:
CONTROL DETAILS:
OTHER COMMENTS: ASSUME WILD/NATURAL BROODSTOCK

234. SPECIES: SH RACE: STOCK(S): KR
MAJOR DRAINAGE: BC SUB DRAINAGE: KEOUGH RIVER
CONTACT: BRUCE WARD PHONE: (604)660-1812
AGENCY: MEBC ADDRESS: 2204 MAIN MALL, UNIV. OF B.C., VANCOUVER, BC V6T 1W5
PROJECT: PEN-REARED STEELHEAD FROM RIVERINE, ESTUARINE & MARINE RELEASES
PURPOSE: SUPPLEMENTATION ONGOING: N
EVALUATION: QN :
SURVIVAL: RETURNS ARE RIVERINE=7-11%, OCEAN=10%, TIDAL=10%
STOCKING DETAILS: FOUR SITES USED, 2 IN RIVER, 1 IN ESTUARY, 1 IN OCEAN
ACCLIMATION DETAILS: SMOLT RELEASE CONINCIDED WITH MIGRATION OF WILD SMOLTS
OTHER PRE STOCKING INFO: HAT. SM MIGRATING THROUGH WEIR WERE COUNTED W/ WILD SM
IMPACTS; RESEARCH:
IMPACTS; OPINION:
CONTROL DETAILS: WILD FISH
OTHER COMMENTS: WILD FISH WERE SHOCKED FROM KEOUGH R. & PROGENY USED FOR STUDY

238. SPECIES: SH RACE: STOCK(S): NP
MAJOR DRAINAGE: CC SUB DRAINAGE: SAN PABLO BAY
CONTACT: GEORGE CARL PHONE: (707)252-1440
AGENCY: NRS ADDRESS: P.O.BOX 2726, NAPA, CA 94558
PROJECT: NAPA RIVER STEELHEAD ENHANCEMENT PROJECT
PURPOSE: SUPPLEMENTATION, ENHANCE RUNS ONGOING: Y
EVALUATION: QN : SPAWNING GROUND SURVEYS
SURVIVAL: N/A
STOCKING DETAILS: TRUCKED; FIN CLIPPING LAST 3 YEARS
ACCLIMATION DETAILS:
OTHER PRE STOCKING INFO:
IMPACTS; RESEARCH: INCREASE IN ADULT RETURNS
IMPACTS; OPINION:
CONTROL DETAILS:
OTHER COMMENTS: PLANTING EFFORTS HAVE BROADENED THE DISTRIBUTION OF RETURNING ADULTS TO THE NAPA RIVER BASIN

248. SPECIES: SH RACE: STOCK(S): YK,SK,RI,PR
MAJOR DRAINAGE: CR SUB DRAINAGE: NACHES RIVER
CONTACT: JIM CUMMINS PHONE: (509)575-2740
AGENCY: WDW ADDRESS: 2802 FRUITVALE BLVD., YAKIMA, WA 98902
PROJECT: YAKIMA WDW
PURPOSE: SUPPLEMENTATION, ENHANCE WILD STOCKS ONGOING: Y
EVALUATION: QA : WILD TO HATCHERY SMOLTS, 80% WILD SINCE 1981, SMOLTS AT DAMS
SURVIVAL:
STOCKING DETAILS: TRUCKED
ACCLIMATION DETAILS: NET OFF SECTIONS OF TOPPENISH CR
OTHER PRE STOCKING INFO: YAKIMA ABOVE ROSA NOT STOCKED
IMPACTS; RESEARCH:
IMPACTS; OPINION: NUMBERS WITHIN THE SYSTEM INCREASING
CONTROL DETAILS: N/A
OTHER COMMENTS: LOOKING AT USING WILD STOCKS IN THE FUTURE

251. SPECIES: SH RACE: SUM STOCK(S):
MAJOR DRAINAGE: CR SUB DRAINAGE: CLEARWATER RIVER
CONTACT: BILL MILLER PHONE: (208)476-7242
AGENCY: FWS ADDRESS: P.O. BOX 18 AHSAHKA, ID 83520
PROJECT: LOLO CREEK ON THE CLEARWATER RIVER
PURPOSE: SUPPLEMENTATION, ENHANCE RUNS ONGOING: Y
EVALUATION: QA : SNORKLING DATA
SURVIVAL:
STOCKING DETAILS: TRUCKED AND RELEASED
ACCLIMATION DETAILS: SMOLTS ON NF CLEARWATER R. WATER 2-3 WKS PRIOR TO RELEASE
OTHER PRE STOCKING INFO:
IMPACTS; RESEARCH:
IMPACTS; OPINION:
CONTROL DETAILS:
OTHER COMMENTS: ADULTS UNUSED IN HATCHERY EGG TAKES ARE OUTPLANTED THEIR EFFECTIVENESS IS UNKNOWN

256. SPECIES: SH RACE: SUM STOCK(S): NR
MAJOR DRAINAGE: BC SUB DRAINAGE: NAMAIMO RIVER
CONTACT: BRAIN BLACKMAN PHONE: (604)565-6413
AGENCY: MEBC ADDRESS: 1011 4TH AVE., PRINCE GEORGE, B.C. V2L 3H9
PROJECT: STEELHEAD FRY HEADWATER STOCKING EVALUATION
PURPOSE: SUPPLEMENTATION, ENHANCE PRODUCTION ONGOING: Y
EVALUATION: QN : EVALUATION OF SCATTER VS. POINT RELEASE
SURVIVAL: FRY TO 1+PARR 35 & 48%, EST. 50% FROM 1+ PARR TO SMOLT
STOCKING DETAILS: SCATTER PLANTED W/ BACKPACK NO MORE THAN 500/ GROUP
ACCLIMATION DETAILS:
OTHER PRE STOCKING INFO: FRY SCATTERED IN 81 WERE DOUBLE THE WT. OF POINT RELS.
IMPACTS; RESEARCH: POINT STOCKING RESULTED IN POOR DISPERSAL & OVERUSE NEAR REL SITES
IMPACTS; OPINION:
CONTROL DETAILS:
OTHER COMMENTS: WILD BROODSTOCK CAPTURED FROM NANAIMO R. BY HOOK AND LINE, OPTIMUM STOCKING DENSITIES FOR THIS SYSTEM = 0.4 FRY/SQ. METER @ 1.5 GMS.

257. SPECIES: SH RACE: SUM STOCK(S): SC
MAJOR DRAINAGE: BC SUB DRAINAGE: SILVERHOPE CREEK
CONTACT: BOB GRIFFITH PHONE: (604)387-3660
AGENCY: ADDRESS: VICTORIA, BC
PROJECT: ENHANCEMENT OF SUMMER RUN STEELHEAD IN SILVERHOPE CREEK
PURPOSE: SUPPLEMENTATION ONGOING: N
EVALUATION: QN :
SURVIVAL: SINGLE POINT RELEASES = 63%, SUB SATURATION RELEASES = 77%
STOCKING DETAILS: 5,700 SINGLE POINT RELEASE, 5.700 UNIFORMLY DISTRIBUTED
ACCLIMATION DETAILS:
OTHER PRE STOCKING INFO:
IMPACTS; RESEARCH: POINT RELEASES RESULTED IN FRY BIOMASS DENSITY OF 5.87 G/SQ METER
IMPACTS; OPINION:
CONTROL DETAILS:
OTHER COMMENTS: UPSTREAMING OF LARGE FRY & DOWNSTREAMING OF SMALL FRY WAS EVIDENCED ABOUT POINT RELEASE SITE, LESS DEFINITE MIGRATIONS FOR SCATTER RELEASES

288. SPECIES: SH RACE: WIN STOCK(S): CH,BG
MAJOR DRAINAGE: WC SUB DRAINAGE: QUILLAYUTE RIVER
CONTACT: BILL FREYMOND PHONE: (206)533-9335
AGENCY: WDW ADDRESS: REGION 6 905 E. HERON, ABERDEEN, WA 98520
PROJECT: QUILLAYUTE
PURPOSE: SUPPLEMENTATION, ENHANCE WILD STOCKS ONGOING: Y
EVALUATION: QN : WILD BROOD RETURN CALCULATED
SURVIVAL: 1-SALT RETURNS=8.20%, 3-SALT=2.30%, OTHER AGES=.48%
STOCKING DETAILS: +/- 100,000 SMOLTS VOLITIONALLY RELASED FROM PONDS
ACCLIMATION DETAILS: REARED TO SMOLTS IN BOGACHIEL & CALAWAH PONDS
OTHER PRE STOCKING INFO: 10-15,000 TRUCKED FROM BOGACHIEL POND TO CALAWAH DRA.
IMPACTS; RESEARCH:
IMPACTS; OPINION: MINIMAL IMPACTS ON WILD FISH DUE TO TIMING DIFFERENCES
CONTROL DETAILS: 622,696 AD & VENT. CLIPS TO AID IN HARVEST MANAG. DETER.
OTHER COMMENTS: WDW CONCERN OF OVERHARVEST ON EARLY WILD FISH ON SOLEDUCK MOST SPORT HARVEST IS WITHIN 3 MILES OF RELEASE SITE AT BOGACHIEL PONDS.

312. SPECIES: SO RACE: STOCK(S):
MAJOR DRAINAGE: AC SUB DRAINAGE: KENAI RIVER
CONTACT: DAVID LITCHFIELD PHONE: (907)262-9369
AGENCY: ADFG ADDRESS: 34828 KALIFORSKY BEACH RD, SUITE B, SOLDOTNA, AK 99669
PROJECT: HIDDEN LAKE SOCKEYE SALMON INVESTIGATIONS, 1983-84
PURPOSE: SUPPLEMENTATION, ENHANCE RUN ONGOING: Y
EVALUATION: QN :
SURVIVAL: FINGERLING TO SMOLT = 20%, SMOLT TO ADULT = 15%
STOCKING DETAILS: STOCKED FINGERLING FROM HATCHERY, ADULTS TAKEN AT LAKE
ACCLIMATION DETAILS:
OTHER PRE STOCKING INFO:
IMPACTS; RESEARCH:
IMPACTS; OPINION: INCREASE PRODUCTION AND ADULT RUN BY PLANTING FINGERLINGS
CONTROL DETAILS:
OTHER COMMENTS: LAKE LACKED ADEQUATE SPAWNING AREA

313. SPECIES: SO RACE: STOCK(S):
MAJOR DRAINAGE: AC SUB DRAINAGE: KARLUK LAKE
CONTACT: LORNE WHITE PHONE: (907)486-4791
AGENCY: ADFG ADDRESS: 211 MISSION ROAD, KODIAK, AK 99615
PROJECT: SOCKEYE SALMON REHABILITATION AT UPPER THUMB RIVER, KARLUK LAKE
PURPOSE: SUPPLEMENTATION, ENHANCE NATURAL RUN ONGOING: Y
EVALUATION: QN :
SURVIVAL: EYED EGG PLANT SURVIVAL TO FRY AVERAGED 41.2% (1.4 TO 61.3%)
STOCKING DETAILS: USED AN EGG PLANTING DEVICE, BACKPACKED EGGS TO AREAS
ACCLIMATION DETAILS:
OTHER PRE STOCKING INFO:
IMPACTS; RESEARCH: NO MARKS FOR CONTIBUTION
IMPACTS; OPINION: USED INCREASE IN SPAWNING ESCAPEMENT TO RATE SUCCESS
CONTROL DETAILS:
OTHER COMMENTS: TRIED USING FRY PLANTS BUT HAD PROBLEMS, DISEASE LOOSES AT HATCHERIES, ETC.

APPENDIX A, Part 3. Codes used in data entry and reporting of supplementation projects.

SPECIES		RACE		STOCK
AS	ATLANTIC SALMON			MIXED
CM	CHUM			
			BJ	BLACKJACK CREEK
			CH	CHAMBERS CREEK
			CW	COWLING CREEK
			EL	ELWHA
			EN	ENETAI
			ES	ELSON CREEK
			FI	FINCH CREEK
			GA	GEORAGE ADAMS
			GO	GOVERS CREEK
			GR	GREEN RIVER
			GS	GARRISON SPRINGS
			HD	HOOD CANAL
			JC	JOHNS CREEK
			KC	KETA CREEK
			KY	KENNEDY CREEK
			NO	NOOKSACK
			NQ	NISQUALLY
			QU	QUILCENE
			WC	WALCOTT
			WL	WALCOTT SLOUGH
CO	COHO			
			AL	ALSEA
			BC	BIG CREEK
			BL	BLACK CREEK
			CK	CLARKS CREEK
			CQ	COQUILLE
			CZ	COWLITZ
			DN	DUNGENESS
			EL	ELWHA
			FR	FRENCH CREEK
			GA	GEORGE ADAMS
			GH	GRAYS HARBOR
			GR	GREEN RIVER
			HO	HOH
			HU	HUMPTULIPS
			IC	INDIAN CREEK
			JG	JOLLY GIANT CREEK
			KL	KLASKANINE
			KA	KALAMA CREEK
			LM	LOST MAN CREEK
			LW	LEWIS RIVER HATCHERY
			MI	MILLSTONE RIVER
			MN	MINTER CREEK
			NO	NOOKSACK
			NY	NOYO
			PR	PRARIE CREEK
			PU	PUYALLUP
			QC	QUILCENE
			QN	QUINAULT
			QU	QUINSAM
			SD	SANDY
			SK	SKAGIT
			SO	SKOOKUMCHUCK
			ST	SCOTT RIVER
			SR	SALMON RIVER
			SY	SKYKOMISH
			SZ	SILETZ
			TM	TEMILE LAKES

APPENDIX A, Part 3. Codes used in data entry and reporting of supplementation projects. (Cont.)

				TR	TRENT RIVER
				WL	WALCOTT SLOUGH
				WR	WALLACE
CH	CHINOOK				
		FAL	FALL		
				AB	ABERNATHY
				AM	AMERICAN RIVER
				BC	BIG CREEK
				BO	BONNEVILLE
				BT	BATTLE CREEK
				BW	BIG WHITE SALMON
				CH	CHETCO RIVER
				ER	EEL RIVER
				FT	FEATHER RIVER
				FW	FRESHWATER CREEK
				HL	HOLLOW CREEK (EEL RIVER)
				HR	HORSE LINTO CREEK
				IC	INDIAN CREEK
				KM	KLAMATH RIVER
				LF	LYONS FERRY
				LR	LITTLE RIVER
				LW	LITTLE WHITE SALMON
				MC	MERCED RIVER
				MD	MAD RIVER
				MO	MOKELUMME RIVER
				MT	MATTOLE RIVER
				RC	ROWDY CREEK
				RS	RUSSIAN RIVER
				RW	REDWOOD CREEK
				SC	SPRING CREEK
				ST	SCOTT RIVER
				TN	TRINITY RIVER
				UR	UP RIVER BRIGHT
				WM	WILLAMETTE
		LFA	LATE FALL		
				BT	BATTLE CREEK
				HP	HIGH PRARIE CREEK (KLAMATH)
				OM	OMAGAR CREEK (KLAMATH)
		SPR	SPRING		
				BO	BONNEVILLE
				CA	CARSON
				CL	CLEARWATER
				CZ	COWLITZ
				EC	EAGLE CREEK
				ET	ENTIAT
				FT	FEATHER RIVER
				HD	HOODSPOT
				KO	KOOSKIA (=CLEAR CREEK)
				LE	LEAVENWORTH
				LW	LITTLE WHITE SALMON
				MK	MCKENZIE
				NK	NOOKSACK
				RG	ROUGH RIVER
				RR	RAPID RIVER
				SS	SOUTH SANTIAM
				SU	SOLEDUCK
				TN	TRINITY RIVER
				TR	TRASK
				WM	WILLAMETTE
				WS	WARM SPRINGS
				WT	WINTHROP

APPENDIX A, Part 3. Codes used in data entry and reporting of supplementation projects. (Cont.)

		SUM	SUMMER		
				MC	Mc CALL
		WIN	WINTER		
				SA	SACRAMENTO RIVER
		UNK	UNKNOWN		
PK	PINK SALMON				
SO	SOCKEYE				
SH	STEELHEAD				
		SUM	SUMMER		
				DS	DESCHUTES RIVER
				DW	DWORSHAK "B"
				EF	EAST FORK "B"
				EL	EEL RIVER
				HC	HELLS CANYON "A"
				LE	LEAVENWORTH
				LF	LYONS FERRY
				MK	MCKENZIE
				PA	PAHSIMEROI "A"
				PB	PAHSIMEROI "B"
				RS	RUSSIAN RIVER
				SK	SKAMANIA
				SS	SOUTH SANTIAM
				SW	SAWTOOTH "A"
		WIN	WINTER		
				AL	ALSEA
				BC	BIG CREEK
				CQ	COQUILLE
				EC	EAGLE CREEK
				FH	FISHHAWK
				KL	KLASKANINE
				KR	KEOGH RIVER
				MA	MAKAH
				MF	MARION FORKS
				NH	NEHALEM
				NN	NORTH NEHALEM
				NS	NORTH SANTIAM
				NU	NORTH UMPQUA
		UNK	UNKNOWN		
				AC	ADOBE CREEK
				AM	AMERICAN RIVER
				BC	BIG CREEK
				BT	BATTLE CREEK
				ER	EEL RIVER
				FT	FEATHER RIVER
				GR	GARCIA RIVER
				IC	INDIAN CREEK
				JG	JOLLY GIANT CREEK
				MO	MOKELUMNE RIVER
				NP	NAPA RIVER
				RC	ROWDY CREEK
				RS	RUSSIAN RIVER
				SL	SALT CREEK
				SM	SMITH RIVER
				SN	SAN LORENZO RIVER
				ST	SCOTT RIVER
				TU	TULE
CU	CUTTHROAT TROUT				
		SEA	SEA-RUN		
				AL	ALSEA
				CO	COASTAL
				SH	SHELTON
				SO	STONE LAGOON

APPENDIX A, Part 3. Codes used in data entry and reporting of supplementation projects. (Cont.)

ANY SPECIES

WI	WILD/NATIVE
UNK	UNKNOWN
MIXED	

EVALUATION

NA	NOT ATTEMPTED
QN	QUANTITATIVE
QA	QUALITATIVE

LIFE STAGES

EG	EGG
FY	FRY
FN	FINGERLING
PS	PRE-SMOLTS
SM	SMOLTS
1O	1 OCEAN
2O	2 OCEAN
3O	3 OCEAN
AD	ADULTS
YR	YEARLING
VA	VARIABLE
PR	PARR

DRAINAGE

CR	COLUMBIA RIVER	
PS	PUGET SOUND DRAINAGES	
OC	OREGON COAST DRAINAGES	
WC	WASHINGTON COAST DRAINAGES	
BC	BRITISH COLUMBIA DRAINAGES	
	AC	ALASKA COAST DRAINAGES
	CC	CALIFORINA COAST DRAINAGES
	SR	SACRAMENTO RIVER
CT	CONNETICUT RIVER	
MR	MERRIMACK RIVER	
MC	MAINE COAST DRAINAGES	
PR	PAWCATUCK RIVER	

AGENCIES

ABREC	ALPHA BIO-RESOURCES ENVIRONMENTAL CONSULTANTS
ADFG	ALASKA DEPT. OF FISH AND GAME
BIA	BUREAU OF INDIAN AFFAIRS
CCSE	CENTRAL COAST SALMON ENHANCEMENT
CDEP	CONNETICUT DEPT. OF ENVIRONMENTAL PROTECTION
CDFG	CALIFORNIA DEPT. OF FISH AND GAME
CFSO	CANADA DEPT. OF FISHERIES AND OCEANS - OPERATIONS
COAPW	CITY OF ARCATA-DEPT OF PUBLIC WORKS
CRSA	CARMEL RIVER STEELHEAD ASSOCIATION
FBSRA	FORT BRAGG SALMON RESTORATION ASSOC.
FOG	FRIENDS OF GARCIA
FWS	US FISH AND WILDLIFE SERVICE
GRC	GARBERVILLE ROTARY CLUB
GRSP	GUALALA RIVER STEELHEAD PROJECT
HBCO	HUMBOLDT COUNTY
HFAC	HUMBOLDT FISH ACTION COUNCIL
HOH	HOH INDIAN TRIBE
HSU	HUMBOLDT STATE UNIVERSITY
HVBC	HOOPA VALLEY BUSINESS COUNCIL
IDFG	IDAHO DEPT. OF FISH AND GAME
LUMM	LUMMI INDIAN TRIBE
MBSTP	MONTEREY BAY SALMON/TROUT PROJECT
MCFG	MENDOCINO COUNTY FISH AND GAME
MEBC	MINISTRY OF ENVIRONMENT, BRITISH COLUMBIA
MFM	MAKAH FISHERIES MANAGEMENT
MSRSC	MAINE SEA RUN SALMON COMMISSION
MUCK	MUCKLESHOOT TRIBE
MWSSG	MATTOLE WATERSHED SALMON SUPPORT GROUP
NCIDC	NORTHERN CALIFORNIA INDIAN DEVELOPMENT COUNCIL
NISQ	NISQUALLY INDIAN TRIBE
NOOK	NOOKSACK TRIBE
NRS	NAPA RIVER STEELHEAD
ODFW	OREGON DEPT. OF FISH AND WILDLIFE
PCFFA	PACIFIC COAST FEDERATION FISHERMAN'S ASSOC.
PNPT	POINT NO POINT TREATY COUNCIL

APPENDIX A, Part 3. Codes used in data entry and reporting of supplementation projects. (Cont.)

PSD	PETULUMA SCHOOL DISTRICT
PUT	PUYALLUP TRIBE
RHSI	RURAL HUMAN SERVICES, INC.
RIDFW	RHODE ISLAND DIV. OF FISH AND WILDLIFE
SFU	SIMON FRASER UNIVERSITY
SKAG	SKAGIT SYSTEMS COOPERATIVE
SOC	STATE OF CALIFORNIA
SQAX	SQUAXIN TRIBE
SRKC	SMITH RIVER KIWANS CLUB
STIL	STILLAQUAMISH INDIAN TRIBE
SUQ	SUQUAMISH TRIBE
TCSF	TYEE CLUB OF SAN FRANCISCO
TULA	TULALIP INDIAN TRIBE
USFS	US FOREST SERVICE
VDFW	VERMONT DEPT. OF FISH AND WILDLIFE
WDF	WASHINGTON DEPT. OF FISHERIES
WDW	WASHINGTON DEPT. OF WILDLIFE
YAKI	YAKIMA INDIAN TRIBE

APPENDIX A

PART 4

Table of all projects included in database (for codes used in data entry and reporting see Part 3 of Appendix A).

SUPPLEMENTATION REPORT

#	SPECIES	RACE	STOCK	LIFE STAGE	MAJOR DRAINAGE	SUB DRAINAGE	EVAL	AGENCY	PRINCIPAL CONTACT	PHONE	#/YEAR RELEASED	PURPOSE OF PROJECT
1.	AS		MIXED	FY	CT		QN	FWS	CARL BARREN	(802)826-4438	100000	RESTORATION
2.	AS		MIXED	FY	CT		QN	USFS	STEVE ROY	(802)773-0300	205000	RESTORATION
3.	AS		MIXED	FY	CT		QN	VDFW	KEN COX	(802)886-2215	0	RESTORATION
4.	AS		MIXED	SM,FY	CT		QN	CDEP	STEVE GEBHARD	(203)443-0166	0	RESTORATION
5.	AS		MIXED	FY,SM,PR	CT			FWS	TED MEYERS	(413)863-3555	2000000	RESTORATION
6.	AS		MIXED	SM,FY,PR	MC		QN	FWS	JERRY MARANCIK	(207)469-6701	1900000	SUPPLEMENTATION, RESTORATION
7.	AS		MIXED	SM,FY,PR	MC		QN	MSRSC	ED BAUM	(207)941-4452	1900000	SUPPLEMENTATION, RESTORATION
8.	AS		MIXED	FY,SM,PR	MR		QN	FWS	LARRY STOLTE	(603)225-1411	1500000	REESTABLISH RUNS
9.	AS		MIXED	PR	PR		QN	RIDFW	MARK GIBSON	(401)789-0281	400000	RESTORATION
10.	CH			AD	BC		QN	ABREC	J. FEE		2150	SUPPLEMENTATION EVALUATION STUDY
11.	CH		-	FY	BC		QN	CFSO	GORDON BEREZAY	(604)666-2600	125000	SUPPLEMENTATION
12.	CH				CC			SRKC	BOB WILLS	(707)487-3443	150000	ENHANCE FISHERIES
13.	CH		AM	SM	SR	18040005	QN	CDFG	RON DUCEY	(916)355-0666	4000000	MITIGATION
14.	CH		BR	FY,SM	BC		QN	CFSO	GORDON BEREZAY	(604)666-2600	107344	SUPPLEMENTATION, ENHANCE RUNS
15.	CH		CA	SM	CR	17030001	NA	YAKI	TOM SCRIBNER	(509)865-5121	0	ENHANCE RUN AND FISHERY
16.	CH		CC	SM	AC		QN	ADFG	GARY KYLE	(907)262-9369	146420	HATCHERY EVALUATION
17.	CH		CC	SM	AC		QN	ADFG	NICK DUDIAK	(907)235-8191	90000	ENHANCE FISHERY
18.	CH		CC	SM	AC		QN	ADFG	NICK DUDIAK	(907)235-8191	150000	ENHANCE FISHERY
19.	CH		CC	SM	AC		QN	ADFG	NICK DUDIAK	(907)235-8191	100000	ENHANCE FISHERY
20.	CH		CR	FN,FY	CR	17070105		ODFW	LARRY DIMMICK	(503)374-8540	900000	MITIGATION
21.	CH		EG	FY	AC		QN	ADFG	KEN ROBERSON	(907)822-5520	16000	ENHANCE PRODUCTION
22.	CH		FR	PR,SM	BC		QN	SFU	G.E. ROSBERG	(604)438-1712	0	STOCK EVALUATION
23.	CH		FT	FN	CC	18050002	QN	TCSF	HACK COLLINS	(415)454-7754	50000	ENHANCE FISHERY
24.	CH		IC	SM	CC	18010206	QN	USFS	BILL BEMIS	(916)842-6131	7000	PROVIDE SPAWNING HABITAT
25.	CH		MIXED	SM	OC		QA	ODFW	JAY NICHOLAS	(503)737-4431	0	RESEARCH
26.	CH		MT	PS,FN	CC	18010108	QN	MWSSG	GARY PETERSON	(707)629-3514	30000	SUPPLEMENTATION, ENHANCE WILD STOCKS
27.	CH		RC	YR	CC	18010209	QN	SOC	TOM GREENER	REFER TO TEXT	50000	EDUCATION
28.	CH		RW	YR	CC	18010102	QN	HBCO	STEVE SANDERS	(707)488-2253	50000	PROVIDE SALMON FOR OFF-SHORE FISHERIES
29.	CH		ST	SM	CC	18010208	QN	USFS	JACK WEST	(916)842-6131	25000	PROVIDE SPAWNING HABITAT
30.	CH		TH	FRY	BC		QN	CSFO	D.C. SEBASTIN	( ) -	0	HABITAT EVALUATION
31.	CH		WI	SM	AC		QN	ADFG	BOB CHLUPACH	(907)892-6816	260000	RESEARCH
32.	CH		WI	PS	OC	17100304	QN	ODFW	JAY NICHOLAS	(503)737-4431	1000000	RESEARCH
33.	CH	FAL		SM	CC	18010102		HFAC	JUD ELLINWOOD	(707)444-8903	12000	ENHANCE WILD STOCKS
34.	CH	FAL	BC	SM	CR	17080006	QA	ODFW	QUENTIN SMITH	(503)325-3653	4000000	MITIGATION
35.	CH	FAL	BT	PS,SM	SR	18020118	QN	FWS	GENE FORBES	(916)365-8622	16000000	MITIGATION
36.	CH	FAL	CH	EG,FY,SM	OC	17100306	QN	ODFW	JAY NICHOLAS	(503)737-4431	400000	SUPPLEMENTATION, ENHANCE RUNS
37.	CH	FAL	CH	SM	OC	17100312	QN	ODFW	AL MCGIE	(503)737-4431	0	RESEARCH, ENHANCE FISHERY
38.	CH	FAL	EL		OC		NA	ODFW	GARY SUSAC	(503)332-4744	185000	ENHANCE WILD STOCKS
39.	CH	FAL	ER	SM	CC	18010106	QN	CDFG	ROYCE GUNTER	(707)433-6325	200000	RE-ESTABLISH RUN, ENHANCE RUNS
40.	CH	FAL	ER	SM,FY,YR	OC	17100306	NA	ODFW	GARY SUSAC	(503)332-4744	1000000	ENHANCE FISHERY
41.	CH	FAL	FT	SM	SR	18020125	QN	CDFG	DON SCHLICTING	(916)538-2222	12000000	MITIGATION
42.	CH	FAL	FT	FY,SM	SR	18050002	QN	FWS	MARTY KJELSON	(209)466-4421	800000	STOCKING EVALUATION
43.	CH	FAL	FW	YR	CC	18010102	QN	HFAC	CHRISTOPHER TOOLE	(707)443-8369	14000	ENHANCE RUNS
44.	CH	FAL	GR,NQ	FN	PS	17110015	QN	NISQ	WILLIAM THOMAS	(206)456-5221	1317610	ENHANCE FISHERY AND RUN
45.	CH	FAL	GR,PU,DS,ES	FN	PS	17110019	QA	SQAX	JOHN BARR	(206)426-9783	330792	ESTABLISH FISHERY
46.	CH	FAL	GR,SS	FY	PS	17110013	NA	MUCK	DENNIS MOORE	(206)939-3311	1606484	PROVIDE FOR FISHERY, UTILIZE HABITAT
47.	CH	FAL	GV,CH,GR,GS	SM	PS	17110019	QN	SUQ	PAUL DORN	(206)598-3311	1308170	PROVIDE FOR FISHERY
48.	CH	FAL	HD,DS,FI,GA	FY,FN	PS	17110017	NA	PNPT	CHRIS WELLER	(206)297-3422	872667	ENHANCE RUN AND FISHERY
49.	CH	FAL	HL	FN,SM	CC	18010106	QN	FBSRA	WAYNE O'BRYANT	(707)925-6458	100000	ENHANCE RUNS, PROVIDE STOCK FOR ELSEWHERE
50.	CH	FAL	HR	YR	CC	18010112	QN	PCFFA	MITCH FARRO	(707)839-5664	30000	SUPPLEMENTATION, ENHANCE RUNS
51.	CH	FAL	KM	YR	CC	18010206	QN	BIA	DELMAR ROBINSON	(916)246-5141	9000	RE-ESTABLISH RUNS
52.	CH	FAL	LR	SM	CC	18010108	QN	PCFFA	MITCH FARRO	(707)839-5664	50000	SUPPLEMENTATION, ENHANCE RUNS
53.	CH	FAL	MA	FN	PS	17110019	QN	FWS	DAVID ZAJAC	(206)753-9460	450000	ENHANCE RUNS
54.	CH	FAL	MC	SM,YR	CC	18040009	QN	CDFG	MICHAEL COZART	(209)563-6410	800000	MITIGATION
55.	CH	FAL	MD	YR	CC	18010105	QN	CDFG	BRUCE BARNGROVER	(707)822-0592	200000	ENHANCE RUNS
56.	CH	FAL	MO	SM	CC	18050002	QN	CDFG	DON ESTEY	(209)759-3383	2500000	MITIGATION, ENHANCEMENT
57.	CH	FAL	NO,GR,SM,SO	FN,PS	PS	17110004	QN	LUMM	STEVE SEYMOUR	(206)734-8180	1242593	ENHANCE FISHERIES
58.	CH	FAL	PU,GR,DS	FN	PS	17110014	NA	PUT	RUSSELL LADLEY	(206)593-0254	384002	ENHANCE FISHERIES
59.	CH	FAL	SS, GR	FN,FR	PS	17110013	QA	MUCK	DENNIS MOORE	(206)939-3311	387630	PROVIDE FOR FISHERIES,
60.	CH	FAL	SY,GR,SM	FN	PS	17110019	QN	TULA	CLIFF BENGSTON	(206)653-7477	925000	PROVIDE FOR FISHERIES
61.	CH	FAL	TN	SM,YR	CC	18010212	QN	CDFG	GERALD BIDELL	(916)778-3931	1400000	MITIGATION
62.	CH	FAL	TN	YR	CC	18010212	QN	HVBC	MICHAEL ORCUTT	(916)625-4268	35000	ENHANCE RUNS
63.	CH	FAL	UM,AL	SM	OC	17100303	NA	ODFW	JERRY SWAFFORD	(503)496-3484	100000	ENHANCE WILD STOCKS
64.	CH	FAL	UNK	FN	SR	18020104	QN	FWS	JAMES SMITH	(916)527-3043	50000	HATCHERY EVALUATION

SUPPLEMENTATION REPORT

#	SPECIES	RACE	STOCK	LIFE STAGE	MAJOR DRAINAGE	SUB DRAINAGE	EVAL	AGENCY	PRINCIPAL CONTACT	PHONE	#/YEAR RELEASED	PURPOSE OF PROJECT
65.	CH	FAL	UR	SM	CR	17030001	NA	YAKI	TOM SCRIBNER	(509)865-5121	302000	ENHANCE RUN
66.	CH	FAL	URB	FY,FN	CR	17080001	NA	WDF	DICK JOHNSON	(206)837-3311	0	HABITAT UTILIZATION
67.	CH	LFA	HP	SM	CC	18010208	NA	NCIDC	RONNIE PIERCE	(707)839-3637	15000	RE-ESTABLISH RUNS
68.	CH	LFA	KM	PS	CC	18010208	QN	NCIDC	WALTER LARA,JR.	(707)482-4535	8000	RE-ESTABLISH RUNS, TRIBAL FISHERY
69.	CH	LFA	OM	WM	CC	18010208	NA	NCIDC	RONNIE PIERCE	(707)839-3637	15000	RE-ESTABLISH RUNS
70.	CH	LFA	SA	YR	SR	18020118	QN	FWS	GENE FORBES	(916)365-8622	900000	MITIGATION, ESTABLISH RUN
71.	CH	SPR		PR	BC			CFSO	GORDON BEREZAY	(604)666-8648	0	HATCHERY EVALUATION
72.	CH	SPR		SM,FY,PS	CR	17030001	QN	YAKI	DAVE FAST	(509)865-5121	100000	ENHANCE RUNS
73.	CH	SPR		FN,SM	CR			FWS	BILL MILLER	(208)476-7242	200000	SUPPLEMENTATION, ENHANCE RUNS
74.	CH	SPR		SM,FN	CR			FWS	BILL MILLER	(208)476-7242	375000	
75.	CH	SPR		FY,FN,SM,AD	CR			IDFG	BURT BOWLER	(208)743-6502	80000	
76.	CH	SPR		FY,EG	CR			IDFG	DICK SKULLY	(208)334-3791	99900	ESTABLISH RUN
77.	CH	SPR	FR	PR	BC		QN	CFSO	GORDON BEREZAY	(604)666-8646	0	EVALUATION
78.	CH	SPR	FT	SM	SR	18020125	QN	CDFG	DON SCHLICTING	(916)538-2222	2000000	MITIGATION
79.	CH	SPR	HD,CZxNK,SU	SM	PS	17110018	QN	FWS	DAVID ZAJAC	(206)753-9460	150000	ASSIST THREATENED SPECIES
80.	CH	SPR	LE	FN,FY	CR	17020011		FWS	JIM MULLEN	(509)548-7573	780000	ENHANCE WILD STOCKS
81.	CH	SPR	LO	AD	CR	17060104	QN	ODFW	RICH CARMICHAEL	(503)963-1777	0	PROVIDE TRIBAL ADULTS
82.	CH	SPR	MK	PS,SM	CR	17090004	QA	ODFW	SCOTT LUSTED	(503)896-3513	1100000	MITIGATION
83.	CH	SPR	NO	FN,PS	PS	17110004	QA	LUMM	STEVE SEYMOUR	(206)734-8180	80719	ESTABLISH FISHERY
84.	CH	SPR	NO	FY	PS	17110004	NA	NOOK	PAT PETUCHOV	(206)592-5176	200000	PROVIDE FOR FISHERY
85.	CH	SPR	RG	AD	OC	17100307	QN	ODFW	MIKE EVENSON	(503)878-2235	0	RESEARCH, ENHANCE RUNS AND FISHERY
86.	CH	SPR	RG	SM	OC	17100307	QN	ODFW	MIKE EVENSON	(503)878-2235	100000	ENHANCE FISHERY
87.	CH	SPR	SS	FY	CR	17090004	NA	ODFW	DENNIS WISE	(503)378-6925	400000	EDUCATION, ENHANCEMENT
88.	CH	SPR	TN	SM,YR	CC	18010212	QN	CDFG	GERALD BIDELL	(916)778-3931	2000000	MITIGATION
89.	CH	SPR	TR	FY	OC		QA	ODFW	JOHN CASTEEL	(503)842-2741	200000	ENHANCEMENT
90.	CH	SPR	WM	PS,SM	CR	17090009	QN	ODFW	BOB SOHLER	(503)782-2933	3300000	MITIGATION
91.	CH	SPR	WM	PS	CR	17090001	QN	ODFW	MAX SMITH	(503)726-3517	1000000	MITIGATION
92.	CH	SUM		SM	CR			IDFG	KENT BALL	(208)756-2271	950000	
93.	CH	SUM	SF	FY	CR	17060208	QN	IDFG	DICK SKULLY	(208)334-3791	178640	ESTABLISH RUN
94.	CH	SUM	ST	FN	PS	17110008	QA	STIL	KIP KILLEBREW	(206)435-8770	81093	SUPPLEMENTATION, ENHANCE RUNS
95.	CH	UNK		YR	CC	18060006		CCSE	PAUL CLEVELAND	(805)773-3316	50000	ESTABLISH RUN
96.	CH	UNK	ER	SM	CC	18010106		PCFFA	SCOTT DOWNIE	(707)923-3459	100000	REESTABLISH RUNS
97.	CH	WIN	SA	PS	SR	18020103	QN	FWS	GENE FORBES	(916)365-8622	0	ASSIST THREATENED SPECIES
98.	CM			FY	AC			ADFG	TOM KOHLER		469000	HARVEST AUGMENTATION
99.	CM			FY	AC		QN	ADFG	JOHN MCNAIR		3549811	EVALUATION
100.	CM		CL	FY	CR	17090007	NA	ODFW	WAYNE BOWERS	(503)657-6822	0	ENHANCE WILD STOCKS
101.	CM		EL,QC,WL,EN	EG,FY	PS	17110019	QA	PNPT	CHRIS WELLER	(206)297-3422	1166286	ENHANCE RUN AND FISHERY
102.	CM		ES,JC	FY,EG	PS	17110019	QN	SQAX	JOHN BARR	(206)426-9783	402767	ESTABLISH FISHERY, INITIALIZE RUN
103.	CM		FI,HD,GR,KC	FY	PS	17110013	QN	MUCK	DENNIS MOORE	(206)939-3311	530350	PROVIDE FOR FISHERY
104.	CM		FI,KC	FY	PS	17110013	QN	MUCK	DENNIS MOORE	(206)939-3311	114467	PROVIDE FOR FISHERIES
105.	CM		MA	FY	PS	17110019	NA	FWS	DAVID ZAJAC	(206)753-9460	1400000	ENHANCE RUNS (?)
106.	CM		NO		AC		QA	ADFG	JIM RAYMOND	(907)452-1531	750000	RESEARCH
107.	CM		NO	FY,EG	PS	17110004	QN	NOOK	GARY MACWILLIAMS	(206)592-5176	81000	ENHANCE FISHERY
108.	CM		NO	FY	PS	17110004	QA	NOOK	GARY MACWILLIAMS	(206)592-5176	299275	PROVIDE FOR FISHERIES, DEVELOP SURPLUS
109.	CM		NO,QC	FY	PS	17110004	QA	LUMM	STEVE SEYMOUR	(206)734-8180	183859	DEVELOP SURPLUS FOR STOCKING
110.	CM		PU,HD,GA,CH	FY	PS	17110014	QA	PUT	RUSSELL LADLEY	(206)593-0254	325050	ENHANCE FISHERIES
111.	CM		ST	FY	PS	17110008	QN	STIL	KIP KILLEBREW	(206)435-8770	460450	ENHANCE FISHERIES, INITIALIZE RUNS
112.	CM		WC	FY	PS	17110018	NA	FWS	DAVID ZAJAC	(206)753-9460	2300000	PROVIDE TRIBAL ADULTS
113.	CM		WL	FY	PS	17110018	QN	FWS	DAVID ZAJAC	(206)753-9460	3693760	ENHANCE FISHERIES
114.	CM	ENL	CW,GO,BJ	EG,FY	PS	17110019	QA	SUQ	PAUL DORN	(206)598-3311	3620000	REESTABLISH FISHERY
115.	CM	L	NQ	EG	PS	17110015	QA	NISQ	WILLIAM THOMAS	(206)456-5221	542133	REESTABLISH RUNS
116.	CM	N	KY	FR,EG	PS	17110015	QA	NISQ	WILLIAM THOMAS	(206)456-5221	312760	REESTABLISH RUNS
117.	CM	N,L	ES,JC,GS	FY,EG	PS	17110019	QA	SQAX	JOHN BARR	(206)426-9783	1906732	ESTABLISH FISHERY, REESTABLISH RUNS
118.	CM	N,L	WL	FY	PS	17110019	QN	TULA	CLIFF BENGSTON	(206)653-7477	4000000	PROVIDE FOR FISHERIES
119.	CO			FN	AC		QN	ADFG	JIM RAYMOND	(907)452-1531	125000	RESEARCH
120.	CO			FY	BC		QN	CFSO	ROBERT HURST	(604)756-7296	9500	SUPPLEMENTATION, STOCK EVALUATION
121.	CO			FN	CC	18010102		HFAC	JUD ELLINWOOD	(707)444-8903	25000	ENHANCE WILD STOCKS
122.	CO			YR	CC	18010102	QA	COAPW	DAVID HULL	(707)822-5957	1500	ENHANCE RUNS
123.	CO			FY	CR	17020011		FWS	JIM MULLAN	(509)548-7573	61800	SMOLT PRODUCTION
124.	CO			FN	CR	17080002	NA	WDF	ROBIN NICHOLAY	(206)225-7413	2000000	ENHANCE RUNS (HATCHERY)
125.	CO			YR	PS	17110008		WDF	JIM AMES	(205)753-0196	0	SUPPLEMENT TRIBAL,COMMERCIAL,NON-INDIAN SPORT FISHERY
126.	CO		AL	SM	OC	17100205	QN	ODFW	MARIO SOLAZZI	(503)737-4431	300000	RESEARCH
127.	CO		AL,SZ,CQ	FY	OC	17100206	QN	ODFW	MARIO SOLAZZI	(503)737-4431	0	RESEARCH
128.	CO		BC	SM	CR	17080006		ODFW	DAVE RIEBEN	(503)458-6512	0	MITIGATION

SUPPLEMENTATION REPORT

#	SPECIES	RACE	STOCK	LIFE STAGE	MAJOR DRAINAGE	SUB DRAINAGE	EVAL	AGENCY	PRINCIPAL CONTACT	PHONE	#/YEAR RELEASED	PURPOSE OF PROJECT
129.	CO		BC,ST	SM	CC	18060012	QN	MBSTP	DAVE STREIG	(408)458-3095	3000	ENHANCE WILD STOCKS, DEVELOP SURPLUS
130.	CO		BG	FN,PS,SM	AC		QN	ADFG	BOB CHLUPACH	(907)892-6816	1500000	
131.	CO		CC	FN	AC		QN	ADFG	NICK DUDIAK	(907)235-8191	200000	ENHANCE FISHERY
132.	CO		CC	SM	AC		QN	ADFG	NICK DUDIAK	(907)235-8191	120000	ENHANCE FISHERY
133.	CO		CH		BC		QN	CFSO	MATTHEW FOY	(604)666-3678	0	INCREASE HABITAT
134.	CO		CK	FY	PS	17110004	QN	WDF	DON HENDRICK	(206)336-9538	160500	RESEARCH, MITIGATION
135.	CO		CK	FY	PS	17110004	QN	WDF	DON HENDRICK	(206)336-9538	78700	RESEARCH, MITIGATION
136.	CO		CK	FY	PS	17110004	QN	WDF	DON HENDRICK	(206)336-9538	65400	RESEARCH, MITIGATION
137.	CO		CK,WL,GA,WR	SM	PS	17110015	QN	NISQ	WILLIAM THOMAS	(206)456-5221	395800	PROVIDE FOR FISHERY
138.	CO		CM	SM	WC	17100204	QN	ODFW	MARIO SOLAZZI	(503)737-4431	240000	RESEARCH
139.	CO		CR	SM	CR		NA	ODFW	WAYNE STENDROSKY	(503)374-8381	850000	INITIALIZE RUN
140.	CO		EL	FY	SJ	17110020	QA	PNPT	CHRIS WELLER	(206)297-3422	788060	ENHANCE RUN AND FISHERY
141.	CO		EL,DN	FY	SJ	17110021	QA	PNPT	CHRIS WELLER	(206)297-3422	94500	ENHANCE RUN AND FISHERIES, RESEARCH
142.	CO		FC	SM,PS	OC	17100205		ODFW	TIM SCHAMBER	(503)487-4152	0	ENHANCE FISHERY
143.	CO		FR	FY	BC		QN	CFSO	ROBERT HURST	(604)756-7296	10000	HABITAT EVALUATION
144.	CO		HL	YR	CC	18010106		GRC	JIM JOHNSON	(707)928-2293	15000	REESTABLISH RUNS
145.	CO		HO,QN	FY,FN	WC	17100101	QN	HOH	JIM JORGENSEN	(206)374-6582	83942	ENHANCE FISHERIES
146.	CO		HU	FY	WC	17100103	QN	WDF	DAVE SEILER	(206)586-1994	132000	
147.	CO		IC	FN,YR	CC	18010206	QN	USFS	BILL BEMIS	(916)842-6131	7000	PROVIDE SPAWNING HABITAT
148.	CO		JG	FN,YR	CC	18010102	QN	COAPW	DAVID HULL	(707)822-5957	5000	REESTABLISH RUNS, RESEARCH
149.	CO		KL,BC	SM	CR	17080006	QA	ODFW	QUENTIN SMITH	(503)325-3653	1400000	MITIGATION
150.	CO		LM	YR	CC	18010102	QN	HBCO	STEVE SANDERS	(707)488-2253	100000	PROVIDE SALMON FOR OFF-SHORE FISHERIES
151.	CO		LR	FY	CC	18010108	QN	PCFFA	MITCH FARRO	(707)839-5664	15000	INITIALIZE RUN, EDUCATION
152.	CO		LS	SM,FN	AC		QN	ADFG	BOB CHLUPACH	(907)892-6816	450000	
153.	CO		MA	FY	PS	17110019		MFM	MARK LARIVIERE	(206)645-2201	244531	ENHANCE FISHERY
154.	CO		MA	SM	PS	17110019	QN	FWS	DAVID ZAJAC	(206)753-9460	265000	ENHANCE RUNS (HATCHERY)
155.	CO		MI	FY	BC		QN	CFSO	ROBERT HURST	(604)756-7296	26000	HABITAT UTILIZATION
156.	CO		MI	FY	PS	17110019	QA	SUQ	PAUL DORN	(206)598-3311	335370	ENHANCE FISHERY
157.	CO		MI	SM	PS	17110019	QA	SUQ	PAUL DORN	(206)598-3311	57053	PROVIDE FOR FISHERY, ENHANCE FISHERY
158.	CO		MI,PU,WR,KA	FY	PS	17110015	QN	NISQ	WILLIAM THOMAS	(206)456-5221	332600	INITIALIZE RUNS
159.	CO		MIXED	SM	OC		QA	ODFW	JAY NICHOLAS	(503)737-4431	0	RESEARCH
160.	CO		MN	FY,FN	PS	17110019	QN	WDF	CHUCK BARANSKI	(206)753-0197	25000	RESEARCH
161.	CO		MT	YR,SM	CC	18010108	QN	MWSSG	GARY PETERSON	(707)629-3514	8000	SUPPLEMENTATION, ENHANCE WILD STOCKS
162.	CO		NE	SM,FY	OC	17100202		ODFW	GARY YEAGER	(503)368-6828	800000	ENHANCE WILD STOCKS
163.	CO		NO,SY,SK,SO	FN,PS	PS	17110004	QN	LUMM	STEVE SEYMOUR	(206)734-8180	1014080	ENHANCE FISHERY
164.	CO		NY	YR	CC	18010102	QN	CDFG	ALLAN GRASS	(707)743-1535	30000	ENHANCE RUNS, DEVELOP STOCKS
165.	CO		NY	YR	CC	18010105	QN	CDFG	BRUCE BARNGROVER	(707)822-0592	225000	INITIATE AND ENHANCE RUNS
166.	CO		NY,PR	YR	CC	18010102	QN	HFAC	CHRISTOPHER TOOLE	(707)443-8369	22000	ENHANCE RUNS
167.	CO		PU	FY	PS	17110014	QA	PUT	RUSSELL LADLEY	(206)593-0254	269455	ENHANCE FISHERIES
168.	CO		QC	SM	PS	17110018	QN	FWS	DAVID ZAJAC	(206)753-9460	500000	ENHANCE FISHERIES
169.	CO		QU,BL	FY	BC		QN	CFSO	ROBERT HURST	(604)756-7296	8500	ENHANCE RUNS
170.	CO		RC	YR	CC	18010209	QN	SOC	TOM GREENER	REFER TO TEXT	4000	EDUCATION
171.	CO		RS	FN,YR	CC	18010106	QN	CDFG	ROYCE GUNTER	(707)433-6325	120000	MITIGATION
172.	CO		SD	FY	CR	17090008	QN	ODFW	DENNIS WISE	(503)378-6925	750000	EDUCATION, INITIALIZE RUN
173.	CO		SN	SM	CC	18060005	QN	MBSTP	DAVE STREIG	(408)845-3095	20000	ENHANCE RUNS
174.	CO		SR	SM,AD	CR	17080001		ODFW	DICK WHITLATCH	(503)668-4222	0	MITIGATION
175.	CO		SR	FY	CR	17090007	NA	ODFW	WAYNE BOWERS	(503)657-6822	0	ENHANCE WILD STOCKS
176.	CO		ST	FN,YR	CC	18010208	QN	USFS	JACK WEST	(916)842-6131	15000	PROVIDE SPAWNING HABITAT
177.	CO		ST,SK	FN	PS	17110008	QA	STIL	KIP KILLEBREW	(206)435-8770	46999	ENHANCE FISHERIES
178.	CO		SY,SK	SM	PS	17110019	QN	TULA	CLIFF BENGSTON	(206)653-7477	718000	PROVIDE FOR FISHERIES
179.	CO		TM	FY,SM	OC	17100304	QN	ODFW	PAUL REIMERS	(503)888-5515	30000	RESEARCH, ENHANCE RUNS
180.	CO		TM	PS,SM	OC	17100304	QN	ODFW	PAUL REIMERS	(503)888-5515	180000	SUPPLEMENTATION, ENHANCE WILD STOCKS
181.	CO		TM,NY	SM,YR	CC	18010209		SRKC	BOB WILLS	(707)487-3443	10000	ENHANCE RIVER & OCEAN FISHERIES
182.	CO		TR	FY	BC		QN	CFSO	ROBERT HURST	(604)756-7296	7500	SUPPLEMENTATION
183.	CO		WA	SM	CR	17070106	NA	WDF	DICK JOHNSON	(206)837-3311	2500000	ENHANCE RUNS (HATCHERY)
184.	CO	FAL	CZ	FN	CR	17070105	QN	WDF	DAVE SEILER	(206)586-1994	505000	PASSAGE EVALUATION
185.	CO	FAL	CZ	FN	CR	17070105	QN	WDF	DAVE SEILER	(206)586-1994	0	PASSAGE EVALUATION
186.	CO	FAL	DN	SM	PS	17110018	QN	WDF	TIM FLINT	(206)753-0198	64850	HATCHERY EVALUATION
187.	CO	FAL	DN	FY	PS	17110018	QN	WDF	TIM FLINT	(206)753-0198	27447	
188.	CO	FAL	GH	FN	WC	17100103	QN	WDF	RICK BRIX	(206)249-4628	716000	RESEARCH
189.	CO	FAL	GH	SM	WC	17100105	QN	WDF	RICK BRIX	(206)249-4628	0	EVALUATION
190.	CO	FAL	GH	PS	WC	17100105	QN	WDF	RICK BRIX	(206)249-4628	257000	EVALUATION
191.	CO	FAL	GR	FY	PS	17110019	QA	WDF	TIM FLINT	(206)753-0198	58000	HATCHERY EVALUATION
192.	CO	FAL	GR	FY	PS	17110013	QN	WDF	DAVE SEILER	(206)586-1994	3099080	PASSAGE EVALUATION

SUPPLEMENTATION REPORT

#	SPECIES	RACE	STOCK	LIFE STAGE	MAJOR DRAINAGE	SUB DRAINAGE	EVAL	AGENCY	PRINCIPAL CONTACT	PHONE	#/YEAR RELEASED	PURPOSE OF PROJECT
193.	CO	FAL	GR,PU	SM	PS	17110015	QN	WDF	TIM FLINT	(206)753-0198	196750	
194.	CO	FAL	HU	PS	WC	17100105	QN	WDF	RICK BRIX	(206)249-4628	0	RESEARCH
195.	CO	FAL	LW	FY,SN	CR	17080002	QN	WDF	GREG JOHNSON	(206)753-3956	161805	RESEARCH
196.	CO	FAL	MI	FN	PS	17110019	QN	WDF	TIM FLINT	(206)753-0198	36000	RESEARCH
197.	CO	FAL	PU	SM	PS	17110015	QN	WDF	TIM FLINT	(206)753-0198	53150	HATCHERY EVALUATION
198.	CO	FAL	PU,MI	FY	PS	17110016	QN	WDF	TIM FLINT	(206)753-0198	1457265	ENHANCE RUNS
199.	CO	FAL	QC,MI	FY	PS	17110018	QN	WDF	RICH KOLB	(206)586-9344	0	
200.	CO	FAL	SD	FY	WC	17100101	QN	WDF	DAVE SEILER	(206)586-1994	0	HATCHERY EVALUATION
201.	CO	FAL	SD,QT	FY	WC	17100101	QN	WDF	DAVE SEILER	(206(586-1994	0	HATCHERY EVALUATION
202.	CO	FAL	SD,SR	FY	WC	17100102	QN	WDF	DAVE SEILER	(206)586-1994	123731	HATCHERY EVALUATION
203.	CO	FAL	SY	SM	PS	17110016	QN	WDF	TIM FLINT	(206)753-0198	0	ENHANCE RUN
204.	CO	FAL	TOUTLE	FN	CR	17080005	QN	WDF	GREG JOHNSON	(206)753-3956	1200000	MITIGATION, ENHANCE FISHERIES
205.	CU	SEA	CO	SM,FN	WC	17100103	QA	WDW	BILL FREYMOND	(206)533-9335	23400	PROVIDE FOR FISHERY
206.	CU	SEA	CO	SM,FN	WC	17100104	QA	WDW	BILL FREYMOND	(206)533-9335	26090	PROVIDE FOR FISHERY
207.	CU	SEA	CO	SM,FN	WC	17100105	QA	WDW	BILL FREYMOND	(206)533-9335	7325	PROVIDE FOR FISHERY
208.	CU	SEA	CO	SM,FN	WC	17100105	QA	WDW	BILL FREYMOND	(206)533-9335	6792	PROVIDE FOR FISHERY
209.	CU	SEA	CO	SM,FN	WC	17100101	QA	WDW	BILL FREYMOND	(206)533-9335	3000	PROVIDE FOR FISHERY
210.	CU	SEA	RW	YR	CC	18010102	QA	HBCO	STEVE SANDERS	(707)488-2253	500	SUPPLEMENTATION, ENHANCE WILD STOCKS
211.	CU	SEA	SH	SM,FN	PS	17110019	QA	WDW	BILL FREYMOND	(206)533-9335	1000	PROVIDE FOR FISHERY
212.	CU	SEA	SH	SM	PS	17110018	QA	WDW	BILL FREYMOND	(206)533-9335	29905	PROVIDE FOR FISHERY
213.	CU	SEA	SH	SM,FN	PS	17110017	QA	WDW	BILL FREYMOND	(206)533-9335	35820	PROVIDE FOR FISHERY
214.	CU	SEA	SO	YR	CC	18010102	QN	HSU	ERIC LOUDENSLAGER	(707)826-3445	40000	ESTABLISH FISHERY
215.	PK			FY	AC		QN	ADFG	TIM MCDANIEL		1200000	ESTABLISH A RUN
216.	PK				AC		QN	ADFG	TOM KOHLER		0	HARVEST AUGMENTATION
217.	PK		ST	FY	PS	17110008	QN	STIL	KIP KILLEBREW	(206)435-8770	172500	ENHANCE FISHERIES
218.	PK		TU	FY	AC		QN	ADFG	NICK DUDIAK	(907)235-8191	300000	ENHANCE FISHERY
219.	SH			FY	BC		QN	MEBC	JEREMY HUME	(604)660-1812	0	SUPPLEMENTATION
220.	SH			SM,YR	CC	18010109	NA	GRSP	DON MCDONALD	(707)884-3884	30000	ENHANCE WILD STOCKS
221.	SH		AC	FN,YR	CC	18010110	NA	PSD	TOM FURRE	(707)778-4703	0	REESTABLISH RUNS
222.	SH		AL	SM	OC		QN	ODFW	KEN KENASTON	(503)737-4431	280000	RESEARCH
223.	SH		AM	TY	SR	18040005	QN	CDFG	RON DUCEY	(916)355-0666	450000	MITIGATION
224.	SH		AR	SM,FN	AC			ADFG	NICK DUDIAK	(907)235-8191	10000	ENHANCE FISHERY
225.	SH		BC,ST	SM	CC	18060012	QN	MBSTP	DAVE STREIG	(408)458-3095	5000	ENHANCE WILD RUNS
226.	SH		CM	YR	CR	17020008	QN	WDW	JOE FOSTER	(506)754-4624	0	MITIGATION
227.	SH		CR	PS,SM,20,30	CC	18060012	NA	CRSA	ROY THOMAS	(408)625-2255	14000	ENHANCE WILD STOCKS
228.	SH		ER	YR	CC	18010106		GRC	JIM JOHNSON	(707)923-2293	25000	REESTABLISH RUNS
229.	SH		ER	YR	CC	18010102	QN	HBCO	STEVE SANDERS	(707)488-2253	50000	ENHANCE IN-RIVER FISHERY
230.	SH		FT	FN,YR	SR	18020125	QN	CDFG	DON SCHLICTING	(916)538-2222	3000000	MITIGATION
231.	SH		GR	YR	CC	18010108	NA	FOG	CRAIG BELL	(707)882-2150	30000	ENHANCE WILD STOCKS
232.	SH		IC	YR	CC	18010206	QN	USFS	BILL BEMIS	(916)842-6131	250	PROVIDE SPAWNING HABITAT
233.	SH		JC	FN,YR	CC	18010102	QN	COAPW	DAVID HULL	(707)822-5957	2000	REESTABLISH RUNS, RESEARCH
234.	SH		KR	SM	BC		QN	MEBC	BRUCE WARD	(604)660-1812	20000	SUPPLEMENTATION
235.	SH		MA	FY	PS	17110019		MFM	MARK LARIVIERE	(206)645-2201	96359	ENHANCE FISHERY
236.	SH		MD	YR	CC	18010105	NA	CDFG	BRUCE BARNGROVER	(707)822-0592	400000	ENHANCE RUNS
237.	SH		MO	YR	CC	18050002	NA	CDFG	DON ESTEY	(209)759-3383	50000	MITIGATION, ENHANCEMENT
238.	SH		NP	YR	CC	18050002	QN	NRS	GEORGE CARL	(707)252-1440	7000	SUPPLEMENTATION, ENHANCE RUNS
239.	SH		RC	YR	CC	18010209		SOC	TOM GREENER	REFER TO TEXT	50000	EDUCATION
240.	SH		RS	YR	CC	18010109	NA	MCFG	BILL TOWNSEND	(707)462-5228	70000	ENHANCE WILD STOCKS
241.	SH		RS	YR	CC	18010106	NA	CDFG	ROYCE GUNTER	(707)433-6325	200000	MITIGATION
242.	SH		SM	PS	SC	18010209	NA	RHSI	DENNIS CONGER	(707)464-7441	800	EDUCATION
243.	SH		SMITH RIVER		CC			SRKC	BOB WILLS	(707)487-3443	75000	ENHANCE FISHERIES
244.	SH		SN	SM	CC	18060005	QN	MBSTP	DAVE STREIG	(408)458-3095	40000	ENHANCE RUNS
245.	SH		ST	VA	CC	18010208	QN	USFS	JACK WEST	(916)842-6131	400	PROVIDE SPAWNING HABITAT
246.	SH		TU,BC,SL	YR	CC	18010112	QN		DAVID REIELS	(916)628-5012	6000	RESCUE STRANDED FISH
247.	SH		VA	SM	OC		QN	ODFW	KEN KENASTON	(503)737-4431	1000000	RESEARCH
248.	SH		YK,SK,RI,PR	SM,FY	CR	17030002	QA	WDW	JIM CUMMINS	(509)575-2740	0	SUPPLEMENTATION, ENHANCE WILD STOCKS
249.	SH	SUM		FN	CR		QN	IDFG	KENT BALL	(208)756-2271	790000	
250.	SH	SUM		SM,AD	CR	17060305	QN	FWS	BILL MILLER	(208)476-7242	1200000	MITIGATION
251.	SH	SUM		AD,FY,SM	CR		QA	FWS	BILL MILLER	(208)476-7242	1000000	SUPPLEMENTATION, ENHANCE RUNS
252.	SH	SUM	CH	SM	PS	17110015	QA	WDW	BOB LELAND	(206)753-5700	23632	PROVIDE FOR FISHERY, ENHANCE WILD STOCKS
253.	SH	SUM	DS	SM	CR	17070306	QN	ODFW	JIM NEWTON	(503)296-4628	162000	MITIGATION
254.	SH	SUM	DS	SM	CR	17070306	QN	ODFW	BOB LINDSAY	(503)737-4431	127000	RESEARCH, ENHANCE FISHERY
255.	SH	SUM	MK,SS	SM	CR	17090004	QA	ODFW	SCOTT LUSTED	(503)896-3513	120000	MITIGATION
256.	SH	SUM	NR	FY	BC		QN	MEBC	BRAIN BLACKMAN	(604)565-6413	23550	SUPPLEMENTATION, ENHANCE PRODUCTION

SUPPLEMENTATION REPORT

#	SPECIES	RACE	STOCK	LIFE STAGE	MAJOR DRAINAGE	SUB DRAINAGE	EVAL	AGENCY	PRINCIPAL CONTACT	PHONE	#/YEAR RELEASED	PURPOSE OF PROJECT
257.	SH	SUM	SC	FY	BC		QN		BOB GRIFFITH	(604)387-3660	11400	SUPPLEMENTATION
258.	SH	SUM	SK	SM	CR	17090004	QA	ODFW	JOHN HOSKINS	(503)896-3294	108000	INITIALIZE RUN, ENHANCE RUN
259.	SH	SUM	SK	SM	OC	17090006		ODFW	GREG LIPSIEA	(503)367-3437	220000	MITIGATION
260.	SH	SUM	SK	SM	PS	17110005	QA	WDW	BOB LELAND	(206)753-5700	25350	PROVIDE FOR FISHERY
261.	SH	SUM	SR	SM,FY,FN,AD	CR		QA	IDFG	KENT BALL	(208)756-2271	900000	REESTABLISH RUN, RELOCATION
262.	SH	WIN		FY	CR	17090007	NA	ODFW	WAYNE BOWERS	(503)657-6822	0	ENHANCE WILD STOCKS
263.	SH	WIN		SM,PS	OC	17090008		ODFW	LYLE CURTIS	(503)994-8606	80000	REESTABLISH RUNS
264.	SH	WIN	AL	SM	OC	17100304		ODFW	PAUL REIMERS	(503)888-5515	30000	INITIALIZE RUN, ENHANCE RUNS
265.	SH	WIN	AL,CQ	SM	OC	17100205		ODFW	TERRY FISHER	(503)487-7240	675000	ENHANCEMENT
266.	SH	WIN	BC	SM	CR	17080003		ODFW	MEL KELLY	(503)455-2234	570000	MITIGATION
267.	SH	WIN	BC	SM	OC	17090005		ODFW	DAN BARRETT	(503)394-2496	75000	ENHANCE RUNS
268.	SH	WIN	BC,KL	SM	CR	17080006	QA	ODFW	QUENTIN SMITH	(503)325-3653	650000	MITIGATION
269.	SH	WIN	BG,QN,CH	SM	WC	17100105	QN	WDW	BILL FREYMOND	(206)533-9335	85825	PROVIDE FOR FISHERY, ENHANCE WILD STOCKS
270.	SH	WIN	BT,SA	YR	SR	18020118	QN	FWS	GENE FORBES	(916)365-8622	1000000	MITIGATION
271.	SH	WIN	CC	SM	OC	17090008		ODFW	CHARLIE STANLEY	(503)392-3485	340000	ENHANCE RUN
272.	SH	WIN	CH	SM	PS	17110019	QA	SQAX	JOHN BARR	(206)426-9783	44258	ESTABLISH FISHERY
273.	SH	WIN	CH	SM	PS	17110018	QN	WDW	BILL FREYMOND	(206)533-9335	80840	PROVIDE FOR FISHERY, ENHANCE WILD STOCKS
274.	SH	WIN	CH	SM	PS	17110017	QN	WDW	BILL FREYMOND	(206)533-9335	24310	PROVIDE FOR FISHERY, ENHANCE WILD STOCKS
275.	SH	WIN	CH	SM	PS	17110014	QN	WDW	BOB LELAND	(206)753-5700	142080	PROVIDE FOR FISHERY, ENHANCE WILD STOCKS
276.	SH	WIN	CH	SM	PS	17110013	QN	WDW	BOB LELAND	(206)753-5700	192580	PROVIDE FOR FISHERY, ENHANCE WILD STOCKS
277.	SH	WIN	CH	SM	PS	17110012	QN	WDW	BOB LELAND	(206)753-5700	58515	PROVIDE FOR FISHERY, ENHANCE WILD STOCKS
278.	SH	WIN	CH	SM	PS	17110007	QN	WDW	BOB LELAND	(206)753-5700	248260	PROVIDE FOR FISHERY, ENHANCE WILD STOCKS
279.	SH	WIN	CH	SM	PS	17110002	QN	WDW	BOB LELAND	(206)753-5700	37255	PROVIDE FOR FISHERY, ENHANCE WILD STOCKS
280.	SH	WIN	CH	SM	PS	17110019	QA	TULA	CLIFF BENGSTON	(206)653-7477	60000	PROVIDE FOR FISHERIES
281.	SH	WIN	CH	SM	PS	17110019	QN	WDW	BOB LELAND	(206)753-5700	22667	PROVIDE FOR FISHERY
282.	SH	WIN	CH	SM	PS	17110016	QN	WDW	BOB LELAND	(206)753-5700	35000	PROVIDE FOR FISHERY
283.	SH	WIN	CH	SM	PS	17110008	QA	WDW	BOB LELAND	(206)753-5700	110425	PROVIDE FOR FISHERY
284.	SH	WIN	CH	SM	SJ	17110020	QN	WDW	BILL FREYMOND	(206)533-9335	3610	PROVIDE FOR FISHERY, ENHANCE WILD STOCKS
285.	SH	WIN	CH	SM	SJ	17110020	QN	WDW	BILL FREYMOND	(206)533-9335	69100	PROVIDE FOR FISHERY, MITIGATION
286.	SH	WIN	CH	SM	SJ	17110021	QN	WDW	BILL FREYMOND	(206)533-9335	63925	PROVIDE FOR FISHERY, ENHANCE WILD STOCKS
287.	SH	WIN	CH	SM	WC	17100104	QN	WDW	BILL FREYMOND	(206)533-9335	17795	ENHANCE FISHERY AND WILD STOCKS
288.	SH	WIN	CH,BG	SM,FY	WC	17100101	QN	WDW	BILL FREYMOND	(206)533-9335	171711	SUPPLEMENTATION, ENHANCE WILD STOCKS
289.	SH	WIN	CH,NO	SM	PS	17110004	QN	WDW	BOB LELAND	(206)753-5700	115600	PROVIDE FOR FISHERY
290.	SH	WIN	CH,SK	SM	PS	17110007	QA	SKAG	JIM GIBSON	(206)466-3163	50000	ENHANCE FISHERY
291.	SH	WIN	CH,SN	SM	PS	17110009	QA	WDW	BOB LELAND	(206)753-5700	339925	PROVIDE FOR FISHERY, ENHANCE WILD STOCKS
292.	SH	WIN	CH,SN	SM	PS	17110010	QA	WDW	BOB LELAND	(206)753-5700	339925	PROVIDE FOR FISHERY, ENHANCE WILD STOCKS
293.	SH	WIN	CH,SN	SM	PS	17110011	QA	WDW	BOB LELAND	(206)753-5700	339925	PROVIDE FOR FISHERY, ENHANCE WILD STOCKS
294.	SH	WIN	CH,SO	SM	WC	17100104	QN	WDW	BILL FREYMOND	(206)533-9335	65793	PROVIDE FOR FISHERY, ENHANCE WILD STOCKS, MITIGATION
295.	SH	WIN	CH,VW	SM	WC	17100104	QN	WDW	BILL FREYMOND	(206)533-9335	11250	PROVIDE FOR FISHERY, ENHANCE WILD STOCKS
296.	SH	WIN	CH,WK	SM	WC	17100104	QN	WDW	BILL FREYMOND	(206)533-9335	51492	PROVIDE FOR FISHERY, ENHANCE WILD STOCKS
297.	SH	WIN	CH,WY	SM	WC	17100104	QN	WDW	BILL FREYMOND	(206)533-9335	63267	PROVIDE FOR FISHERY, ENHANCE WILD STOCKS, MITIGATION
298.	SH	WIN	CL	SM	CR	17090011		ODFW	GEORGE NANDOR	(503)630-7210	30000	MITIGATION
299.	SH	WIN	CO,CH	SM,EG	CR	17070105	NA	WDW	ULF RASSMUSSEN	(206)837-3131	300000	ENHANCE FISHERY
300.	SH	WIN	EL	FN	PS	17110017	QA	PNPT	CHRIS WELLER	(206)297-3422	71545	ENHANCE RUN AND FISHERY, HATCHERY EVALUATION
301.	SH	WIN	GR,GS	FN	PS	17110013	NA	MUCK	DENNIS MOORE	(206)939-3311	30035	PROVIDE FOR FISHERY, UTILIZE HABITAT
302.	SH	WIN	GS,CH,GR	SM	PS	17110013	QN	MUCK	DENNIS MOORE	(206)939-3311	31665	PROVIDE FOR FISHERY
303.	SH	WIN	KR		BC		QN	CFSO	PAT A. SLANEY	(604)228-1158	0	ENHANCE PRODUCTION
304.	SH	WIN	MA	SM	PS	17110019	QN	FWS	DAVID ZAJAC	(206)753-9460	65000	ENHANCE RUNS (HATCHERY)
305.	SH	WIN	MF	FY	CR	17090005	QN	ODFW	DENNIS WISE	(503)378-6925	150000	EDUCATION, ENHANCEMENT
306.	SH	WIN	NS	FY	CR	17090008	QN	ODFW	DENNIS WISE	(503)378-6925	150000	EDUCATION, ENHANCEMENT
307.	SH	WIN	NS	SM	OC	17090005		ODFW	RANDY WINTERS	(503)854-3522	220000	MITIGATION
308.	SH	WIN	PU,QN	FN	PS	17110014	QA	PUT	RUSSELL LADLEY	(206)593-0254	35778	ENHANCE FISHERIES
309.	SH	WIN	QN,GV	SM	PS	17110019	QN	SUQ	PAUL DORN	(206)598-3311	36715	DEVELOP SURPLUS FOR STOCKING
310.	SH	WIN	WI	FY	PS	17110019	QN	WDW	TOM JOHNSON	(206)765-3979	0	RESEARCH
311.	SO			FN,FY	AC		QN	ADFG	NICK DUDIAK	(907)235-8191	2000000	ENHANCE FISHERY
312.	SO			FN	AC		QN	ADFG	DAVID LITCHFIELD	(907)262-9369	1400000	SUPPLEMENTATION, ENHANCE RUN
313.	SO			EG	AC		QN	ADFG	LORNE WHITE	(907)486-4791	6000000	SUPPLEMENTATION, ENHANCE NATURAL RUN
314.	SO		GU	FY	AC		QA	ADFG	KEN ROBERSON	(907)822-5520	9999999	PROVIDE BROODSTOCK AND ENHANCE FISHERIES
315.	SO		GU	FRY	AC		QN	ADFG	KEN ROBERSON	(907)822-5520	9999999	ENHANCE FISHERIES
316.	SO		GU	FY	AC		QA	ADFG	KEN ROBERSON	(907)822-5520	3000000	EVALUATE ENHANCEMENT

Technical Report 90-1

SUPPLEMENTATION OF SALMON AND STEELHEAD STOCKS WITH HATCHERY FISH: A SYNTHESIS OF PUBLISHED LITERATURE

by

C.R. Steward and T.C. Bjornn

Idaho Cooperative Fish and Wildlife Research Unit
University of Idaho, Moscow, Idaho

for

The Office of Information Transfer
U.S. Fish and Wildlife Service
Fort Collins, Colorado

Dworshak Fisheries Assistance Office
U.S. Fish and Wildlife Service
Ahasaka, Idaho

and

Bonneville Power Administration
Portland, Oregon

1990

Preface

This report was prepared as part of a Bonneville Power Administration (BPA) funded project to summarize information on supplementation of salmon and steelhead stocks with hatchery fish, Project No. 88-100. Tom Vogel was BPA project officer. The primary geographic area of concern was the northwestern United States with special emphasis on the Columbia River basin.

Three reports were prepared for the BPA project:

1. Analysis of Salmon and Steelhead Supplementation: Emphasis on Unpublished Reports and Present Programs, by W.H. Miller, T.C. Coley, H.L. Burge, and T.T. Kisanuki.

2. Supplementation of Salmon and Steelhead Stocks with Hatchery Fish: A Synthesis of Published Literature, by C.R. Steward and T.C. Bjornn.

3. Concepts for a Model to Evaluate Supplementation of Natural Salmon and Steelhead Stocks with Hatchery Fish, by T.C. Bjornn and C.R. Steward.

Reports 2 and 3 were prepared under contract with the Idaho Cooperative Fish and Wildlife Research Unit at the University of Idaho. The U.S. Fish and Wildlife Service, Office of Information Transfer helped fund the preparation of Report 2.

The overall objectives of the BPA funded project were to: (1) summarize and evaluate past and current supplementation of salmon and steelhead, (2) develop a conceptual model of processes affecting the results of supplementation, and (3) make recommendations relative to future supplementation research and needs.

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Abstract

A synthesis of information related to the supplementation of salmon and steelhead stocks with hatchery fish was prepared from a review of published literature. We located few studies where the effects of supplementation (defined as the use of hatchery-propagated fish to augment naturally producing stocks) were directly assessed. However, a large number of related studies contained useful information. We focused on hatchery x wild fish interactions and various ecological and methodological factors that influence them.

Genetic and ecological effects, and changes in productivity of the native stocks that can result from supplementation remain largely unmeasured. Releases of hatchery fish into areas inhabitated by wild stocks can theoretically cause a loss of genetic variation and adaptedness when wild and hatchery fish interbreed, and a reduction in stock size resulting from competitive interactions, increased predation (including fishing), and the introduction of disease.

For many stocks of salmon and steelhead under consideration for supplementation, the environments that they migrate through and in which they must spawn and rear no longer exist in a pristine state. The environmental changes have created a new assortment of selective pressures to which the stocks must respond. Adaptations that formerly enhanced survival and reproduction may prove to be inadequate or even maladaptive in the altered habitats. Supplementation, if done improperly, can be an added burden for the native stocks attempting to adapt to significant environmental changes.

Based on principles of population genetics and a limited number of empirical observations, offspring of matings between hatchery x wild spawners would be expected to perform less well on average than pure wild-strain progeny, unless the hatchery fish are indistinguishable from the wild fish. Hybridization can break down complex genetic adaptations to specific environments, and thereby reduce the fitness of progeny of hatchery x wild matings. Many fisheries geneticists, therefore, recommend that locally adapted wild fish be used to start and replenish hatchery broodstocks. Management practices that promote genetic or phenotypic divergence between hatchery and wild stocks are discouraged where the hatchery fish are going to be used to supplement wild stocks of fish. Gene flow into non-targeted wild stocks due to straying should also be minimized to maintain and strengthen the adaptation of stocks to their environment.

The risk of hatchery stocks developing undesirable genetic characteristics increases when small numbers of closely related individuals are used as broodstock, when there is purposeful

selection for specific traits, and when outcrossing with wild fish does not occur routinely. If the traits responsible for poor performance by hatchery fish have a genetic basis, and hatchery and wild fish subsequently interbreed, the wild gene pool may be diluted or otherwise altered. Potentially negative impacts include the introduction or increase in frequency of undesirable alleles, the disruption of locally adapted gene complexes, and the swamping or homogenization of the indigenous gene pool through substantial and repeated introductions of hatchery fish. Even when reproductively isolated from the wild stock, hatchery fish can act as agents of natural selection if they interaction with other components of the ecosystem that interact with the wild fish.

Most stocks of anadromous salmonids used for supplementation do not appear to have experienced significant population bottlenecks or inbreeding effects, but there have been instances of maladaptive selection. An example is the lower reproductive success observed among naturally spawning hatchery fish that have been selected for early spawning. Hatchery fish and their progeny are more likely to encounter unfavorable conditions, and therefore experience higher natural mortality, when they spawn earlier than normal in a given environment.

Once released from the hatchery, stocked salmonids may interact with their environment, including wild fish, through competition, predator-prey, parasite-host, and pathologic relationships. Hatchery and wild fish have similar ecological requirements and therefore are potential competitors, but the competitiveness of hatchery fish varies with broodstock, hatchery history, fish health, and environment. In general, the longer a fish has been held in the hatchery the less likely it will be able to compete successfully with wild fish once released. In the absence of natural stimuli, fish in the hatchery fail to acquire learned recognition of natural food and predators. Stocked hatchery fry experience high mortality (as do wild fry), but are thought to be least impaired by hatchery conditioning. Hatchery fish stocked as smolts tend to fare well because of reduced competitive pressures, if they are healthy and migrate to the sea soon after release.

Whether hatchery fish significantly alter the behavior, growth, and survival of wild fish remains a controversial subject. Recently introduced hatchery fish, even those poorly adapted to the environment, may elicit high levels of activity and stress among wild fish. Although rare, wild fish may be displaced under certain circumstances. Hatchery fish may out compete smaller wild fish, especially if they are stocked as fry or fingerlings prior to emergence of the wild fish.

Growth and survival of salmon and trout that rear for extended periods in freshwater is believed to be density-dependent. The potential for density-dependent effects depends on the abundance and distribution of hatchery and wild fish relative to the carrying capacity of the environment. A few studies have reported lower growth or survival among wild fish following supplementation.

Adding hatchery salmon and steelhead to drainages can also affect the status of other taxa, particularly closely related salmonid species, through competition and predation. Even when they are not pisciverous, hatchery salmonids may indirectly increase predation mortality among wild fish. Large concentrations of hatchery fish may attract larger than normal numbers of bird, fish, and human predators.

Disease must be considered in an evaluation of supplementation because it is a major cause of mortality in hatchery fish and the hatchery fish may serve as disease vectors. Fish immunogenetic defense systems are often species- and stock-specific, providing another argument for using native or closely related salmonid stocks for hatchery broodstock.

Survival of hatchery-produced fish in streams depends on the match of the stocks with environmental conditions, rearing procedures, the method of stocking, stocking densities, size or age at release, and time and location of release. Supplementation managers must consider stocking densities and schedules in light of program objectives and resources, the carrying capacity of the ecosystem, the proportion of limiting resources used by competitors, and the viability (survival and reproductive success) of hatchery-produced fish.

Introduction

Scope of the Review

Anadromous salmonids are artificially propagated in many parts of the world to supplement natural production. In the Pacific Northwest, supplementation is used to maintain commercial and recreational fisheries at acceptable levels and to rebuild natural stocks that have been weakened by overharvest or habitat alteration. The effectiveness of supplementation is currently the subject of much debate and controversy. There have been successes in restoring and supplementing natural runs of salmonids using hatchery-produced fish (Miller et al. 1990). However, the general failure of supplementation to achieve management objectives is evident from the continued decline of wild stocks in some areas despite, and perhaps partly due to, increases in hatchery production (Hankin 1982; National Council on Gene Resources 1982; Nelson and Soule 1987).

The purpose of this report is to provide a synthesis of existing knowledge of supplementation based on a review of published scientific literature. The success of supplementation hinges on the post-stocking growth, survival, and reproduction of hatchery fish, their subsequent integration into existing runs of wild fish, and the subsequent productivity of the wild-hatchery stock. We consider, therefore, not only the consequences of superimposing hatchery-produced fish on wild stocks, but how intrinsic (behavioral, physiological, and morphological) and extrinsic (hatchery procedures, release strategies and conditions) factors affect the ecological performance of hatchery fish. We note where appropriate those observations that appear to lack a firm scientific basis.

Of particular interest with regard to supplementation are the potential genetic and disease implications of stocking, the degree and types of ecological interactions (chiefly competition and predation), and the exploitation and management of mixed-stock fisheries. We discuss stocking parameters and release strategies that are likely to affect interactions between hatchery and naturally-produced fish. This review does not provide comment on economic, political, or social constraints affecting management decisions, even though these factors have a strong bearing on the direction and success of supplementation programs.

Emphasis is on anadromous stocks of salmon and steelhead from the Pacific Northwest. Where possible, we report findings from studies of Columbia and Snake River salmonid stocks. Investigations of other salmonid species and geographic locales are discussed if they provide useful information.

Goals of Supplementation

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.

Although the emphasis and practical details may vary, several goals are common to most supplementation programs:

1. protect or restore the genetic integrity and productivity of natural stocks,

2. optimize use of natural habitats (through stocking and management for optimum spawning escapements), and

3. maximize cost-effectiveness, and

4. provide a harvestable surplus of fish.

The attainment of these goals requires an understanding of the genetic and ecological consequences of overlapping and possibly interbreeding stocks of hatchery and wild fish, and a resourcefulness and commitment on the part of managers in applying this knowledge. Acceptable levels of productivity and ecosystem stability require management policies that are based on an understanding of long-term effects and requirements to conserve the gene resources of natural stocks. Habitat alterations, increased fishing demand (recreational, commercial, and subsistence), and increased consumption of fish will amplify the need to consider supplementation as a means of producing more fish. Better information than is now available will be needed to improve the effectiveness of supplementation, including the operation of existing and proposed hatcheries and fisheries management (Davidson et al. 1989).

Some Definitions

In this report, we distinguish salmonids that are naturally produced from those that are artificially-propagated. Naturally-produced fish are those that result from natural spawning in streams and are usually of three types: (1) stocks that have been present in a drainage for several thousand years and are usually referred to as native or indigenous stocks, (2) stocks that have been established in vacant areas or restored in depopulated areas by man during the last 200 years and have developed into self-perpetuating stocks that some may call feral stocks, and (3) a stock that has been supplemented (regularly or sporadically) and includes fish of types 2 or 3 above and hatchery fish that spawn naturally (mating with each other) and produce offspring that spend their lives in the natural environment. We use the term wild synonymously with natural to refer to naturally-produced fish without regard to the origin or genetic history of the parental stock (Hankin 1981; Leider et al. 1984, 1986).

Hatchery fish are those that, regardless of parent stock, have been spawned, incubated, hatched or reared in a hatchery or other artificial production facility. The divergence between hatchery and wild stocks that may be supplemented depends in large part on the origin of the hatchery broodstock and the duration and history of their captivity.

Sources of Information

References used in this review were obtained through computer-aided searches of the following literature databases: Biosis, Dissertation Abstracts, Aquatic Sciences Abstracts, Aquaculture, and Water Resources. Separate searches were made of FISHLIB - the fisheries literature database maintained by the Idaho Cooperative Fish and Wildlife Research Unit - and various published reviews which addressed supplementation issues. The bibliography of this report contains references that we consider relevant to supplementation, even

if they are not specifically mentioned in the text. With few exceptions, the references cited in the review and listed in the bibliography are published articles from journals and symposia.

Worthy of special recognition are several reviews and symposia proceedings which describe the propagation and stocking of anadromous salmonids. Of the literature reviews obtained, Kelly et al. (1988a, b) summarized interactions between hatchery and wild salmonids, giving particular attention to genetic and management concerns. Potter et al. (1982) reviewed the effects of stocking on the population and structural parameters of native and non-native salmonids. Kelly et al. (1988) and Potter et al. (1982) discuss management techniques and criteria for evaluating the success of stocking programs. Competition and predator-prey interactions are reviewed in Miller (1958) and Clady (1973). Post-stocking movements of fish are discussed by Cresswell (1981). Clady (1973) reviews management procedures influencing the return to the creel of stocked catchable-size rainbow trout.

Prominent among the supplementation literature are several papers presented at the Symposium on the Role of Fish Culture in Fisheries Management (R.H. Stroud [editor] 1986). The symposium proceedings contain a surfite of information on subjects related to the stocking of cold and warmwater fish species. We recommend it as a companion piece to this report. Also recommended are the collection of papers presented in the book "Population Genetics and Fishery Management," edited by Nils Ryman and Fred Utter (1987).

Genetic Concerns

Overview

Genetic resources are important to the well-being of hatchery and wild salmon and trout stocks and the fisheries they support (National Council on Gene Resources 1982). Increases in fishing intensity and gear selectivity, developments in hatchery technology and stocking programs, and habitat alterations and losses are all suspected to have affected the genetic composition of hatchery and wild stocks (Philipp et al. 1986; Nelson and Soule 1987). The effects may be precipitous, as when stocks are overfished (Berst and Simon 1981), decimated by disease (O'Brien and Evermann 1989), or otherwise rapidly reduced to a few individuals. Genetic material may also be lost more gradually through intraspecific hybridization, inbreeding, genetic drift and artificial selection (Kapuscinski and Jacobson 1987).

Salmonid species consist of numerous, more or less reproductively isolated subpopulations, that we refer to as stocks, each adapted in varying degrees to their respective environments (Ihssen et al. 1981; Kapuscinski and Philipp 1988). Genetic variability arising from within- and between-stock differences in genetic composition is important for two reasons. First, genetic diversity is necessary if species are to successfully adapt to future natural and man-caused environmental changes (Thorpe et al. 1981). Preventing the erosion of existing genetic diversity is essential if stock productivity is to be maintained (Wilkins 1981). Second, genetic diversity is the basis of artificial selection programs (National Council on Gene Resources 1982; Davidson et al. 1989). Best results

are obtained when the hatchery stock contains a large amount of genetic variability (Allendorf and Ryman 1987).

A certain amount of selection is inevitable in all aquaculture ventures, including supplementation. Selection, intentional or otherwise, increases the risk that hatchery fish will perform poorly under natural conditions. If the phenotypic traits responsible for the poor performance are heritable, and hatchery and wild fish subsequently interbreed, the gene pool of the wild stock may be altered and performance of the resulting population lowered. Hatchery fish can altering the genetic structure of wild stocks through interbreeding, and can also alter the natural selection factors through their interaction with other components of the ecosystem (Krueger and Menzel 1979; Tiedje et al. 1989). Thus, supplementation has the potential for reducing the long-term fitness and productivity of existing wild stocks.

In the following sections, we discuss some of the consequences of altering the genetic makeup of hatchery stocks, and the potential effects of using hatchery fish to supplement genetically different wild stocks. We also consider the role of microevolutionary processes (recombination, gene flow, and genetic drift) in the context of hatchery x wild fish interactions. Potentially harmful genetic effects include the loss of genetic variability, the breakdown of adaptive gene combinations, an increase in the frequency of undesirable "hatchery" genes, and interspecific hybridization (Allendorf et al. 1987). The effect of supplementation on wild gene pools had not been measured and described in the literature we reviewed, but there was there were numerous warnings that the potential exists for damaging the genetic resources of wild stocks through poorly planned releases of hatchery fish.

Genetic Variation

Evidence for intraspecies variability in growth and survival rates, food and habitat preferences, morphology, age and size at maturity, disease resistance, catchability, and other phenotypic traits is provided in the studies listed in Table 1. The influence of selective forces in shaping the characteristics of stocks is evident in the studies listed and underscores the need to consider stock-specific morphological, life-history, and genetic attributes when choosing hatchery stocks for supplementation purposes.

Several factors are responsible for the intraspecific structuring of salmonid stocks. Meteorologic, geologic, and anthropomorphic events affect genetic differentiation by influencing the distribution of stocks. Natural selection ensures that genes and genotypes associated with fitness-enhancing traits increase in relative frequency and thus stocks adapt to local environmental conditions (Sibly and Calow 1986). The tendency of anadromous salmonids to home to their natal streams or lakes to spawn helps to maintain and strengthen stock differences (Davidson 1934; Scheer 1939; Brannon 1967; Ricker 1972; Bams 1972; Grant et al. 1980; MacLean and Evans 1981).

Because anadromous salmonids encounter diverse habitats during their life cycle, they experience multiple and possibly conflicting selective pressures. The degree to which a stock is adapted to its environment is limited by environmental uncertainty, gene flow (e.g., straying or introductions of

Table 1. Evidence for between-stock variability in adaptive characteristics.

Species	Stock Differences	References
Pink salmon	Odd-year spawning stocks from southern British Columbia varied with respect to egg size, egg survival, and alevin and fry size parameters.	Beacham and Murray (1986).
	Adults from early-spawning northern stocks in British Columbia had higher growth rates but were smaller than adults from late-spawning stocks.	Beacham and Murray (1988).
Chum salmon	Incubation rates at different water temperatures varied between autumn- and winter-spawning stocks from British Columbia.	Tallman (1986).
	Differences in egg size, developmental rates, incubation survival, and alevin and fry size were found among seasonally distinct British Columbia stocks. Head, fin, and caudal peduncle size of adults increased with river size.	Beacham and Murray (1987).
	Adult Yukon River salmon matured at a smaller size and had smaller fins and caudal peduncles than fish from British Columbia stocks. They were also less fecund, had smaller eggs, and their embryos took less time to reach hatching and emergence than did British Columbia stocks.	Beacham et al. (1988).
Sockeye salmon	The downstream and upstream migration behavior of recently-emerged fry from inlet- and outlet-spawning stocks was under genetic control.	Brannon (1967).
	Two stocks occur in the same river system in in southeast Alaska; fish in the early-spawning stock entered freshwater in a less advanced state of sexual maturity, had smaller eggs, and migrated further upstream than fish from the late-spawning stock.	Craig (1985).
	When compared to coastal-spawning stocks, fish from interior-spawning stocks exhibited higher survival, faster developmental rates, and larger alevin or fry size at lower incubation temperatures.	Beacham and Murray (1988).
	Female investment into egg production was greater in hatchery as opposed to wild spawners as a consequence of reduced breeding competition.	Fleming and Gross (1989).

Table 1. (continued).

Coho salmon	Several morphological characters were found to vary significantly among 35 stocks from the Pacific Northwest, allowing discrimination of five major groups of stocks. Hatchery and wild stocks were differentiated on the basis of phenotypic traits.	Hjort and Screck (1982).
	Juveniles from coastal British Columbia streams had faster burst swimming speeds but less stamina than individuals from interior streams. They were also more robust-bodied than fish from inland stocks.	Taylor and McPhail (1985a, b).
	Interpopulation differences in agonistic behavior were recorded for juveniles from two tributaries to the lower Fraser River (British Columbia).	Rosenau and McPhail (1987).
	Female morphological characters associated with swimming and spawning performance varied with migration distance to spawning areas and degree of hatchery domestication.	Fleming and Gross (1989).
	Stream-rearing juveniles had different body shapes, fin positions, and fin coloration than did lake-rearing fish. Aggressive behaviors were more pronounced among stream-rearing fish.	Swain and Holtby (1989).
Chinook salmon	Juveniles of three life history types in a British Columbia river exhibited different morphologies and allelic frequencies.	Carl and Healey (1984).
	Application of a discriminate function developed from several morphometric measurements correctly classified juveniles to their respective stocks 86-90% of the time.	Winans (1984).
	Interpopulation variation in juvenile aggressive behavior was observed in 10 stocks of stream- and ocean-type salmon.	Taylor and Larkin (1986).
	Differences in levels of aggression between stream- and ocean-type salmon were demonstrated to be inherited.	Taylor (1988).
	Embryos of interior-spawning stocks survived better, developed faster, and attained larger size at hatching and emergence at lower incubation temperatures in comparison to coastal stocks. Eggs of red-fleshed salmon survived better than those of white-fleshed salmon when incubated at higher temperatures.	Beacham and Murray (1988).

Table 1. (continued).

	Juvenile salmon living in fast water tributaries of the Yukon River had larger fins and more streamlined bodies than fish living in slower velocity streams.	Beacham et al. (1989).
Atlantic salmon	Genetic variation in length and weight after the freshwater phase was measured in 32 Norwegian stocks.	Refstie and Steine (1978).
	Growth in the ocean varied among 37 Norwegian stocks.	Gunnes and Gjedrem (1978).
	Differences between stocks in the proportion of grilse (fish which mature after only one year in the sea) were observed.	Naevdal et al. (1978).
	Adaptive, genetically controlled differences in juvenile body morphology were found between fish from different tributaries of the Miramichi River, New Brunswick. Timing of downstream migration also differed significantly.	Riddell and Leggett (1981); Riddell et al. (1981).
	The lower temperature limit for juvenile growth was stock-specific for fish from three Norwegian streams.	Jensen and Johnson (1986).
	Growth rate and allelic frequency differences were found among presmolts from different sections of a large Norwegian river.	Heggberget et al. (1986).
Steelhead trout	Juveniles from the Thompson River had greater swimming stamina and higher LDH-A (lactate	Tsuyuki and Willis-croft dehydrogenase) allele
frequencies than	(1977). juveniles from the Vedder River (British Columbia).	
	Differences in tolerance to high temperatures between interior and coastal stocks were attributed to adaptive variation in IDH (isocitrate dehydrogenase) allelic frequencies.	Redding and Schreck (1979).
Rainbow trout	Meristic characters and LDH genotypic frequencies varied in populations of rainbow trout living above and below a waterfall in two British Columbia streams. Directional response to water current differed between two homozygous LDH phenotypes.	Northcote et al. (1970); Northcote Kelso (1981).

Table 1. (continued).

	Swimming endurance varied significantly between two groups of resident rainbow trout that were homozygous for alternate LDH alleles.	Tsuyuki and Williscroft (1977).
Cutthroat trout	The direction of migration of cutthroat trout fry from incubation gravel to rearing areas following emergence from inlet and outlet spawning streams was genetically determined.	Raleigh and Chapman (1971); Raleigh (1971); Bowler (1975).
Brown trout	Survival when exposed to low pH varied among stocks.	Swartz et al. (1979).
	Freshwater resident and anadromous stocks from Norwegian rivers were found to have different genetic compositions.	Skaala and Naevdal (1989).
Brook trout	Tolerance to low pH levels varied among genetically distinct stocks.	Gjedrem (1976).
Lake trout	Retention of swimbladder gas differed between between two populations.	Ihssen and Tait (1974).

hatchery fish), mutation, and selective advantages for rare alleles (Tiedje et al. 1989).

The genetic basis for the observed phenotypic variability among salmonid stocks has not been well documented (Allendorf et al. 1987). There is a lack of standardization in methods used to differentiate genetic and environmental components of variation for phenotypic traits (Gjedrem 1983; Bailey and Loudenslager 1986). Correlations between measured genetic makeup and phenotypic traits tend to be weak and difficult to interpret when environmental factors predominate in the selection process. Environmentally-mediated variation in phenotype may override or at least modify the effect of the genome. Genotype x environment interactions have been demonstrated for several traits among salmonids, most notably growth and survival (Aulstad et al. 1972; Ricker 1972; Ayles 1975; Ayles and Baker 1983; Naevdal 1983; Iwamoto et al. 1986; Beacham and Murray 1987, 1988; Beacham 1988).

Genetic variation, its distribution among stocks, and the need to use hatchery fish that are genetically similar to wild stocks are important elements of supplementation programs. Genetic variation has been positively correlated with survival for hatchery stocks (Altukhov 1983). Large differences in the genetic structure of hatchery and wild stocks can potentially lead to lower survival (Altukhov et al. 1980; Altukhov and Salmenkova 1987) and undesirable alterations of the wild gene pool (Allendorf and Ryman 1987). A summary of studies in which the stock structure of salmonid species was deduced from genetic relationships is provided in Table 2. In several instances, hatchery stocks have been found to be more closely related to each other than to local wild stocks (Stahl 1983; Hjort and Schreck 1982; and Taylor 1986).

Table 2. Electrophoretic and DNA-level studies of the population structure of selected anadromous salmonid species within the Pacific region.

Species	Geographical area	Comments	References
Pink salmon			
		Genetic variability was greater on a temporal rather than a geographic scale.	Altukhov et al. (1983).
	Northeast Pacific	An analysis of 32 populations from Washington to Alaska indicated genetic differences between even- and odd-year races.	Aspinwall (1974).
	British Columbia, Washington	Heterogeneity of allelic frequencies was greater among even- and odd-year broodlines than among stocks within each broodline. Significant interpopulation variation was observed only within the odd-year broodline.	Beacham et al. (1985a).
	Northwest Alaska	Bering Sea and Aleutian Island stocks were genetically distinct from the Kodiak Island stock. The genetic profile of Norton Sound fish more closely resembles Asian stocks than North American stocks to the southeast.	Gharrett et al. (1988).
Chum salmon			
	Washington, British Columbia	Stocks from north Puget Sound and Georgia Strait were distinguishable from those of south Puget Sound.	Okazaki (1981).
	Southern British Columbia	Stocks from four regions could be genetically differentiated; there was significant heterogeneity in allelic frequencies within regions.	Beacham et al. (1985a)

Table 2. (continued)

Species	Geographical area	Comments	References
	British Columbia	differentiated; there was significant heterogeneity in allelic frequencies within regions.	(1985).
	British Columbia	Five major regional groups of chum salmon were discriminated.	Beacham et al. (1987).
Sockeye salmon			
	Alaska	Kasilof River stocks were genetically differentiated from Kenai and Susitna River stocks in Alaska. Within-drainage heterogeneity among allelic frequencies was found in all but the Kasilof River populations.	Grant et al. (1980).
		Identified genetically distinct populations from the Russian and Karluk River systems in Alaska. Within-river differences were also found among early- and late-spawning stocks.	Wilmot and Burger (1984).
Coho salmon			
	Washington	Interdrainage genetic variation indicated stock differentiation, but within-drainage variation was also high.	Reisenbichler and Phelps 1987.
	British Columbia, Oregon	Stock separation was possible on a regional basis. The mean heterozygosity of southern BC stocks was an order of magnitude less than values reported for wild Oregon coho.	Wehrhahn and Powell (1987).

Table 2. (continued)

Species	Geographical area	Comments	References
Chinook salmon			
	Alaska	Observed inter- and intra-drainage genetic differences among populations from the Yukon and Alsek Rivers.	Beacham et al. (1989).
	British Columbia	Allozyme differences among three stocks from the Nanaimo River were related to juvenile life history.	Carl and Healey (1984).
	Alaska, British Columbia	Stocks from southeast Alaska had genetic profiles that were intermediate to those of more western and southern stocks.	Gharrett et al. (1987).
	Oregon, Washington	Significant genetic differences were found between races of spring and fall chinook in the Columbia River.	Kristiansson and McIntyre (1977).
	Washington	Interdrainage variation among stocks from four coastal drainages was not observed. However, differences occured between summer and fall run fish, between hatchery and wild stocks, and between year classes.	Reisenbichler and Phelps (1987).
	Pacific Northwest	Identified nine major stock groups distributed from the Sacramento River northward to the Skeena River.	Utter et al. (1989).

Table 2. (continued)

Species	Geographical area	Comments	References
	Alaska, British Columbia	Mitochondrial DNA analysis of fish from seven stocks corroborated earlier electrophoretic studies.	Wilson et al. (1987).
Rainbow trout			
	California	High within-stock and low between-stock genetic variation was measured in 31 coastal populations.	Berg and Gall (1988).
	Washington	Wild steelhead trout from the Yakima River had genetic profiles that were intermediate to introduced hatchery stocks and inland stocks native to other areas of the Columbia River basin.	Campton and Johnston (1985).
	Washington	Summer and winter run steelhead from the Kalama River could not be differentiated.	Chilcote et al. (1980).
	British	Three major regional groups of steelhead Columbia were identified. Significant genetic variation frequently occurred among stocks from adjacent streams.	Parkinson (1984).
	Midwest U.S.A., Ontario	Reported genetic divergence of steelhead stocks from ten drainages in the Lake Superior watershed and among several streams in a single large river system. Fall- and spring-run fish could not be differentiated.	Krueger and May(1987).

Table 2. (continued)

Species	Geographical area	Comments	References
	British Columbia	Mitochondrial DNA analysis indicated increasing levels of genetic divergence between populations of (1) steelhead, (2) steelhead and resident rainbow trout, and (3) rainbow and cutthroat trout.	Wilson et al. (1985).
		Significant variation was detected between hatchery and wild stocks of resident rainbow trout, coastal steelhead stocks and resident "redband" rainbow trout.	Wishard et al. (1984).
Cutthroat Trout			
	Washington	Anadromous cutthroat trout populations in the Puget Sound area differed genetically on both regional and drainage-wide basis.	Campton and Utter (1987).
	Western U.S.A., Sweden	Based on an analysis of mitochondrial DNA, two subspecies of cutthroat trout could be differentiated from three stocks of rainbow trout.	Gyllensten and Wilson (1987).
	Western U.S.A.	Considerable genetic divergence was detected among coastal, Lahontan, and westslope subspecies of cutthroat trout, but little heterogeneity occurred among Colorado River, finespotted, greenback, and Yellowstone subspecies. The first three subspecies were genetically more similar to resident rainbow trout than to other cutthroat trout subspecies.	Leary et al. (1987).

Table 2. (continued)

Species	Geographical area	Comments	References
	Montana	Little introgressive hybridization between native and introduced cutthroat trout was observed among lake populations in Glacier National Park.	Marnell et al. (1987).
Atlantic salmon			
	Newfoundland	Anadromous and resident stocks could not be differentiated from an analysis of mitochondrial DNA patterns.	Birt et al. (1986).
	United Kingdom	The existence of two races of salmon in the British Isles was postulated on the basis of differences in transferrin allele frequencies.	Child et al. (1976).
	Northern Ireland	Analysis revealed considerable genetic variation in wild stocks within and between several river systems.	Crozier and Moffett (1989).
	Norway	Electrophoretic analysis of presmolts indicated that separate stocks exist within the River Alta.	Heggberget et al.(1986).
	United Kingdom	Northern and southern stocks in the UK were electrophoretically distinct, but populations from the north-east and north-west could not be differentiated.	Hovey et al. (1989).
	Eastern Canada	Three major groups were identified on the basis of transferrin allele frequencies:	Moller (1970)

Table 2. (continued)

Species	Geographical area	Comments	References
		Newfoundland/Labrador, New Brunswick/ Nova Scotia, and Maine.	
	Baltic Sea	Separate stocks were identified within and between major drainages.	Stahl (1981; 1983).
		Based on genetic distance values, major stock groups correspond to Western Atlantic, Eastern Atlantic, and Baltic Sea drainages. Further subdivisions were identified.	Stahl (1987).
	Newfoundland	Genetically distinct and reproductively isolated stocks of anadromous and resident salmon coexisted in a lake.	Verspoor and Cole (1988).

Other investigators have suggested that: (1) most of the total gene diversity resides within individual stocks (Ryman 1983; Kreuger and May 1987; Hindar et al. in press; brown trout appear to be the exception - Ferguson 1989), (2) genetic variation tends to be greater between stocks of different regions than between stocks within regions (Beacham et al. 1987; Stahl 1987; Verspoor and Jordan 1989), (3) gene flow may be restricted over very short distances (Parkinson 1984; Skaala and Naevdal 1989), (4) some stocks have lower genetic variability than others (Wehrhahn and Powell 1987; Winans 1989; Utter et al. 1989), and (5) intraspecific gene flow between anadromous and non-migratory populations is limited (Davidson et al. 1989; Foote et al. 1989).

Genetic differences are not always discerned between stocks from different drainages, even when phenotypic differences are apparent. The fish may actually belong to the same stock (Berg and Gall 1988), or they may be discrete stocks that cannot be differentiated because of sampling problems, unsuitable genetic markers, limitations of electrophoretic techniques, and inappropriate statistical analyses (Hallerman and Beckmann 1988). The effect of electrophoretic proteins on survival and production characteristics is a subject of considerable debate (Gauldie 1984; Kapuscinski and Jacobson 1987). Discrete stocks probably exist when electrophoretic data and statistical results indicate clear genetic differences, but the lack of electrophoretically detectable differences does not preclude the existence of important genetic differences or status as separate stocks (Riddell et al. 1981).

Effective supplementation requires additional information about the organization, temporal stability, and ecological significance of genetic variation within salmonid species (Kapuscinski and Lannan 1986). Continued emphasis should be placed on obtaining reliable estimates of genetic patterns and behavior in hatchery and wild stocks. Recently developed techniques using DNA-level polymorphisms (as opposed to allozyme markers) have been used to identify intraspecific relationships among salmonids and should improve our ability to select genetically suitable stocks for supplementation (Hallerman and Beckmann 1988; Ferris and Berg 1987; Davidson et al. 1989; Hynes et al. 1989).

Hatchery Stocks

The success of supplementation depends on the viability of the hatchery stocks used to augment natural production. Stock viability can be defined as the collective fitness, or reproductive capacity, of fish comprising the stock. From a genetics standpoint, the viability of a stock is affected by evolutionary forces operating both within and outside the confines of the hatchery.

Hatchery fish that survive and return as adults following their release into the wild may eventually breed with naturally-spawning fish. The genetic composition of the wild stock will be altered unless the hatchery stock is genetically equivalent to the wild fish (Evans and Smith 1986). Genetic equivalency is affected by the source of hatchery broodstock, by mating and rearing conditions within the hatchery environment, and by the "culling" effect of natural selection. Many of the potential genetic effects of supplementation depend on answers to the following questions (Kincaid 1983). Are some species or races of salmonids better suited to supplementation than others? Where will the brood stock be obtained? How many individuals will be used, both initially and on an ongoing basis, in the breeding program? Will a breeding

program be used which emphasizes specific production traits? What protocols will be followed to minimize genetic problems?

Source of Broodstock

The source of fish used to start and maintain a hatchery stock is an important component of supplementation programs. With evidence accumulating that stocking maladapted fish may be counterproductive (Ricker 1972; Altukhov and Salmenkova 1987), greater consideration has been given to genetic resources in the design and operation of hatcheries (Heard and Crone 1976; Reimers 1979).

Broodstocks for new hatcheries are obtained in a variety of ways: transfers between hatcheries, crosses between broodstocks, selection programs that emphasize the enhancement of specific traits, and collection of fish from natural stocks (Kincaid and Berry 1986). Locally adapted fish, when used to establish and maintain hatchery stocks, are likely to be better for supplementation than are fish from other populations (Bams 1976; Reisenbichler 1981; Altukhov and Salmenkova 1987). Smolt-adult return rates generally decrease with increasing distance from the natal stream for stocked chinook salmon (Reisenbichler 1988), Atlantic salmon (Ritter 1975), and chum salmon (Kijima and Fujo 1982).

Some species appear to be less sensitive to transplanting than others, perhaps a function of the species' dependency on freshwater habitats. Pink salmon may be more easily supplemented that other species because they are efficient colonizers of new habitats (Beacham et al. 1985), possess a relatively uniform or "unspecialized" genetic structure (Ryman 1983; Utter et al. 1980; Altukhov and Salmenkova 1987), and do not require extensive freshwater rearing. Because they migrate to the ocean soon after emergence, pink salmon would presumably receive minimal exposure to selection in the hatchery over time. Following similar reasoning, "ocean type" populations of chinook salmon, defined as those producing subyearling smolts (Gilbert 1913; Healey 1983), may be more tolerant to artificial propagation than would "stream type" (yearling and older smolts) chinooks. Interior stocks of anadromous salmonids may be more uniquely adapted to their respective drainages than are coastal populations due to a tendency for smolting age to increase with shorter and colder growing seasons (Beacham et al. 1989).

Size of Stock

The number of spawners used to propagate hatchery stocks for supplementation purposes should be maintained at levels that ensure that most of the genetic variability is passed from one generation to the next (Wilkins 1981). If appreciable amounts of genetic diversity are lost then the viability of the hatchery stock may decline, wild stock adaptability may be impaired, and supplementation goals may be thwarted. These predictions are based on studies which show that even minimal losses of genetic variability can result in lower survival and productivity (Kincaid 1983; Allendorf and Ryman 1987).

All finite populations, hatchery and natural, experience some genetic drift (the direction of change is random but may include permanent losses of rare alleles) due to natural genetic processes that occur in each generation. The potential for unwanted genetic change increases whenever too few or too

closely related individuals are chosen for breeding. Genetic material can be replenished only through mutation or infusions of fish from outside the hatchery.

The rate at which genetic variability is lost in a hatchery stock depends on the number, relative reproductive contribution, and genetic similarity of individuals used for breeding purposes. The proportion of fish that are heterozygous (having two different alleles at the same locus), within a population of size N decreases at the rate of 1 - (1/2N) in each generation, assuming that each individual spawns successfully. For example, where a large number (100 or more) of individuals are randomly mated, a reduction of less than 0.5% of the original genetic variation is expected after one generation (Figure 1). All else being equal, no more than 5% of the heterozygosity will be lost in large populations after 10 generations. When 10 fish are used as broodstock, 5% of the initial heterozygosity is lost in the first generation alone, and 40% is lost after 10 generations.

Loss of genetic variability is also reflected by the reduction in the mean number of alleles per locus, expressed as a percentage of the alleles originally present (allelic diversity; Denniston 1977). The number of alleles expected to be retained by loci with varying numbers of alleles is a function of breeding population size (Figure 2). The potential reduction in allelic diversity is most dramatic (up to 50%) at moderately polymorphic loci when the number of breeding individuals is small.

Several authors have noted that genetic diversity is low in salmonids (Ryman 1983; Allendorf and Ryman 1987; Davidson et al. 1989). Examples of reductions in genetic variability within hatchery stocks, ranging to 20-30% below wild stock levels, are common for non-anadromous salmonid species and Atlantic salmon (Table 3). We found few cases of reduced levels of genetic variability among hatchery stocks of Pacific salmon and steelhead trout. Busack et al. (1979) and Thompson (1985) observed levels of genetic variation in hatchery stocks of cutthroat and rainbow trout that were in some cases greater than that present in wild stocks.

Because not all fish within a stock have equal reproductive capacities, the effective population size (Ne - the number of successfully reproducing adults) rather than the total population size actually determines how much genetic variation is lost from one generation to the next. Age, fecundity, fertility, sex, and the degree and magnitude of environmental "accidents" (including those perpetrated by man) affect the reproductive contribution of each individual relative to other fish in the stock.

An example of a reduction in the effective population size of a hatchery stock attributed to spawning technique was given by Gharrett and Shirley (1985). Milt from adult male pink salmon spawned under identical conditions varied substantially in its ability to fertilize eggs, the most plausible explanation being unequal states of maturation among the male subjects. For this reason, the common practice of simultaneously adding the milt of several males to the eggs of a single female cannot be expected to yield progeny with genotypes proportional to the ratio of males to females used. For species like chinook salmon and steelhead trout, where large numbers of spawners are frequently unavailable, the best insurance against unequal potencies among spawners is to fertilize the eggs of each

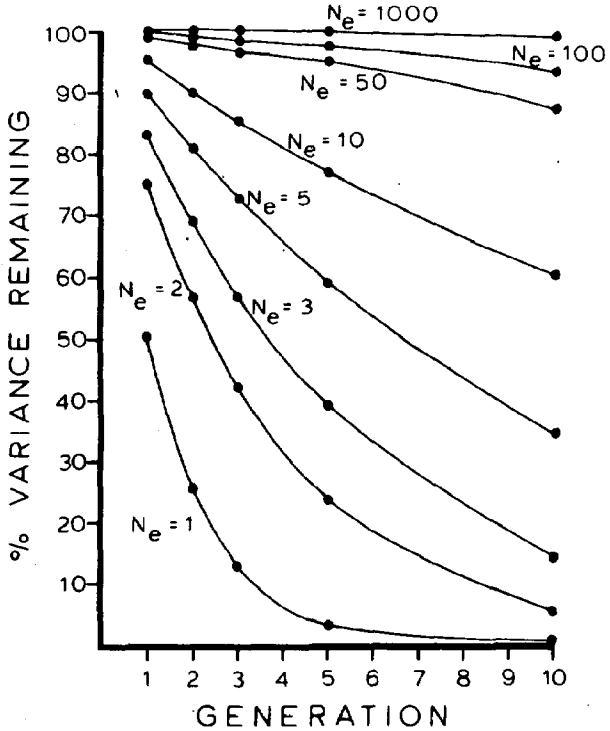

Figure 1. Rate of loss of genetic variance (heterozygosity) per generation as a function of effective population size. Taken from Meffe (1986).

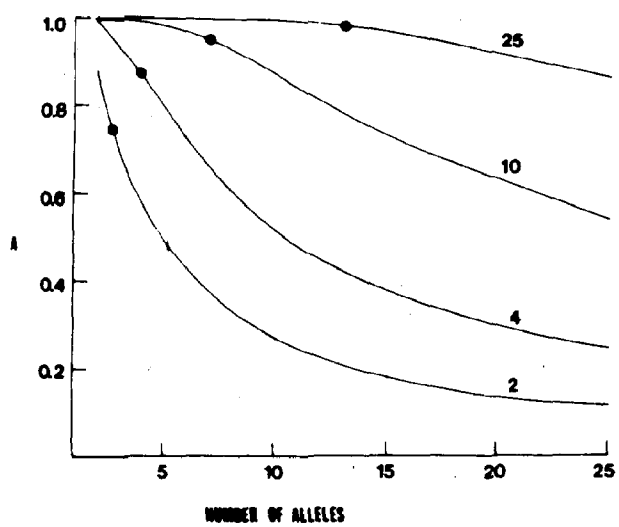

Figure 2. Proportion of allelic diversity (A) remaining following a single generation bottleneck in population size of 2, 4, 10, and 25 individuals. Initial allelic frequencies are assumed to be equal. Modified from Allendorf and Ryman (1987).

Table 3. A summary of findings from studies which evaluated changes in genetic variability within hatchery populations of anadromous salmonids. Taken in part from Table 6.1 Allendorf and Ryman (1987).

Species	Genetic Attributes	References
Coho salmon	Although statistically insignificant, the mean heterozygosity of fish from Capilano Hatchery was 2.7 times greater than that of wild stocks from nearby coastal mainland streams of southern British Columbia.	Wehrhahn and Powell(1987).
Chinook salmon	The mean heterozygosity and allelic diversity between 7 hatchery and 6 wild stocks from the Oregon coast were not significantly different.	Utter et al. (1989).
Atlantic salmon	Heterozygosity and allelic diversity were reduced in a hatchery population five generations removed from the wild (western Ireland).	Cross and King (1983)
	In eastern Canada, mean heterozygosity and allelic diversity averaged 26% and 12%, respectively, lower in first-generation hatchery smolts than in wild stocks.	Verspoor (1988).
	Hatchery stocks exhibited 20% lower levels of genetic variability than natural populations from the Baltic Sea.	Stahl (1983; 1987).
	Mean heterozygosity was not reduced in a hatchery stock in Northern Ireland.	Crozier and Moffett (1989).
Rainbow trout	Inbreeding was suspected as a cause of a reduction in genetic variation.	Allendorf and Utter (1979).
	Higher levels of mean heterozygosity were observed in several hatchery stocks compared to wild stocks.	Thompson (1985).
	Little loss of genetic variability in two hatchery populations was observed.	Berg and Gall (1988).
Cutthroat trout	Hatchery stock retained about 80% of the mean heterozygosity of the wild founder stock.	Allendorf and Phelps (1980).
	Number of polymorphic loci, allelic diversity, and average heterozygosity were reduced by 57%, 29%, and 21%, respectively.	Leary et al. (1985).

Table 3. (continued)

Species	Genetic Attributes	References
Brown trout	Proportion of polymorphic loci reduced by up to 50%.	Ryman and Stahl (1980; 1981).
	Mean heterozygosity reduced by 33%.	Vuorinen (1984)
	Mitochondrial DNA heterozygosity in Swedish hatchery stocks was 25% of the variability of natural stocks.	Gyllensten and Wilson (1987)

female with the milt from a single male, each fish being used just once.

Effective population sizes that have been recommended to maintain genetic diversity vary widely (Ryman and Stahl 1980; Allendorf and Phelps 1980; Hynes et al. 1981; Kreuger et al. 1981; Allendorf and Ryman 1987; Kapuscinski and Jacobson 1987); the minimum acceptable value probably depends on the environment and the reproductive biology of the species (Simon et al. 1986). Theory (Allendorf and Ryman 1987) and empirical (Verspoor 1988) evidence suggests that little (<1%) genetic variability will be lost in most salmonid species if Ne of the founding population is >50. Conservative Ne values recommended by two groups of fish population geneticists are higher: Kapuscinski and Jacobson (1987) suggest 100 fish, whereas Allendorf and Ryman (1987) recommend 200 individuals, split evenly by sex, as a lower population bound for hatchery stocks that are used to supplement wild stocks.

Reductions in Ne among wild or hybridized hatchery and wild stocks may derive from individual variation in breeding success and decreases in total population size. Effective population sizes are less than the observed number of spawners whenever the sex ratio is unbalanced. However, straying, multiple age spawning, polygamy, and overlapping generations among wild stocks tend to maintain Ne and genetic diversity at higher levels than would be possible for isolated populations made up of monogamous spawners of uniform age (Helle 1981; Gall 1983; Simon et al. 1986).

Wehrhahn and Powell (1987) and Winans (1989) speculated that the low levels of genetic diversity which they measured within present day wild stocks of coho salmon in British Columbia and chinook salmon in the Snake River drainage resulted from historical population bottlenecks. Plausible explanations included natural and man-caused reductions in effective population sizes.

Selection

Selective breeding is frequently used in aquaculture to increase the incidence of one or more desired traits in the hatchery stock (Hynes et al. 1981). Directional or intentional selection may, through the elimination of specific alleles and genotypes, alter the existing genetic composition and lower

genetic diversity. For reasons stated above, the gene pool of wild stocks can be altered if they hybridize with genetically distinct or impoverished hatchery fish.

Salmonid fishes have several characteristics that facilitate artificial selection in hatcheries: external fertilization, high fecundity, high fertility, short generation interval, ease of hybridization, moderately high heritability for some important traits, and large phenotypic variability (Wilkins 1981; Kincaid and Berry 1986; Parker 1986). These qualities, exploited under diverse aquaculture programs, have resulted in the development of a large number of hatchery strains (Busack and Gall 1980; Kincaid 1983). Strain-specific differences have been documented for several traits, including, but not limited to, egg size and number, growth rate, body composition, and feed conversion (Kincaid and Berry 1986).

Genetic protocols and objectives associated with supplementation using anadromous salmonids differ from conventional fish farming techniques applied to captive stocks of non-anadromous salmonids (Allendorf and Ryman 1987). Management goals, rearing and breeding strategies, and criteria used to gauge the success of the two programs, the one emphasizing ecosystem integrity and the other production within a closed artificial system, are largely incompatible. Kapuscinski and Jacobson (1987) and others (Calaprice 1969; Simon 1970; Purdom 1972) review culture techniques such as selective breeding, development of inbred lines (i.e., the intentional reduction of heterozygosity), and heterosis (hybrid vigor due to overdominance and heterozygosity at many loci) that have been used to improve the production traits of fish used primarily for aquaculture purposes. Hynes et al. (1981), Simon (1986), Kapuscinski and Jacobson (1987), and Kapuscinski and Philipp (1988) have summarized key issues that are relevant to the design and implementation of artificial selection programs. The general impression imparted by these authors is that selective breeding will eventually become an effective and important tool in supplementation efforts, although as recently as 1987 it was the opinion of Allendorf et al. (1987; p. 19) that "...genetic conservation and (intentional and inadvertent) selection cannot be achieved simultaneously..." To give but one example: selective breeding for increased survival of hatchery coho salmon may have inadvertently contributed to an overall decline in stock fitness (McIntyre et al. 1988).

More information is needed of life history, ecological, and genetic characteristics and interactions of hatchery and wild stocks before artificial selection can be safely and effectively used in supplementation programs. Kapuscinski and Philipp (1988) recommend a conservative approach involving manipulation of no more than a few traits, adherence to procedures which maximize genetic diversity, and careful monitoring and evaluation of post-selection effects.

Recently developed genetic engineering techniques appear to hold promise as a means of bestowing desirable traits, such as disease resistance or faster growth, on hatchery stocks (Kapuscinski and Jacobson 1987). Although the relative merits and demerits of gene transfers are still unclear (relatively few structural genes have actually been transferred), genetic engineering may eventually prove useful in supplementation programs (Davidson et al. 1989). Potential impacts associated with the introduction of transgenic fish are discussed by Kapuscinski and Hallerman (1990).

A certain amount of unintentional selection is unavoidable in all fish rearing operations, including programs and facilities used for supplementation (Hynes et al. 1981)(Table 4). There is evidence that many of the observed changes are maladaptive in a natural environment. Selection for early run timing of returning hatchery spawners is a frequently cited example (Ayerst 1977; Rosentreter 1977; Smoker 1985; Reisenbichler 1986a; Leider et al. 1986). Hatchery managers frequently select for early sexual maturation by taking fish from the early portion of the returning run of adults. There are practical benefits to advancing the time of spawning and incubation in the hatchery: adult mortalities are decreased by reducing the time they are held prior to spawning, more time is available to grow fish before they are released on a fixed date or, alternatively, fish can be reared to acceptable sizes for release earlier in the season (Zaugg et al. 1986; Reisenbichler 1986a).

However, selection for early spawning can have unwelcome results when hatchery fish attempt to spawn naturally. Early spawners may encounter temperature and flow conditions that adversely affect intragravel and post-emergence survival (Cederholm 1984) and they may out compete later emerging wild fish (Chandler and Bjornn 1988).

Genes coding for traits selected for in the hatchery environment may be part of larger coadapted gene complexes (Dobzhansky 1970). Selection may disrupt these systems, leading to reduced genetic variance and population fitness (Strickberger 1976; Reisenbichler 1984, 1986b; Chilcote et al. 1986). This type of genetic disturbance, as yet undocumented in hatchery stocks, merits future research.

Inbreeding

Inbreeding occurs when spawning pairs of fish are more closely related to each other than to other individuals in the population (Gall 1987). A potential cause of loss of genetic variability at both the individual and population level, inbreeding is promoted by directional and unintentional selection and the use of small numbers of fish to establish and perpetuate the hatchery stock. Gall (1987) provides an excellent discussion of the theory of inbreeding as it applies to hatchery management.

Although inbreeding has long been recognized as a potential problem in hatcheries, only recently have studies documented its negative effects on salmonid stocks (Ryman and Stahl 1980; Allendorf and Phelps 1980; Gall 1983). Kincaid (1983) reviewed a number of studies in which inbreeding depression, defined as an increase in the percentage of individuals that are homozygotes for recessive deleterious alleles, had a detrimental effect on fitness measures such as survival, reproductive capacity, physiological efficiency, and the occurrence of deformities in hatchery stocks. However, there is little evidence of extensive inbreeding depression among hatchery stocks of Pacific salmon used for supplementation. Likewise, an infusion of deleterious alleles into wild stocks via supplementation has not been demonstrated.

A positive aspect of artificial propagation of hatchery stocks is that problems associated with selection, inbreeding, and loss of genetic variation can often be remedied through careful management. New broodstock can be obtained, hatchery operations altered, and objectionable selective forces alleviated to

Table 4. Phenotypic traits that were purportedly altered by inadvertent selection in the hatchery.

Trait	References
Body morphology	Fleming and Gross (1989).
Deformities	Aulstad and Kittlesen (1971); Kincaid (1976, 1983).
Secondary sexual characters	Fleming and Gross (1989).
Sex ratio	Altukhov 1981; Doyle (1983).
Age at maturation	Rosentreter (1977); Fraser (1981).
Spawning timing and duration	Millenbach (1973); Hjort and Schreck (1982); Nickelson et al. (1986); Rosentreter (1977); Leider et al. (1986).
Repeat spawning	Rosentreter (1977); Leider et al. (1986).
Reproduction (fecundity, egg size, etc.)	Aulstad et al. (1972); Fleming and Gross 1989; Gall and Gross (1978); Kincaid 1976, 1983.
Physiology (temperature tolerance; stamina, etc.)	Greene (1952); Vincent (1960); Hynes et al. (1981).
Stress resistance	Vincent (1960), Barton et al. (1986); Woodward and Schreck (1987).
Behavior (docility, habitat preference, etc.)	Vincent (1960); Moyle (1969); Doyle and Talbot (1986).
Catchability	Flick and Webster (1962).
Growth	Webster and Flick (1964; 1975, 1976); Reisenbichler and McIntyre (1977); Gjerde 1983; Kincaid (1976, 1983).
Survival	Greene (1952); Gall (1969); Aulstad and Kittlesen (1971); Flick and Webster (1976); Reisenbichler and McIntyre (1977); Chilcote et al.(1981); Hynes et al. (1981); Ryman (1982); Kincaid (1976, 1983); Gjerde (1983).

produce the desired effect in a relatively brief period of time, owing to the short life cycle and high reproductive rate of the species.

Genetic Impacts on Wild Fish

The genetic impacts of superimposing hatchery fish on natural runs can be detrimental, benign, or beneficial. Because few studies have measured the long-term genetic response of wild stocks to supplementation, there exists more conjecture than fact on this subject. Negative consequences tend to be stressed in the scientific literature; the disruption of adaptive genes or gene combinations (coadapted systems; Reisenbichler 1984, 1986b; Chilcote et al. 1986; Taggart and Ferguson 1986), genetic homogenization caused by the swamping of native gene pools (Temple 1978; Utter et al. 1989; Hindar et al. in press), and interspecific hybridization (Behnke 1972; Busack and Gall 1981; Leary et al. 1984; Allendorf and Leary 1988). Genetic risks to wild stocks increase whenever nonadaptive traits are selected in the hatchery stock, or genetic variation within the hatchery stock is small relative to the wild stock (Lannan and Kapuscinski 1984). The extent to which wild stocks are affected depends on the level of genetic dissimilarity, the reproductive contribution of hatchery and wild fish, the amount of interbreeding, and the relative fitness of progeny. Hatchery fish not only are capable of influencing genetic structure through interbreeding, they are also likely to effect genetic change through their interaction with the ecosystem, especially as competitors and predators (Kreuger and Menzel 1979).

Obviously, the introduction of hatchery-produced individuals carrying maladapted genes is not a productive supplementation strategy. The potential for unwanted genetic impacts increases when non-local stocks are used to establish and maintain hatchery stocks. Even small differences in adaptive traits may cause problems if significant interbreeding occurs. For example, Bams (1976) found that the accuracy of return by adult pink salmon to native tributaries was greatest among progeny of resident wild fish, intermediate among progeny created by crossing non-native and resident fish, and least among offspring of non-native stock. Unpredictable migrational responses, including straying, among hatchery fish not only undermines efforts to supplement wild stocks but may also affect the productivity of non-targeted stocks in nearby rivers (Calaprice 1969; Ricker 1972; Bams 1976).

Wohlfarth (1986) reviewed six studies in which researchers evaluated the relative performance of hatchery, wild, and hybrid (hatchery x wild) salmonids. Performance data from these studies and one by Mason et al. (1967) are summarized in Table 5. Hybrid progeny of nonanadromous cutthroat and brook trout had greater viability, in terms of better survival, faster growth, or both relative to purebred hatchery and wild stocks. In most cases the performance of pure strain hatchery fish was worse than that of hybrid and wild fish (Mason et al. 1967).

The two studies reviewed by Wohlfarth (1986) which involved anadromous species give a clear impression that the long term fitness of interspecific hybrids may be less than that of purebred wild fish. Reisenbichler and McIntyre (1977) demonstrated significantly greater survival among offspring of wild steelhead trout compared with hatchery x wild progeny stocked in natural streams. Bams (1976) did not observe any survival advantage of native pink salmon over progeny created by mating fish from separate wild stocks, but

Table 5. A summary of seven studies which evaluated the relative performance of hatchery, wild and hybrid salmonids (from Wohlfarth 1986).

Cutthroat trout (Donaldson et al. 1957)

Background: Parental strain and reciprocal (F - female, M - male) crossbreds of age-0 hatchery (H) and wild (W) cutthroat trout were stocked into Lake Whatcom, Washington. Mean weight and the numbers of fish caught on opening day of the fishing season were measured over the next two years.

		Individual weight (g)			Percent caught	
Stock	Number stocked	Initial (Age 0)	Age 1	Age 2	Age 1	Age 2
HF x HM	3006	5.2	98.4	289.3	1.0	0.3
HF x WM	2213	5.4	79.2	256.0	5.6	0.9
WF x HM	4802	5.2	88.5	338.3	6.2	0.4
WF x WM	5890	3.5	66.2	321.3	1.7	0.8

Brook trout (Mason et al. 1967)

Background: A comparison was made of the survival, growth and harvest of age-0 brook trout progeny of hatchery, wild, and reciprocal (F = female, M = male) hatchery x wild matings that were stocked into five Wisconsin streams. Sources of stock: H = Osceola hatchery; W-L = hatchery-reared progeny of wild Lawrence Creek stock; W-R = naturally produced progeny of wild Big Roche-a-Cri stock.

	Percent survival		Mean length (in.)		
Stock	1 year after stocking	2 years after stocking	At time of stocking	1 year after stocking	Percentage caught by anglers
H	38.0	0.4	5.6	9.6	21.0
HF x WM	40.0	2.6	5.1	8.6	15.1
HM x WF	29.9	4.5	4.6	8.5	-
W-L	25.3	9.8	3.6	7.3	4.9
W-R	54.8	10.8	3.3	6.7	6.9

Table 5. (continued)

Brook trout (Flick and Webster 1976)

Background: The survival and growth of purebred stocks of hatchery (New York strain) and wild (Assinica and Temiscamie strains) brook trout stocked at age-0 into Bay Pond, New York, was compared against the performance of progeny from a HF x WM (Assinica) mating.

		Number caught (Mean weight/fish in grams)					
		Age in years					
Stock	Number stocked	1	2	3	4	5	Total Number caught (%)
HNY	2995	2 (77)		58 (349)	4 (422)	-	64 (2.1)
HNY x WA	3050	7 (136)	242 (572)	38 (803)	13 (826)	26 (844)	326 (10.7)
WA	3126		31 (354)	8 (603)	12 (826)	8 (640)	59 (1.9)
WT	1351	2 (122)	30 (367)	4 (626)	8 (640)	5 (644)	42 (3.1)

Brook trout (Webster and Flick 1981)

Background: Growth and survival was estimated for pure hatchery (Cortland stock), pure wild (Assinica, Honnedaga, Long Island Pond, and Temiscamie stocks) and hybrid (four wild x hatchery crossbreds) age-0 brook trout stocked into Laramie Pond, New York. We report weighted means for percent survival, instantaneous growth rate (= ln(weight at recovery - ln(weight at stocking))/number of days), and R/S (= total weight recovered/total weight stocked).

Stock	Total number stocked	Percent survival	Instantaneous growth rate	Mean R/S
Hatchery	750	41.3	13.5	1.6
Hatchery x Wild	1895	68.1	16.2	3.0
Wild	1747	52.2	17.0	2.5

Table 5. (continued)

Brook trout (Fraser 1981)

Background: Growth and survival was estimated for pure hatchery (HH = Hill's Lake stock), pure wild (WN = Nippigon; WD = Dickson) and hybrid (HH x WN; HH x WD; and WN x WD crossbreds) brook trout stocked into nine lakes in Algonquin Park, Ontario. We report weighted means for percent survival, instantaneous growth rate (= ln(weight at recovery - ln(weight at stocking))/number of days), and R/S (= total weight recovered/total weight stocked).

Stock	Total number stocked	Percent recovery	Instantaneous Growth rate	Mean R/S
H	636	4.5	10.6	0.9
H x WN	264	7.4	16.3	8.0
H x WD	217	7.2	13.4	2.1
WN	63	3.4	12.7	1.1
WD	134	11.8	14.4	6.4
WN x WD	46	9.9	15.8	9.9

Steelhead trout (Reisenbichler and McIntyre 1977)

Background: Measured relative performance of hatchery, hybrid, and wild steelhead trout stocked as embryos and swim-up fry in a hatchery pond and in four tributaries of Deschutes River, Oregon. H = hatchery fish were progeny of wild steelhead captured in the Deschutes River and reared in a hatchery; W = wild Deschutes River steelhead.

		Total number stocked		Percent survival		Percent recovered		Mean length of final sample (mm)	
Stock	Life stage	Stream	Pond	Stream	Pond	Stream	Pond	Stream	Pond
H	Egg	24000	-	78.4	-	2.9	-	62	-
	Fry	7500	6000	-	-	5.5	3.3	63	60
H x W	Egg	24000	-	79.5	-	3.3	-	62	-
	Fry	7500	6000	-	-	5.6	2.6	65	56
W	Egg	24000	-	86.1	-	3.7	-	62	-
	Fry	7500	6000	-	-	7.2	2.4	63	56

Table 5. (continued)

Pink salmon (Bams 1976)

Background: Measured relative performance of purebred donor (wild Kakweiken River stock) and donor x natal (wild Tsolum River stock) pink salmon released into the Tsolum River. A = green to eyed egg stage, B = eyed egg to fry emergence.

	Percent survival			Total number recovered	
Stock	Green to eyed egg	Eyed egg to swim-up	Number marked and released	Offshore	Rivers
Donor	72.0	96.2	109658	205	45
Donor x natal	84.2	96.3	124792	247	236

suggested that the lower homing accuracy of the hybrid salmon was indicative of a reduction in overall fitness.

Wolhfarth (1986), however, chose to discount this evidence and concluded, as Moav et al. (1978) had previously, that heterosis (hybrid vigor) confers distinct advantages in performance in the natural environment among first generation interstrain crossbreds. These authors envision a continual "upgrading" of the genetic resources of wild stocks through repeated introductions of nonendemic hatchery fish in subsequent generations.

Kapuscinski and Philipp (1988) concluded that more study of the long-term genetic effects of supplementation is needed before contemplating such a strategy. One approach would be to label hatchery fish with one or more genetic marks and then monitor marker frequencies in subsequent generations. It is dangerous to infer significant changes in individual and stock fitness from measurements of survival or reproductive success made over brief time intervals. The assumption that maximizing short-term growth, survival, or reproductive success is equivalent to maximizing the long-term viability of the stock may be untenable since additional factors are probably involved on an evolutionary time scale.

We were unable to locate any published studies in which the fitness of progeny of hatchery x wild matings was measured over multiple generations and compared with the fitness of the original hatchery and wild parental stocks. Chilcote et al. (1986) presented evidence that the survival to smolt age of naturally spawned progeny of hatchery steelhead trout was approximately 28% that of offspring from wild spawners. Krueger and Menzel (1979) and Wishard et al. (1984) also documented poor reproductive success among nonanadromous hatchery brook trout and rainbow trout.

The belief that native fish are always genetically superior to hatchery stocks has been disputed (Kapuscinski and Lannan 1984). Many stocks of wild fish have been subjected to intense selection triggered by recent environmental changes. Some fisheries geneticists (J. Lannan, pers. comm) contend that fishing, habitat alteration, pollution and other environmental factors may pose a greater threat to the genetic integrity and persistence of wild stocks than do current supplementation practices. Large hatchery stocks may be more capable than small wild stocks of adapting to major environmental changes such as reduced flows at critical migration periods, pollution, or altered community structure.

Gene flow from a hatchery stock might have beneficial consequences when the wild stock has become so small that it has lost or is threatened with the loss of genetic variation through inbreeding, genetic drift, etc. Under these circumstances, hybridization of genetically divergent hatchery and local stocks may constitute the best management option. A potential drawback: genetic diversity is promoted at the stock level, but is lost at the species level. To quote Nelson and Soule (1987), "the effect of gene exchange between subpopulations is to increase the variance within groups, decrease the variance between groups, and decrease the total variance."

It is debatable whether genetic losses can be reversed once supplementation is stopped and natural production is restored to adequate levels. High reproductive rates potentially lead to a greater absolute number of mutations

and recombinations within the population. This, in concert with gene flow, would theoretically provide favorable alleles which can be selected for and spread through the population, thus restoring genetic variability (Lovejoy 1977). However, recent evidence suggests that mutations occur and spread very slowly through salmonid populations (Chakraborty and Leimar 1987; Davidson et al. 1989).

An important question, as yet unanswered, concerns the rate and extent to which fish of hatchery origin naturalize, that is, develop a level of adaptation to local conditions approaching that of the wild stock. Krueger and May (1987) noted that nonindigenous brown trout stocked in Lake Superior tributaries in the early 1900s have segregated into genetically distinct stocks within 80 years. Riggs (1986) argued that naturalization is a complex process which proceeds at variable rates depending on the selective agents and the genetic characteristics of the traits involved. The continual infusion of hatchery fish into the breeding structure of a wild stock may further complicate and hinder the process of naturalization. Until more empirical evidence is obtained (through carefully controlled studies in confined ecological settings), a conservative tack should be taken, to include maintaining acceptable population sizes, avoiding unnatural selection, and preserving the genetic purity of wild stocks.

Given the potential for genetic destabilization within hatchery stocks and hybridization between hatchery and wild stocks, why isn't there more conclusive evidence of genetic damage among wild stocks that is directly attributable to supplementation? Examples exist of gene flow from hatchery to wild stocks (e.g., Campton and Johnston 1985; Taggart and Ferguson 1986; Altukhov and Salmenkova 1987; Gyllensten and Wilson 1987) and of genetic swamping through interspecific hybridization (Behnke 1972; Allendorf and Leary 1988), but these results do not provide compelling evidence of genetic harm. More disturbing are the few known cases where hatchery introductions are thought to have caused the effacement of native gene pools at the intraspecific level (Altukhov 1981; Campton and Johnston 1985; Gyllensten and Wilson 1987; Allendorf and Leary 1988). Nonetheless, referring to the impact of hatchery-produced chinook salmon on wild stocks in the Columbia River, Utter et al. (1989) remarked that "hatchery populations established from (and still reflecting) exotic origins have not noticeably perturbed the allelic distributions of adjacent populations having indigenous origins."

There is no conclusive evidence to suggest that wild stocks have genetically benefitted from supplementation. We speculate as to why more definitive evidence of genetic impact - good or bad - has not been obtained:

- Genetic differences between many hatchery and wild stocks may in fact be small; hatchery practices may not have appreciably altered historic genetic compositions in the comparatively short time that anadromous salmon and trout have been cultured,

- The extent of genetic differences and subsequent introgression has not been assessed or cannot be discerned using available technology,

- Hypothesized cause-and-effect relationships involving genetic changes and stock viability have not been subjected to rigorous experimentation,

- The effects of gene flow cannot be distinguished from changes prompted by natural selection or genetic drift,

- Interbreeding and gene flow may not be extensive owing to poor survival of hatchery fish, strong and rapid selection against unfit genotypes, and genetic and life history mechanisms that help to buffer the wild genome against deleterious change.

Environmental Effects

We consider the effects of various environmental factors on genetic resources because supplementation is often used or proposed as mitigation for production losses resulting from a variety of causes, and because these causes continue to influence the demographic and genetic characteristics of stocks. The need for supplementation in the Columbia River basin has arisen because of increased mortality rates from overfishing, habitat alteration, and changes in the biotic community.

Wild stocks are at greater risk of genetic harm when subjected to environmental stress because more hatchery fish are produced that can interact with wild fish to compensate for the higher mortality rates in the wild stocks. If wild spawners breed with and are greatly outnumbered by spawners of hatchery origin, genetic instability and degradation may ensue. The results of supplemental stocking, even if hatchery fish are genetically equivalent to the native stock, may remain unsatisfactory unless the factors responsible for the decline of wild fish are removed. Appropriately, Ryder et al. (1981) suggest that if supplementation efforts are to succeed, equal consideration must be given to restoring degraded ecosystems to some semblance of their former state.

Environmental perturbation, if severe enough, can result in the partial or total reproductive failure of a stock, with corresponding genetic effect. Wild stocks are susceptible to overexploitation in multistock fisheries, especially when hatchery fish are abundant. If stocks are depleted to low levels, the loss of genetic variation becomes a major concern (Nelson and Soule 1987). Even moderate levels of exploitation may result in the selective loss of certain phenotypes and a concomitant genetic response (Ricker 1958, 1973, 1981; Larkin 1963; Paulik et al. 1967; Loftus 1976; Ferguson 1989). Traits most likely to be affected would be those most desirable to the fishery, such as rapid growth (large fish) and high catchability (Favro et al. 1979; Ricker 1982). When intense selection is applied over several generations, genetic variability within and between stocks can be expected to decline, potentially lowering the viability and commercial value of the affected stocks.

Recommendations

The genetic impacts of supplementation need to be carefully addressed in fisheries management planning and policy. Management decisions should be based on a consideration of the underlying stock structure of the species and an assessment of the genetic risks of proposed actions. It is important that information on life history, ecological, genetic, and exploitation parameters be obtained before and after supplementation commences, even if this means program delays or added costs. Gene flow between hatchery and wild stocks, ecological interactions, and long-term impacts on natural production should be evaluated (Kapuscinski and Philipp 1988).

Supplementation is a positive and viable strategy as long as it does not compromise the genetic integrity of existing wild stocks. Supplementation can play an important role in restoring and maintaining the genetic resources of wild stocks. However, where healthy stocks of wild fish exist (including non-target species), deliberation should be given to maintaining natural production with no interference from hatchery fish. Native stocks should be preserved for their genetic, cultural, and aesthetic value (Wagner 1979; Hankin 1981; Martin 1984). Wild stock genomes may be preserved through the establishment of refuges (Helle 1981) - streams and lakes that are maintained in pristine condition - and "egg bank" programs (Gjedrem 1981). Cryo-preservation of newly fertilized eggs, while not yet technically feasible (Parsons and Thorgaard 1985), may someday offer a means of restocking rivers with indigenous strains (Hindar et al. in press).

Several management approaches to avoiding deleterious genetic impacts from supplementation programs have been proposed (Reisenbichler 1986b). One is to minimize the opportunity for hatchery and wild fish to interbreed. This may be accomplished by keeping the ratio of hatchery to wild spawners small, by either scaling back hatchery production, increasing the harvest of hatchery adults, or increasing wild stock escapement through harvest regulation (Leider et al. 1986; Reisenbichler 1986a). Reproductive isolation can also be promoted through the careful selection of release sites, the use of sterile fish, and by artificially manipulating the time of spawning of hatchery fish so that they do not reproduce at the same time as wild fish.

In cases where interbreeding between hatchery and wild fish is desired, genetic disturbances can be minimized by starting the hatchery stock with locally-adapted fish, by continually "refreshing" the hatchery stock with wild genes, and by limiting maladaptive selection in the hatchery environment (Meffe 1986; Reisenbichler 1986b). The hatchery environment and rearing protocols can be made to ensure that the hatchery stock remains well adapted to the natural environment. Semi-natural spawning and rearing channels have proven useful in this regard.

Nonadaptive mating and rearing practices in the hatchery should be minimized, even if some production is forgone. Guidelines for mating and rearing hatchery salmonids consistent with the goals of supplementing wild stocks and maintaining desirable genetic characters include (Kapuscinski and Philipp 1988): (1) collecting as many wild spawners as is feasible and selecting parental pairs that are phenotypically representative of the associated stock, and (2) selecting a subsample of fertilized eggs for rearing and subsequent outplanting. Subsampling should be random at each step, and a surplus of

gametes or fish available relative to hatchery rearing space or outplanting program needs. Hatchery fish should be released at an early age at sizes and densities that are compatible with those of wild fish and the carrying capacity of the streams. It is important that hatchery practices which might promote straying are avoided.

Kreuger et al. (1981) and Kincaid (1983) have proposed random mating and systematic line crossing strategies for selecting and maintaining hatchery stocks to reduce the risk of inbreeding. Inbreeding can be ameliorated and genetic drift counteracted by maintaining large effective population sizes and by periodically adding eggs or sperm from wild donor stock. Allendorf and Ryman (1987) suggest as a rule of thumb a 10% contribution of wild genes every second or third generation to introduce new alleles and to minimize adaptation to the hatchery.

The development and propagation of a hatchery stock intended to supplement remnant (i.e., endangered or threatened) stocks of wild fish requires special considerations (Meffe 1986; Kapuscinski and Philipp 1988). It may not be possible to use fish from an endangered population as source stock without causing unacceptable reductions in population size and genetic variation. Closely related stocks or, failing that, fish having similar life history requirements should be used to rebuild severely depleted stocks. Populations with high genetic diversity are preferred as donors. Hybridization with the indigenous stock should initially be carefully controlled so that the hybrid line can be terminated if results are unsatisfactory. Meffe (1986) provides several recommendations for managing the long-term genetic resources of endangered species (Table 6).

In cases of local extinctions and severely altered habitat, Krueger et al. (1981) suggest crossbreeding fish from a large number of local stocks to create a single hatchery strain. This strategy would theoretically produce highly diverse genotypes among the progeny, some of which should be successful when stocked in the new environment. Marsden et al. (1989) describe a restoration program for Lake Ontario lake trout populations which aims to maximize genetic variability through multi-strain stocking.

Current thinking, however, holds that extensive outcrossing may disrupt coadapted genes that are optimally beneficial when collectively expressed under conditions to which they are adapted (Reisenbichler 1984, 1986b; Chilcote et al. 1986; Nelson and Soule 1987). There is a current need for more information on the role and pervasiveness of coadapted gene complexes in fish. Until such information is forthcoming, the development of hatchery stocks through the homogenization of discrete gene pools should probably be restricted to situations in which the between-stock component of the total genetic variation is significant (Allendorf et al. 1987) and where significant gene flow is not expected to occur between the stocked fish and wild populations (Krueger et al. 1981).

Table 6. Steps that can be taken to minimize adverse genetic impacts when supplementing endangered wild stocks. Based in part on Table 1 of Meffe (1986).

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1. Monitor genetics of wild and hatchery stocks.

2. Maintain largest feasible effective population size in wild and hatchery stocks.
   Effects:
   - Reduces the loss of genetic variation.
   - Reduces the loss of rare alleles.
   - Reduces the potential for inbreeding.

3. Integrate wild spawners from supplemented stock into hatchery broodstock.

4. Avoid inbreeding through selective mating.

5. Supplement with non-smolt life history stages.
   Effects:
   - Reduces selection for hatchery adapted traits.
   - Reduces hatchery conditioning (domestication).
   - Minimizes chances of catastrophic loss of stocks.

6. Do not use hatchery stock to supplement genetically dissimilar wild stocks.
   Effect:
   - Maintain among-population genetic variability.

Ecological Relations

Overview

Once released from the hatchery, salmonids may interact with their environment in several ways. Biological interactions include competition, predator-prey, parasite-host, and pathologic (disease) relations between salmonids and other organisms. Environmental factors, especially those that influence system productivity and habitat characteristics, may exert complex and variable control over each of these processes. In reviewing the effects of biotic and abiotic factors on supplementation, we extracted information from a variety of sources including observations reported for closely related nonanadromous species.

At the intraspecific level, hatchery and wild fish may: (1) compete directly for food and space during the freshwater rearing phase, (2) prey on one another, (3) transmit diseases or parasites to one another, (4) alter migratory responses, (5) vie for food resources during estuarine and marine phases, (6) redirect and amplify predation or exploitation, and (7) influence spawning

success through differences in reproductive behavior, timing, and genetic exchange.

Few studies have been explicitly designed to evaluate the effects of supplementation on the ecology of wild fish. In most studies, the post-release behavior, food habits, growth and survival of hatchery fish have been compared against the normal ecological attributes (as we understand them) of wild salmonids. Freshwater environments have received the most attention since fish living in streams, and to a lesser extent lakes, can be readily observed and because the juvenile life stage is sensitive to compensatory regulatory mechanisms that are amenable to study (Ricker 1954). Considerably less is known about competition and predation in saltwater.

Supplementation also affects interspecific relations. High densities of hatchery fish that are larger than the coexisting species may affect the competition for resources.

Supplementation may increase the intensity of predation on both hatchery and wild fish by stimulating aggregative, reproductive, or preferential feeding responses among non-human predators. The role of man-as-predator is an important one since differences in fishing mortality among hatchery and wild stocks will affect the outcome of supplementation. Concerns about the transmission of disease from hatchery to wild fish and vice versa have increased coincident with recent outbreaks of infectious diseases in anadromous fish hatcheries of the Pacific Northwest.

Competition

Competition between individuals of one or more species ensues when the demand for a resource in the environment exceeds its actual or perceived availability (Larkin 1956). The potential for intra- and interspecific competition between hatchery and wild stocks depends on the degree of spatial and temporal overlap in resource demand and supply. Several authors reported that hatchery fish, especially those reared in the hatchery for several months, were less efficient than wild salmonids in exploiting and defending limiting resources, and therefore at a competitive disadvantage (Clady 1973; Butler 1975; Krueger and Menzel 1979; Reisenbichler and McIntyre 1977; Vincent 1972, 1975, 1987; Petrosky and Bjornn 1988). Direct competition with wild conspecifics is often cited as a reason that hatchery fish exhibit reduced growth and survival in the wild. Conversely, it has been argued that hatchery fish have thrived in some areas because of reduced competition from declining numbers of wild fish (Campton and Johnston 1985; Seelbach and Whelan 1988), or because the hatchery fish had a size or prior residence advantage (Chandler and Bjornn 1988).

The capacity for hatchery fish to significantly alter the behavior, growth and survival of wild fish via competition remains a controversial subject. Supplementation can lower wild stock production if large numbers of hatchery fish are released (Snow 1974; Thuember 1975; Bjornn 1978; McMullin 1982; Vincent 1975, 1987; Nickelson et al. 1986; Kennedy and Strange 1986; Petrosky and Bjornn 1988).

We conclude from the available data that hatchery fish kept in the hatchery for extended periods before release as pre-smolts may have different food and

habitat preferenda than wild fish, that they will be unlikely to out compete wild fish, and that post-release growth rates and survival will be low if the wild stock is at or near carrying capacity in abundance. Hatchery fish put out as eyed eggs or released as swim-up fry can compete successfully with wild fish, with the outcome depending on the abundance and size of both the wild and hatchery fish. Competition from hatchery fish released as smolts could be minimal if the fish are truly smolts and they are released at the appropriate time so that they migrate seaward without undue delay. Hatchery steelhead released as "smolts" that do not migrate to the sea, for whatever reason, can pose a competition threat to wild fish. In some years, large numbers of hatchery steelhead residualize but often have trouble adapting to life in a stream; many die within months.

Dispersal

Point releases of hatchery-reared presmolts (eggs, fry and parr) and smolts are a commonly used supplementation technique (Hume and Parkinson 1987). Limited dispersal or emigration may result in excessive local densities of fish, underseeded sections of stream between stocking sites, and poor smolting success (Reisenbichler 1986a). Dispersal patterns of wild and hatchery fish are often either the cause or the effect of competitive interactions.

Several factors affect the post-stocking movements of hatchery fish (Cresswell 1981; Murphy and Kelso 1986): (1) species or strain of fish stocked, (2) physiological status (i.e., readiness to smolt), (3) age, size, and numbers of fish stocked, (4) water quality and discharge conditions, (5) habitat quality and quantity, (7) food availability, and (8) interactions with resident fish. The influence of many of these variables on the dispersal and subsequent distribution of hatchery fish is poorly understood.

Hatchery fish stocked as presmolts are expected to move into vacant areas to rear. Rapid and uniform dispersal following release presumably eases competitive pressures and optimizes natural production. Although wild fish seem to disperse within a stream in response to density or habitat availability (Gerking 1959), the rate and pattern of dispersal of hatchery fish from the point of release in streams is highly variable. In an Idaho stream where steelhead trout were stocked as eyed eggs and as buttoned-up fry, dispersion from stocking sites during the summer increased with increasing stocking densities (Bjornn 1978). Jenkins (1969) and Hesthagen (1988) reported a positive relationship between the movement of stocked brown trout and densities of wild fish. Large groups of hatchery-reared rainbow trout migrated faster and further from the point of liberation than did smaller groups of fish (Jenkins 1971). Dispersal distance was not related to stocking density of hatchery-reared steelhead trout fry released into Hastings Creek, British Columbia (Hume and Parkinson 1987). Petrosky and Bjornn (1988) reported that the proportion of smolt-size hatchery rainbow trout that dispersed from release sites in an Idaho stream was not related to stocking levels.

Several environmental factors have been implicated in the movement of stocked fish. Hatchery fish are more prone to disperse under conditions of high or fluctuating flow (Brynildson 1967; Irvine 1986; Reisenbichler 1986a; Heggenes 1988; Havey 1974), low turbidity (Sigler et al. 1984) and extreme water temperatures (Cooper 1952; Bjornn 1978). Channel morphology and the abundance of instream cover may influence the post-release movement,

distribution, and density of hatchery presmolts. Bilby and Bisson (1987) cited the availability of pools and cover as being more important than trophic conditions in determining the number of hatchery coho salmon fry remaining in western Washington streams after stocking. Dispersal may be more pronounced and rapid in streams with poor habitat.

Several researchers have reported that, at least initially, hatchery presmolts do not disperse readily from the point of release. Hume and Parkinson (1987) found that most of the steelhead fry released into a coastal British Columbia stream did not move into nearby vacant areas. Seelbach (1987) and Hillman and Chapman (1989) reported limited movement of stocked hatchery steelhead juveniles. In an Idaho stream, most hatchery-reared spring chinook salmon moved less than 2 km downstream of the point of release (Richards and Cernera 1989). Limited dispersal has been observed in stocked Atlantic salmon (Egglishaw and Shackley 1980), steelhead trout (Hume and Parkinson 1987), anadromous brown trout (Mortensen 1977; Solomon and Templeton 1976), chum salmon (Shustov et al. 1980) and various non-anadromous species and strains (Bjornn and Mallet 1964; Clady 1973; Cresswell 1981; Helfrich and Kendall 1982).

A possible cause of the lack of movement of hatchery salmonids is the social conditioning they are subjected to at the hatchery. Hatchery fish may be insensitive to density-dependent migrational stimuli (Symons 1969). Release methods may also a play a role. For example, dispersal of coho salmon smolts immediately after stocking was inversely related to the time spent in transit (Specker and Schreck 1980).

Hatchery presmolts that disperse following release tend to move downstream (Bilby and Bisson 1987; Mullan and McIntyre 1986; Hillman and Mullan 1989; Richards and Cernera 1989) under low light intensities (Elliott 1987), but this again appears to vary with species (Moring and Buchanan 1979), developmental stage and condition of the fish (Godin 1982; Thorpe 1982). Upstream movements, generally over a limited distance, have also been documented (Ruggles 1966; Hearn and Kynard 1986; Hesthagen 1988; Spaulding et al. 1989). Juvenile chinook salmon and steelhead trout allowed to emigrate from laboratory streams did so mainly at night (Taylor 1988).

Water temperature and stream flow also affect the directional movements of stocked salmonids. Exceedingly warm or cold water temperatures may induce movement into cooler tributaries or into areas containing suitable overwintering habitat (Bjornn 1978). Cooper (1952) observed trout to move downstream when stocked at low water temperatures. Some investigators have observed greater downstream movements of stocked rainbow trout released under high discharge conditions (Brynildson 1967; Moring and Buchanan 1979), and greater upstream movement during low flow periods (Clothier 1953). Others, however, have reported little or no effect of flow on dispersal patterns (Newell 1957).

Hatchery-produced fish that are undergoing the physiological and behavioral changes associated with smoltification are likely to emigrate seaward soon after liberation (Hansen and Jonsson 1985). Timing of the smoltification process varies some by species and race of fish and is dependent on growth rate (Zaugg et al. 1986). Hatchery smolts come into contact with wild fish as they migrate down the larger river systems (Levings and Lauzier 1988), but

generally, the potential for intraspecific competition is minimized when smolts are stocked if they migrate soon after release. In some anadromous species (e.g., steelhead trout, Atlantic salmon) smoltification does not take place in all fish at the same age, even under carefully controlled rearing conditions, and large numbers of released fish may not be ready to migrate seaward when released. Although their long-term chances of survival are often small (Petrosky and Bjornn 1988), "residualized" hatchery fish may interact with wild fish until they either emigrate or die.

Hatchery-released smolts may induce previously stocked or wild fish to join them in their seaward migration (Kuehn and Schumacher 1957; Hansen and Jonsson 1984; Hillman and Mullan 1989). This response may prove detrimental to wild fish if they have not yet reached smolt stage or if it increases their susceptibility to predation. A tendency to emigrate prematurely has been associated with species-specific behavioral differences and the presence of instream cover (Hillman and Mullan 1989).

Wild fish may be competitively displaced by hatchery fish early in life, especially when the latter are more numerous, of equal or greater size, and have taken up residency before wild fry emerge from redds. Naturally-produced fry normally disperse soon after emergence; smaller fish may be forced to emigrate under the influence of density- and size-dependent factors (Chapman 1962; LeCren 1965; Mason and Chapman 1965; Lister and Genoe 1970; Stein et al. 1972; Elliott 1989; Chandler and Bjornn 1988). This may explain why Hume and Parkinson (1987) found that young steelhead fry (0.2 g) dispersed up to three times farther than did older hatchery fry (1 g) released later. Salmonid post-sac fry that emigrate prematurely are not apt to survive in some situations (Heland 1980a, 1980b; Slaney and Northcote 1974; Mason 1966; Chapman 1962; Gee et al. 1978).

We could not determine from the literature whether wild parr face significant risk of displacement by introduced hatchery fish. A wide range of outcomes from wild-hatchery fish interactions has been reported. Wild rainbow trout did not migrate differentially from heavily stocked sections versus unstocked sections of an Idaho stream (Petrosky and Bjornn 1989). Similarly, introductions of hatchery-reared coho salmon or Atlantic salmon did not cause wild salmonids in the vicinity to emigrate (Hillman and Chapman 1989; Hearn and Kynard 1986). The distribution of wild steelhead parr in summer was altered slightly when catchable-size hatchery trout were added to a stream (Pollard and Bjornn 1973) and a small number of resident brown trout were displaced by hatchery trout (Bachman 1984). Symons (1969) noted that wild Atlantic salmon fry dispersed more readily than hatchery fry stocked simultaneously at the same location. The movement of wild brown trout in a creek in Montana increased substantially with the introduction of hatchery rainbow trout. The fraction of brown trout which moved up to 400 m increased from an average of 19% in non-stocking years to 33% in stocking years. Brown trout moving over 400 m increased from 2% to 10% for the same periods (Vincent 1987).

Habitat Use

The use of habitat by hatchery trout and salmon is often indistinguishable from that of wild fish, particularly when the hatchery fish are stocked as eggs, fry, or young parr (Bjornn 1978), but may differ from that of wild fish if the

hatchery fish have been kept in the hatchery for an extended period. Divergence in habitat use may be caused by behavioral conditioning that occurs in the hatchery and by competition-related interactions after release. Pollard and Bjornn (1973) reported that stocked rainbow trout congregated in deeper water than did native steelhead trout in an Idaho river, similar to the observations of Hillman and Chapman (1989), who found the hatchery rainbows in pools and the wild steelhead in riffles, runs, and cascades. In both studies, hatchery and wild rainbow trout were spatially segregated.

Petrosky and Bjornn (1988), after introducing catchable-size hatchery rainbows into two Idaho streams, concluded that hatchery fish did not use the same habitats as native cutthroat and wild rainbow trout. Bachman (1984) observed that hatchery brown trout, on average, used less energy-efficient foraging sites than did wild brown trout.

Hatchery-reared fish often fail to seek cover after release (Raney and Lachner 1942; Vincent 1960). In stream tank studies, Dickson and MacCrimmon (1982) and Sosiak (1978, 1982) observed that hatchery Atlantic salmon parr occupied positions further from the substratum than did wild salmon. The higher stationing probably reflects the joint effects of hatchery conditioning and competition with resident fish. Since wild Atlantic salmon normally remain close to the streambed (Gibson 1973), and inasmuch that this behavior has energy and predation cost-minimization value (Fenderson et al. 1968), we infer that such shifts in habitat use are detrimental to hatchery-reared fish.

In the cases where hatchery fish are stocked as eggs, fry, or young parr, we would expect a high degree of habitat use overlap between wild and hatchery fish and significant competition for resources. Stocked steelhead fry competed effectively with wild rainbow trout in a productive Idaho stream, and the population in the stream was changed from wild rainbow trout to mainly juvenile steelhead after a few years of fry stocking (Bjornn 1978).

Behavior

The success of supplemention using presmolts hinges on the ability of the hatchery fish to behave in a way that will allow them to grow and survive following release. The differences in behavior between wild and hatchery fish appear to be minimal early in life and increase with length of time spent in the hatchery. Differences in the behavior of hatchery and wild fish which seem to affect competitive interactions, habitat use, growth, and survival have been found (Sosiak et al. 1979; Dickson and MacCrimmon 1982). Ersbak and Haase (1983) have identified several behaviors that were successful in the hatchery rearing environment, but maladaptive in the wild: (1) a lack of wariness and a surface or mid-water orientation (Vincent 1960; Moyle 1969; Sosiak et al. 1979; Legault and Lalancette 1985; Dickson and MacCrimmon 1982), (2) an inability to form social hierarchies or hold positions in the natural stream environment (Chapman 1966; Bachman 1984), (3) excessive activity (Moyle 1969), and (4) high levels of aggression (Fenderson et al. 1968). To this list may be added sub-optimal foraging strategies (see the section on Feeding below). Some of these behavioral differences may be genetically based, but are more likely environmentally induced (Suboski and Templeton 1989).

Unusual physiological and behavioral characteristics of hatchery fish may predispose them, as Fenderson et al. (1968) remarked, to "loss of feeding time, excessive use of energy, and increased exposure to predators." Bachman (1984) came to much the same conclusion, suggesting that excessive energy expenditures were primarily responsible for the high mortality of hatchery brown trout he observed in a Pennsylvania stream. Petrosky's (1984; p. 86) description of the behavior of hatchery rainbow trout and resident wild cutthroat trout in a natural stream is instructive:

> "Upon release, hatchery rainbow trout formed aggregations in generally deeper and swifter water in midstream than that preferred by cutthroat trout...Most hatchery trout remained in groups segregated from wild cutthroat trout. These aggregates had no apparent hierarchy. During infrequent feeding, several group members pursued and fought over single items drifting past the group...Hatchery rainbow trout charged, drove, and nipped each other proportionately more often than wild cutthroat trout."

Hatchery salmonids are apparently less adept at conserving energy, and they do not perform as well as wild fish in stamina tests (Vincent 1960; Reimers 1956; Miller 1955, 1958; Green 1964; Bams 1967; Cresswell and Williams 1983). Horak (1972), working with nonanadromous rainbow trout, found hatchery fish had more stamina than wild fish. Hatchery-reared fish examined by Phillips et al. (1957) and Green (1964) had more fat and poorer muscle tone than wild fish. Nutritional deficiencies, notably imbalances in fatty acid composition, were suggested as a cause of reduced viability among hatchery fish by Bolgova et al. (1977).

The high level of aggressive behavior observed among hatchery fish following stocking (Fenderson et al. 1968; Moyle 1969; Fenderson and Carpenter 1971; McLaren 1979; Dickson and MacCrimmon 1982; Swain and Riddell 1990) may be misleading, and one must be careful in concluding that hatchery fish are more aggressive than wild fish. Aggressive encounters between wild fish begin immediately after emergence and occur as needed to establish and maintain dominance hierarchies or territories. Natural aggressive tendencies of salmon and trout may be suppressed in the hatchery, and the high level of aggression observed following release should not be unexpected when the fish are placed in an environment where there is diversity of habitat and food for which to compete. Doyle and Talbot (1986), found that selection for rapid growth in the hatchery did not result in higher levels of aggression; using game theory analysis, the authors predicted that hatchery selection may actually favor more docile fish. Elson (1975) hypothesized that newly stocked hatchery juveniles would be less aggressive than resident wild fish and therefore easily displaced. Swain and Riddell (1990) provide data which suggest that differences in aggressiveness may be genetic. These authors argue that hatchery juveniles may aggressively displace resident wild fish, only to suffer high predation mortality as a result of their conspicuous behavior. This hypothesis has yet to be tested.

Competitive bouts between hatchery and wild fish were usually more intense or prolonged than similar encounters between wild individuals (Fenderson et al. 1968; Dickson and MacCrimmon 1982). Excessive visual and social contact between "unfamiliar" hatchery and wild fish may elicit high levels of excitement and aggression in both groups (Li and Brocksen 1977). The

sudden change in environment probably contributes to the social disorientation of recently released hatchery fish.

From direct underwater observations, Shustov et al. (1981) concluded that 2 to 4 weeks are necessary before hatchery-produced juvenile Atlantic salmon display normal territorial behavior in the wild. Fenderson et al. (1968), on the other hand, found that hatchery Atlantic salmon parr attained social dominance over wild salmon parr in aquaria within one or two days. We suspect that the relatively poor performance of the wild salmon in the latter study was caused by the combined stresses of electrofishing, handling and subsequent confinement in unnatural surroundings. Woodward and Strange (1987) reported that wild rainbow trout are more susceptible to stress than are hatchery trout. Bachman (1984) found that hatchery brown trout, although initially achieving social parity with wild fish, did not successfully penetrate the long-term social fabric of the wild stock.

Feeding

The foraging success of hatchery fish following their release into the wild depends on their experiences, feeding opportunities, and habitat quality. Dietary overlap and competition between hatchery and wild salmonids is influenced by differences in microhabitat use, differences in foraging tactics and abilities, and size-dependent differences in prey selection. As far as we know, the diet or feeding habits of wild fish are unaffected by the introduction of hatchery fish. Theoretically, the amount of food available to individual fish should decrease with supplementation, but that depends on how well the hatchery fish adapt to feeding in the natural environment.

Salmonids have little opportunity to capture live prey while confined in hatchery raceways and ponds. Nevertheless, hatchery-reared fish appear capable of switching to a natural diet following release (Lord 1934; Raney and Lachner 1942; Jenkins et al. 1970; Ware 1971; Bryan 1973; Ringler 1979; Vinyard et al. 1982; Paszkowski and Olla 1985a, 1985b). Salmonids previously fed only hatchery pellets soon selected wild prey over artificial food when offered a choice (Bryan 1973; Paszkowski and Olla 1985b). In light of these results, suggestions by Kanid'yev (1970) and Suboski and Templeton (1989) to train hatchery fish to recognize natural food prior to release appear to be inappropriate.

If hatchery fish are able to switch to natural food items, why is malnutrition and starvation so often the fate of some hatchery fish in the wild (Klak 1941; Miller 1951; Reimers 1963; Ersbak and Haase 1983; Bachman 1984)? Again, a distinction must be made between hatchery fish released early in life (eggs, fry, young parr) and those that are reared for an extented period in a hatchery. The former usually adapt to feeding in the wild and grow naturally (Bjornn 1978), while the latter may have difficulty adapting fully to life in a stream, especially in relatively infertile streams where food likely limits production of fish. Hatchery fish that had spent significant time in the hatchery appear to be inefficient foragers that exist on suboptimal natural diets (Klak 1941; Reimers 1963; Fenderson et al. 1968; Moyle 1969; Elliot 1975; Sosiak et al. 1979; Shustov et al. 1981; Bachman 1984; Marnell 1986). Ersbak and Haase (1983) suggested that hatchery trout may have greater difficulty in detecting and exploiting increasing densities of certain forage items than do wild trout.

Hatchery juvenile Atlantic salmon examined 1-3 months after release ate a less varied diet than did wild fish (Sosiak et al. 1979).

Differences in stream microhabitats occupied by hatchery and wild salmonids may account for dietary differences during presmolt stages. Hatchery-reared juvenile Atlantic salmon assume positions higher in the stream water column than do wild salmon (Sosiak 1978), reflecting a conditioned response to feed at the surface (Peterson 1973). A comparison of the diets of hatchery fingerling rainbow trout with wild rainbow, brook and brown trout in the Salmon River of New York by Johnson (1981) revealed considerable dietary overlap. Interestingly, the types of food eaten by hatchery rainbow trout more closely resembled the diets of resident brook and brown trout than wild rainbow trout.

Interspecific Competition

Interspecific competition within the context of supplementation has not received much attention even though there are compelling reasons to consider interactions between hatchery fish and other species of fish living in the streams to be supplemented. Resident fish may affect the survival of the hatchery fish, and, conversely, hatchery fish may affect the abundance or productivity of coexisting species.

We presented evidence earlier that hatchery fish frequently segregate spatially from wild conspecifics in streams. It is not known whether this segregation is a product of intraspecific competition or hatchery conditioning, but the use of different habitats by the hatchery fish may explain why the diet of hatchery rainbow trout resembled that of wild brook and brown trout more that of wild rainbow trout in a New York stream (Johnson 1981).

Many of the behavioral anomalies of hatchery fish described in the sections on intraspecific interactions are also liable to affect interactions with other species. High densities of hatchery fish may suppress the normal behavior of other species (Stringer 1952, cited by Fraser 1968).

Size differences between hatchery trout or salmon and other species of fish affect competitive interactions and the partitioning of stream resources (Lister and Genoe 1970; Everest and Chapman 1972; Griffith 1972; Allee 1982; Cunjak and Green 1984). Petrosky (1984) reported that hatchery rainbow trout occasionally challenged wild cutthroat trout for permanent feeding stations after stocking in an Idaho stream. Only a few hatchery fish - always larger individuals - were successfully integrated into the size dominance hierarchy of the wild cutthroat trout population.

The potential for interspecific competition depends on the relative abundance of the stocked and resident fish species and the degree of niche overlap between them. Growth and survival are affected when the stream is "overseeded" and access to limiting shared resources is regulated by competition. By experimentally manipulating the relative densities of steelhead trout and coho salmon fry, Fraser (1968) observed interspecific effects on growth and mortality at high stocking densities (14.22 fish/m2). Likewise, LeCren (1965) found that the survival of stocked Atlantic salmon was inversely proportional to the total density of brown trout and Atlantic salmon present; the survival of resident brown trout did not vary with stocking level. Kennedy

and Strange (1980, 1986), on the other hand, observed a large decline in brown trout fry populations in lagged response to repeated introductions of Atlantic salmon fry. Reductions in the growth and survival of trout fry were attributed to interspecific competition with older (age-1) salmon that had been stocked as fry. Reciprocal effects were also noted: stocked salmon fry survived better and grew faster when older age classes of trout had been removed. Interestingly, competition between salmon and trout fry did not appear to affect the survival of either species. In an Idaho stream, annual stocking of steelhead fry resulted in a substantial decrease in the abundance of wild (non-anadromous) rainbow trout, but had little effect on brook trout that were present (Bjornn 1978). In the same stream, removal of all fish larger that 15 cm resulted in a doubling of the survival rate during the first summer of life for stocked steelhead fry (Horner 1978).

Growth

When densities of presmolts are increased through supplementation, the result is usually a decrease in the amount of food available per individual (Colby et al. 1972). Freshwater growth among salmonids is apparently density-dependent (McFadden 1968; LeCren 1972; Mortensen 1977; Bjornn 1978) so we should expect growth rates of wild fish to decline following stocking if the hatchery fish begin feeding on natural foods and the abundance of fish is near carrying capacity of the stream. Unfortunately, we could find few instances where the growth rates of wild fish were measured coincidence with the stocking of hatchery fish. Vincent (1987) measured a decline in the annual growth rates of several age classes of wild brown trout after catchable-size rainbow trout were stocked in some Montana streams. In a productive Idaho stream, Petrosky and Bjornn (1988) reported that growth of wild rainbow trout was not reduced when catchable-size rainbow trout were stocked at a rate that doubled the density.

In other studies, wild salmonids reportedly grew more rapidly than hatchery fish in natural environments (Needham and Slater 1943), but more slowly in hatchery environments (Reisenbichler and McIntyre 1977). Nielson et al. (1956) reported that the hatchery-reared trout he studied grew as well as native trout in the wild. Subyearling hatchery steelhead stocked at different densities in a Vermont stream showed little evidence of compensatory growth (Wentworth and LaBar 1984). In an Idaho stream stocked with varying densities of steelhead fry and chinook salmon parr, the steelhead were 10 mm or more shorter at the end of summer when the highest densities of fish were present (1.5 fish/m_2) compared to their length at lower densities (Bjornn 1978). Hume and Parkinson (1987) observed a weak (but significant) inverse correlation between the density and growth of outplanted steelhead fry and yearlings after one to two months of stream residence. Similarly, Egglishaw and Shackley (1980) and Egglishaw (1984) established that the growth of stocked underyearling Atlantic salmon was inversely related to the density of age-1+ salmon.

It is not uncommon for catchable-size hatchery trout and residualized steelhead smolts to lose weight during the weeks or months following stocking (Miller 1953, 1958; Ersbak and Haase 1983) and many do not survive to migrate seaward the following spring. In two studies where the growth of subyearling chinook salmon was monitored during the summer after stocking, the fish lost weight in one stream, and more than doubled their weight in the

other. Age-0 chinook salmon stocked in an infertile stream in late July of two years at mean total lengths of 71 and 75 mm and weights of 4.4 and 5.4 g, lost about 20% of their weight during the remainder of the summer (Sekulich 1980). Smaller chinook salmon (55-60 mm in length) stocked in a productive stream in June increased in length and more than doubled their weight during the summer (Bjornn 1978). Negative or reduced growth experienced by hatchery fish in some situations is a consequence of inadequate food supplies in some cases, such as in infertile streams, but their inability to feed as effectively as wild fish because of conditioning while in the hatchery probably is a major factor that intensifies the longer a fish is kept in the hatchery. Starvation and the metabolic costs of competing unsuccessfully for access to food (Doyle and Talbot 1986; Miller 1952, 1958; Bachman 1984) can cause to severe weight loss in the hatchery fish that ultimately leads to mortality (Reimers 1963).

Salmon and steelhead reared to the smolt stage and then released may grow a significant amount while migrating to the ocean if the rivers are relatively clear, but may have to rely on body reserves if the rivers are turbid and food items are not visible. Smolts that must migrate long distances from the upper reaches of the Columbia River drainage, for example, probably have enough energy reserves unless they are delayed migrating through the reservoirs and are unable to find food.

Survival

Survival of hatchery fish following stocking is a function of several factors including stream productivity, habitat quality, the physical condition of hatchery fish and their ability to acclimatize to stream conditions, the size and stocking density of hatchery relative to wild fish, depredation and disease, and stocking practices and techniques (e.g., season, rate, and location) (Murphy and Kelso 1986; Schuck 1948; Nielson et al. 1957; Clady 1973).

The high post-stocking mortality that is characteristic of transplanted anadromous (Table 7) and non-anadromous salmonids has been associated with several unfavorable conditions. Physiological stress due to crowded rearing conditions, transportation, handling, increased social interactions, and novel environmental demands probably increases the mortality of stream-stocked salmonids (Mason and Chapman 1965; Specker and Schreck 1980). Excessive levels of stress can deplete energy reserves and upset osmoregulatory and metabolic function (Wedemeyer 1972; Selye 1973; Mazeaud et al. 1977; Strange et al. 1977). Miller (1958) found that hatchery rainbow trout accumulated high levels of blood lactate levels following stocking and suggested that socially-instigated stress may have contributed to their poor survival.

Lack of exercise in the hatchery environment has been suggested as a cause of lowered vitality and a concomitant reduction in survival (Schuck 1948). A rapid decline in the condition of hatchery trout as energy stores are depleted has been cited as a possible cause of generally poor survival in streams (Klak 1941; Miller 1952, 1954, 1958; Reimers 1963; Ersbak and Haase 1983). Miller (1951) found that 30% of age 3+ and 50% of age 2+ hatchery-reared cutthroat trout died during the first 40 d after release in streams, apparently from exhaustion and starvation. The survival of fed coho

Table 7. Estimates of post-stocking mortality reported for hatchery-produced Atlantic salmon and steelhead trout. Modified from Bley and Moring (1986).

Species	Location	Life stage	Percent survival	Reference
Atlantic salmon	Scotland	Egg to fry	11.1-14.8	Egglishaw and Shackley (1980)
		Fry to 0+	9.4-31.0	
		0+ to 1+	51 (22-88)	
	Scotland	Egg to smolt	1.0-3.0	Egglishaw and Shackley (1977)
	N. Ireland	Green egg to fry	1.4	Kennedy and Strange (1981)
	N. Ireland	Eyed egg to fry	6.8-37.1	Kennedy and Strange (1980, 1984)
		Fry to 0+	16.7	Kennedy and Strange (1984)
		0+ to 1+	14.3-31.7	
	Ireland	Smolt to adult	12.7-4.4	Piggins (1980)
	Scotland	Fry to 0+	1.3-23.3	Mills (1969)
	Scotland	Fry to smolt	2.4-3.1	Mills (1964)
	Scotland	Egg to 0+	1.7-2.0	Shearer (1961)
		Egg to 1+	0.08-0.46	
	United Kingdom	Fry to 0+	1.7-8.8	Stewart (1963)
		Fry to 1+	3.6	
	United Kingdom	Fry to smolt	0.25-1.7	Harris (1973)
		Smolt to adult	2.1-3.8	

Table 7. (continued)

Species	Location	Life stage	Percent survival	Reference
	France	Eyed egg to fry	50-80	Brunet (1980)
		0+ to 1+	up to 90	
	Sweden	Smolt to adult	0.4-13.1	Wendt and Saunders (1973)
	Sweden	Smolt to adult	12.5	Larsson (1984)
	Ontario	Fry to 0+	12.7 (10.7-14.6)	MacCrimmon (1954)
		Fry to 1+	9.2 (9.0-9.2)	
		Fry to smolt	3.0	
	Quebec	Fry to age-0+	5 - 72	Cote and Pomerleau (1985)
		0+ to 1+	1 - 31	
	New Brunswick	Fry to 1+	8.0-12.0	Dickson and MacCrimmon (1982)
	Maine	Smolt to adult	0.7-1.4	Baum (1983)
Steelhead trout				
	California	Egg to emergence	30-80	Shapovalov (1937).
	Oregon	Egg to emergence	18-99	Phillips et al. (1975).
	Idaho	Egg to emergence	40-95	Bjornn (1978).

Table 7. (continued)

Species	Location	Life stage	Percent survival	Reference
	California	Emergence to:		Burns (1971).
		age-0	27	
		age-1 +	56	
	Idaho	Emergence to:		Bjornn (1978).
		age-0	10-20	
		age-1	6-41	
		smolt	0.4-3.8	
	California	Fingerling to adult	2	Hallock et al. (1961).
	California	Smolt to adult	2.1-18	Shapovalov (1967)
	Oregon	Smolt to adult	0-10	Wagner (1963).
	Oregon	Smolt to adult	3.9-10.9	Wagner (1968).
	Oregon	Smolt to adult	1.7-7.0	Wagner (1969).
	British Columbia	Smolt to adult	5	Hume and Parkinson (1988).
Coho salmon				
	Western Washington	Fry (spring to autumn)	13-34	Bilby and Bisson (1987).

salmon fry was greater than unfed fry following stocking in Puget Sound streams (T. Flint, pers. comm., cited by Wunderlich 1982).

The post-stocking survival of hatchery presmolts and smolts is sensitive to the number of fish stocked (Wentworth and LaBar 1984; Hume and Parkinson 1987) and local densities of prior residents (Kennedy and Strange 1986). In a Washington study (Royal 1972), a density-dependent relation was found between steelhead smolt production and adult returns for hatchery fish that were forced to migrate long distances to the ocean. A freshwater mortality agent was implicated (but never identified) when the survival rates of fish from coastal hatcheries did not show similar trends. Although some biologists consider density-dependent mortality during freshwater migration to be negligible (Lichatowich and McIntyre 1987), supplementation managers should consider the potential for unwanted density-dependent interactions between hatchery and wild smolts.

Competition-induced shifts in habitat selection by hatchery trout may reduce their chances of survival. High mortality of hatchery-reared salmonids has been attributed to their selection of microhabitats which are not conducive to survival (Vincent 1960; Dickson and MacCrimmon 1982; Petrosky and Bjornn 1988). Competition for preferred microhabitats can be dampened and feeding opportunities increased by scattering fish in underseeded, high quality rearing areas. Bilby and Bisson (1987) concluded that the survival of hatchery fish was enhanced by the presence of pools and instream cover. Greater structural heterogeneity would reduce visual contact with potential competitors and predators, and it might temper the effect of floods on stocked fish (Odonera and Ueno 1961).

Overwinter survival of hatchery fish can be very low, often nil (Needham and Slater 1944; Heimer et al. 1985; Petrosky 1984), although Adelman and Bingham (1955) found little or no difference between hatchery and native brook trout in their ability to survive the winter months. Overwinter survival was highest for fall-stocked hatchery brook, brown and rainbow trout in streams where surface ice was rare and cover was present (Brynildson and Christenson 1961). Mason et al. (1967) noted higher overwinter survival of hatchery fish relative to wild fish in 3 of 5 streams, which they attributed to the larger size and good condition of hatchery fish going into winter. Reimers (1963) discusses the nutritional status of stocked hatchery trout as it relates to overwinter survival.

The survival to returning adult of hatchery-reared chinook salmon (Reisenbichler et al. 1982), coho salmon (Salo and Bayliff 1958; Nickelson et al. 1986) and steelhead trout (Wagner et al. 1963) was positively related to their size at release. The liberation of large presmolts has at least two important consequences with regard to their competitive abilities and subsequent survival. First, a large average size at release may reduce the length of time spent in the stream, thereby increasing chances for survival to smolt stage. Second, hatchery fish, if larger than wild cohabitants, are more likely to be successful in agonistic encounters. Flick and Webster (1964) and Mason et al (1967) were able to demonstrate higher survival among hatchery salmonids when they possessed a size and presumably a competitive advantage over wild residents.

As reported by Nickelson et al. (1986), juvenile hatchery coho salmon used to supplement wild stocks in Oregon streams averaged half again as large as resident wild coho (62 versus 39 mm in length) when released in late spring. Hatchery fish were larger due to earlier emergence and accelerated growth in hatchery facilities. Outplanting hatchery coho salmon presmolts increased by 41% the density of juveniles rearing in pools (the preferred habitat) during the summer following release. However, the average density of wild coho salmon declined by 44% over the same period. Nickelson et al. (1986) suggested that the decline was due to the size advantage enjoyed by the larger hatchery coho salmon in competitive encounters with smaller wild fish. Based on additional studies (Chapman 1962; Mason and Chapman 1965; Chandler and Bjornn 1988), differences in fish size are known to be important in determining the outcome of competitive interactions; larger salmonids generally grow and survive better than smaller ones.

Studies by Miller (1954, 1958), Bjornn (1978), Petrosky and Bjornn (1988), and Vincent (1987) illustrate the complex and somewhat unpredictable response of wild salmonids to supplementation. Miller (1954, 1958) found that wild fish were able to outcompete stocked trout without incurring additional mortality. Petrosky and Bjornn (1988) observed that the survival of wild salmonids declined only at very high stocking densities. A compensatory downward adjustment in the summer mortality rate of wild rainbow trout was observed when 400 catchable-size rainbow were released into a 146-m section of stream (Petrosky 1984). At low and intermediate stocking densities (50 and 150 fish, respectively, per 106-m sections), densities of wild rainbow trout in Big Springs Creek were no different than in previous years of no stocking. This implies that hatchery vs. wild trout competition was muted due either to (1) significant losses (mortality or emigration) of hatchery trout, or (2) a non-limiting supply of resources. The former explanation seems justified: only 1% of the hatchery trout remained in the study sections a year after their release.

Vincent (1975, 1987) contended that hatchery fish had a significant effect on the survival of resident wild salmonids. A 49% decline in wild trout numbers in a previously unstocked section of O'Dell Creek, Montana, coincided with introductions of hatchery rainbow trout, and the abundance of age 2 and older brown trout and rainbow trout in the Madison River increased after stocking was terminated. In an Idaho stream, the number and percentage of older resident (non-anadromous) rainbow trout declined during 10 consecutive years of stocking of steelhead fry (Bjornn 1978). The steelhead fry competed successfully with the age-0 wild rainbow trout and reduced the number of wild fish that survived the first summer.

Salmon and Steelhead in the Marine Environment

In this section we discuss competitive interactions and the relative growth and survival of hatchery and wild anadromous salmonids in marine environments. Because few studies have addressed these topics within the context of supplementation, much of the following synthesis is based on results obtained from more general studies of marine salmonid ecology.

The ocean segment of the anadromous salmonid life cycle consists of several distinct migratory phases, including estuarine, coastal, offshore, high seas, and return to freshwater. During this time fish gain approximately 98%

of their final body weight (Peterman 1987) while survival rates are typically less than 15% (Foerster 1968; Bley and Moring 1988).

In general, hatchery fish experience higher mortality rates than wild salmonids from the same river system (Bley and Moring 1988; Raymond 1988; Piggins 1989). Rates of return for hatchery spring chinook salmon and steelhead trout from the Snake River were lower, by as much as one order of magnitude, than return rates estimated for wild stocks during 1966-1984 (Figure 3A and B). The record 1982 return for hatchery steelhead stands in sharp contrast to the extremely low rates recorded for hatchery spring chinook salmon. Raymond (1988) believes that disease-related mortality may have decimated hatchery chinook salmon smolts either en route or upon entry into saltwater.

In Ireland, Piggins (1989) reported a 3.6:1 ratio of wild-to-hatchery Atlantic salmon returns. Isaksson (1979, cited by Bley and Moring 1988) obtained similar results (2.8:1) for Atlantic salmon escapement to Icelandic streams. Bley and Moring (1988) summarized references (included in Table 7) and reported an average smolt-to-adult survival of wild steelhead trout of 13%, compared to 5% for hatchery-produced fish. Marine survival rates have on occasion been higher for hatchery-produced fish than for wild fish. In an Oregon study (Aho et al. 1979), hatchery and wild steelhead trout were reared to smolt stage in a hatchery, released, and enumerated upon their return as adults. Return rates were higher for progeny of hatchery fish in one year, and for progeny of "wild" fish in a second year.

Competition between hatchery and wild salmonids in the ocean has not been unequivocally demonstrated, because there is little or no competition, or perhaps because of the complexity of factors involved (see Mathews 1984 for a review), a paucity of experimental data, and natural variability in the occurrence of competition and its effects. Nevertheless, noting that(1) hatchery-reared fish forage successfully upon reaching the ocean (Paszkowski and Olla 1985a, 1985b), (2) food production is frequently patchy in time and space (Healey and Groot 1987), (3) migratory salmonids remain in fairly cohesive groups (Pearcy 1984), (4) migration routes of different stocks and species may overlap, and (5) ocean distributions do not change significantly either seasonally or with fish age (Healey 1986; Healey and Groot 1987), one could conclude that competition is possible between hatchery and wild fish in the ocean, particularly in nearshore areas and during periods of low productivity.

Peterman, in a series of publications (1977, 1978, 1981, 1982, 1987, 1989), has championed the view that, for many salmonid species, survival and growth rates in the ocean depend on stock abundance. Interpretations of the data available have been conflicting. Analyses provided by McGie (1981, 1984), ODFW (1981), McCarl and Rettig (1983), Peterman and Routledge (1983), and Emlen and Reisenbichler (1988) favor the interpretation that marine survival of Oregon coho salmon has been limited by density-dependent factors. The opposite conclusion, drawn from the same data set but based on different model specifications and data manipulations, was reached by Peterman (1981), ODFW (1981), Clark and McCarl (1983), and Nickelson (1986), who provided a synopsis of the debate. The failure of the escapement of adult coho salmon from the Oregon Production Index Area to continue rising despite increased releases of hatchery-produced smolts since about 1970 (Figure 4) added to the

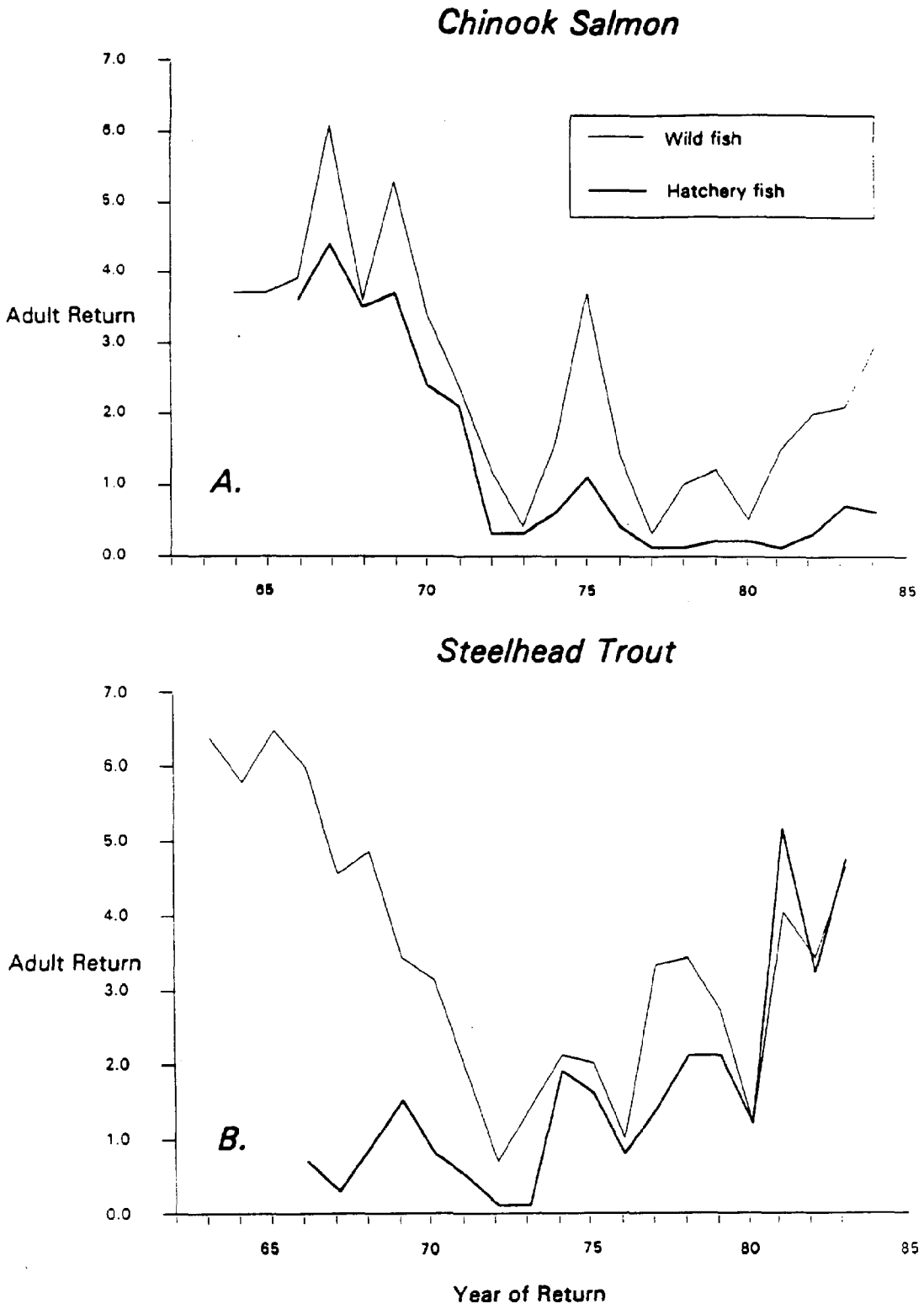

Figure 3. A comparison of the 1964-1984 rates of return of hatchery and wild spring chinook salmon (A) and steelhead trout (B) from the Snake River drainage. Data are from Raymond (1988).

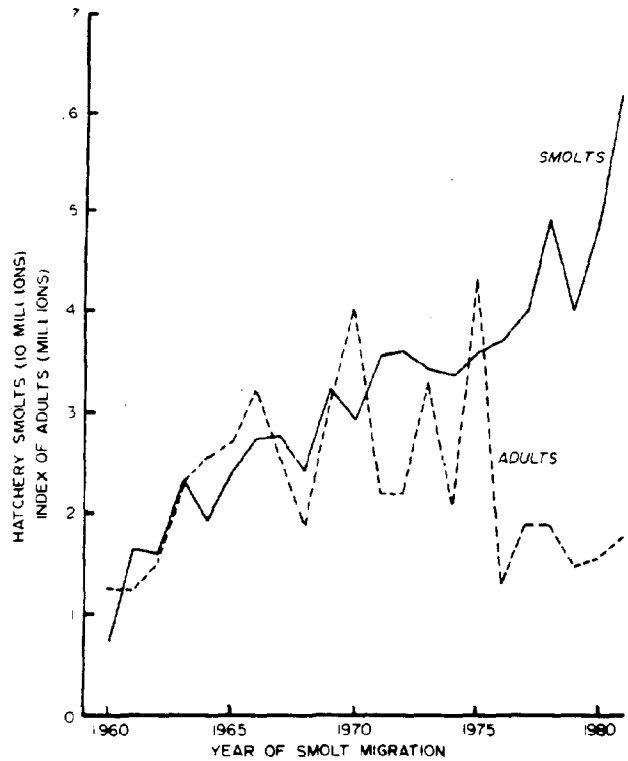

Figure 4. Recent (1976-1985) trends in the number of hatchery smolts released and the escapement of adult coho salmon from the Oregon Production Index Area. Taken from Nickelson (1986).

debate about density-dependent survival in the ocean. The marine survival of hatchery coho salmon released during years of strong coastal upwelling was about twice that in weak upwelling years, but survival of both hatchery and wild fish was lower during years when sea-surface temperatures were lower than average (Nickelson 1986, Peterman 1989). McGie (1984) and Peterman and Routledge (1983) reported a non-linear relationship between smolts released and adult production for years of weak upwelling, implying density-dependent mortality, at least during low productivity periods.

Additional evidence of density-dependent growth or survival in saltwater has been presented by Anderson and Bailey (1974), Anderson and Wilen (1985), Rogers (1980, 1984), McDonald and Hume (1984), Eggers et al. (1984), and Reisenbichler (1985). Of particular interest are data which suggest that interspecific competition between adult chum and pink salmon in Puget Sound may affect their mutual survival (Reisenbichler 1985).

Levy and Northcote (1981) concluded that the marine survival of chinook salmon was determined to a large extent by the duration and quality of estuarine residence. Length of estuarine residence is dependent on species, developmental stage, food quantity and quality (Mason 1974), river discharge and tidal influences, and estuarine topography (Iwamoto and Salo1977). Levings et al. (1986) reported that the presence of hatchery chinook salmon did not affect residency times and growth rates of wild juveniles in a British Columbia estuary and the adjacent foreshore region. Hatchery fish used the

estuary for about one-half the length of time that wild fry were present (40-50 d). Other investigators provide evidence that competition between hatchery and wild salmonids could occur and cause growth and survival to be density-dependent in estuaries (Reimers 1973; Bailey et al. 1975; Levy and Levings 1978; Healey 1979, 1982; Simenstad et al. 1979; Neilson et al. 1985).

Adults in Freshwater

Anadromous salmon and trout are renowned for their homing abilities and the reliable timing of their spawning migrations. Reviews of these topics may be found in Banks (1969), Leggett (1977), Brannon (1982), and Hasler and Scholz (1983). Although recent research has advanced our understanding of how salmonids are guided in their movements (McIssac and Quinn 1988), there have been few comparative studies of the migratory abilities or inriver survival of hatchery versus wild adults. The obvious question, "Does supplementation adversely affect the spawning migration of wild salmonids?" cannot be definitively answered from the information at hand.

Migratory tendencies and homing accuracy varies considerably between species and strains of salmonids (Webster and Flick 1981; Kincaid and Berry 1986). Straying of wild fish was the means of colonizing most drainages covered by the last ice sheet and still represents a potential source of new genetic material. Straying by hatchery fish, however, may be a detrimental infusion of genes into a wild stock if large numbers of hatchery fish stray and if their genetic makeup is significantly different from the wild stocks. There is evidence that the progeny of transplanted pink (Bams 1976) and Atlantic salmon (Stabell 1981, 1984) home less precisely than locally adapted stocks, but such was not the case for coho salmon (Reisenbichler 1988).

The accuracy with which hatchery fish return to the hatchery or stream into which they are stocked is influenced by stocking and transportation practices. Straying rates increase if the release from the hatchery is delayed until after smolt transformation is complete (Peck 1970; Larson and Ward 1954; Scholz et al. 1978), if portions of the downstream migration route are bypassed (Hansen et al. 1989), and as the distance between the hatchery or parental stream and release site increases (Lister et al. 1981; Gunnerod et al. 1988). Hatchery fish can return with high fidelity to the stream where they were planted, and to the area of release (Wagner 1969).

A high incidence of straying is generally unacceptable from a supplementation standpoint because of harvest complications and the possibility that, if spawning occurs, wild stocks might be adversely affected (Buchanan and Moring 1986; Evans and Smith 1986). Assuming that stocked hatchery fish can be induced to home with some precision, managers may be able to (1) reduce the sport harvest of wild stocks while increasing the catch of hatchery-produced fish, (2) optimize the distribution of naturally spawning fish, and (3) better seed the streams with naturally-produced fry.

Behavioral interactions between migrating hatchery and wild salmonids appear to have little effect on supplementation programs. Overcrowding in prime holding areas may increase the dispersal of adults (Cramer 1981), possibly to the detriment of displaced fish.

We found little information to evaluate the claim that natural mortality rates differ between upstream hatchery and wild migrants. Leider et al. (1986) argued that the lower abundance of repeat spawners among hatchery-produced steelhead trout relative to wild fish was due to higher mortalities of hatchery steelhead during repeat spawning migrations. The basis for this conclusion was not determined, but the authors suggested that energetic bankruptcy among hatchery fish following the initial migration may have contributed to their poorer survival. Rosentreter (1977) also reported a low incidence of repeat spawners for hatchery winter steelhead in an Oregon stream.

Surplus hatchery spawners have at times been returned to the river to provide anglers with an additional opportunity to harvest them (Buchanan and Moring 1987). Adults transported and released downstream from their natal hatchery usually return rapidly and offer little opportunity to anglers (Bjornn 1986). Adults distributed upstream may also return to the site where they were released as smolts, but the likelihood of doing so diminishes as the transportation distance increases (Reingold 1975; Cramer 1981). The primary drawback of returning surplus adults to the fishing areas is the possibility that the fish will not be caught and may stray into spawning areas where they are not wanted (Buchanan and Moring 1987).

The relative success of wild and hatchery fish spawning in natural environments has been studied in recent years, and there is evidence that hatchery adults may produce fewer smolts and returning adults than wild adults (Leider et al. 1986; Chilcote et al. 1986; Nickelson et al. 1986). In studies of steelhead in the Kalama River (Washington), Leider et al. (1986) and Chilcote et al. (1986) found low reproductive success among naturally spawning hatchery fish compared to wild spawners. Although hatchery spawners outnumbered wild spawners by at least 4.5 to 1, only 62% of the naturally produced steelhead smolts were offspring of hatchery fish. Differences in viability were thought to be a consequence of earlier than normal spawning by hatchery steelhead.

Stocking of coho salmon presmolts into selected Oregon coastal streams boosted juvenile densities (at the expense of juvenile wild coho salmon), but did not increase the number of returning spawners compared to unstocked streams. The adults returning from presmolt releases spawned several weeks earlier than wild fish, and Nickelson et al. (1986) concluded that the early spawners, primarily hatchery fish, contributed little to natural production. The density of the later spawning wild coho salmon returning to the stocked streams was about half that observed in unstocked streams. After stocking ceased, densities of naturally produced salmon fry averaged 32% less in the formerly stocked streams than were found in the streams that had never been stocked.

Whether hatchery and wild fish interbreed depends on their relative abundance, the degree of spatial and temporal overlap, and the outcome of sexual competition for mates and spawning sites. In the study of steelhead in the Kalama River, the spatial and temporal overlap among hatchery and wild spawners was sufficient to permit crossbreeding (Leider et al. 1984). Differences in primary (e.g., egg size and fecundity) and secondary (e.g., body coloration and size) sexual characters between hatchery and wild spawners may lead to unequal reproductive contributions by members of the respective groups (Schroeder 1981; Gross 1985; Fleming and Gross 1989; Foote 1989).

Predation

Predation is a major source of mortality for anadromous salmonids both in freshwater and in the ocean - estimates range as high as 98% (Fresh et al., unpubl. manuscript).

Fish are believed to be the major predators of hatchery and wild salmonids, but predation by birds and mammals can be substantial (Elson 1962; Fraser 1974; Mace 1983; Ruggerone 1986; Wood 1987). Few direct estimates of the severity of these losses are available. Based on dietary studies and relative abundance estimates, the primary freshwater consumers of hatchery fish in the Pacific northwest include salmonid, cyprinid, and cottid fishes, and mergansers, kingfishers, and gulls. Blue sharks, sea lions, and harbor seals are encountered in coastal regions, whereas sharks and lampreys are major predators in the high seas (Ricker 1976).

Losses to predation may be higher for hatchery fish than for wild salmonids because of inappropriate avoidance and foraging behaviors, an inability to accurately assess predation risks, secondary stress effects, and a general unfamiliarity with their new surroundings for the hatchery fish. Several studies (MacCrimmon 1954; Piggins 1959; Kanid'yev 1966; Larsson 1985) have revealed intense post-release predation mortality among hatchery-reared salmonids. Brown trout, for example, prey heavily on stocked Atlantic salmon fry during the first few days after stocking (Mills 1964). Kanid'yev (1966) reported that predators consumed 14-30% more hatchery-reared chum salmon than wild chum fry during the first month following release. Studies by Bams (1967) and Mead and Woodall (1968) suggest that artificially-propagated sockeye salmon fry are more prone than wild sockeye fry to predation. Hatchery fish were found to be more vulnerable to kingfisher predation than were wild salmonids (Male 1966).

Predation mortality may increase when physiological stress, either natural or man-caused, is induced in hatchery-reared and wild fish (Congleton et al. 1985). Juvenile salmonids, while stressed, may have impaired swimming ability (Schreck et al. 1985). Sources of stress include poor water quality, disease pathogens and parasites, overcrowding, handling, transportation (Specker and Schreck 1980), and situations requiring extraordinary physical exertion (e.g., passage through dams and diversions; Fresh et al., unpub. manuscript).

Environmental factors such as light intensity, discharge, turbidity and water temperature play important roles in determining the magnitude of predation mortality (Ginetz and Larkin 1976; Sylvester 1971). Variation in the amount of predation by resident brown trout on planted Atlantic salmon fry was found to depend on habitat type (MacCrimmon 1954). Tagmaz'yan (1971) noted that predation was less severe in larger rivers than in small streams due to their frequently turbid nature, fast current, and larger volume of water. Predation rates during seaward migrations appear to be negatively correlated with stream discharge (Hvidsten and Hansen 1988), presumably because transit times are shortened and higher turbidities reduce the chance of detection by predators.

Salmonids released from hatcheries at sizes larger than wild residents are potential predators, whereas fish stocked as smaller individuals are potential prey. The apparent susceptibility of small fry to predation suggests that older

life stages may have greater survival potential (Mead and Woodall 1968; Warner 1972). Cannibalism of hatchery-reared salmonid fry by wild resident fish is common (Symons and Heland 1978; Kennedy and Strange 1986; Semko 1954a, 1954b). Conversely, hatchery salmonids may prey on wild fish or cannibalize their own; as, for example, when yearling fish are released when wild fry are emerging from redds (Reisenbichler 1986b; Nietzel and Fickeisen 1990). Sholes and Hallock (1979) reported that 0.5 million yearling chinook salmon stocked in the Feather River, California, ate 7.5 million wild chinook and steelhead fry. Levings and Lauzier (1988), however, found no evidence of cannibalism of emigrating wild chinook fry by larger hatchery smolts in the Nicola River, British Columbia. The authors suggested that wild fry avoided predation by remaining in the shallow margins of the river.

The extent of predation upon non-salmonid species by hatchery salmonids is not well-known (Evans and Smith 1986). Pisciverous hatchery-reared brown trout, however, were observed to consume fish of other species roughly in proportion to their abundance (Garman and Nielsen 1982). Millard and McCrimmon (1972) suggested that, in some cases, intra- and interspecific predation may be buffered by the presence of stocked fish.

Even when they are not pisciverous, hatchery salmonids may expose wild fish to greater predation risks. Competitively displaced wild fish may be more conspicuous through their movements or residence in suboptimal habitats. Large concentrations of hatchery fish may adversely affect wild juveniles by stimulating numerical (e.g., at dams, river mouths, etc.) and functional responses among bird and fish predators. In many cases predation mortality is nonlinear and depensatory so that the proportion of fish eaten is greater when prey populations are small (Figure 5A, 5B) (Neave 1953; Hunter 1959; Peterman and Gatto 1978; Mace 1983; Wood 1984). This type of predation mortality was termed type-II predation by Holling 1973. An alternate form of predation, called type-III predation, may be compensatory at low prey abundance, but depensatory at higher densities (Figure 5C). Since wild smolts are frequently dwarfed in number by hatchery releases, we would expect disproportionately higher mortality rates among the wild fish.

The vulnerability of hatchery and wild salmonids to predation depends on a number of factors. During underwater observations of predatory attacks by large rainbow trout on mixed groups of outmigrating hatchery and wild chinook salmon in the Wenatchee River, Washington, Hillman and Mullan (1989) reported that wild fish were preferentially preyed upon, probably because they were half the size of the hatchery fish. In 23 attempts (all successful), the trout caught and ate wild fry on all but one occasion, when a hatchery chinook salmon was taken. In other studies, there was either no difference (Hvidsten and Lund 1988) or higher levels (Osterdahl 1969; Ruggles 1980) of predation on hatchery-produced smolts compared to wild smolts.

The effect of predation on hatchery and natural salmonid production has been further revealed by predator removal experiments. Better survival of stocked Atlantic salmon fry was obtained by reducing the population of predators in several Scottish streams (Mills 1969). Survival of hatchery steelhead fry stocked in an Idaho stream doubled following removal of fish predators (Horner 1978). Sekulich (1980) found that 49% of the age 0 spring chinook salmon introduced into another Idaho stream remained in pools from which predaceous brook and steelhead trout had been removed, compared to

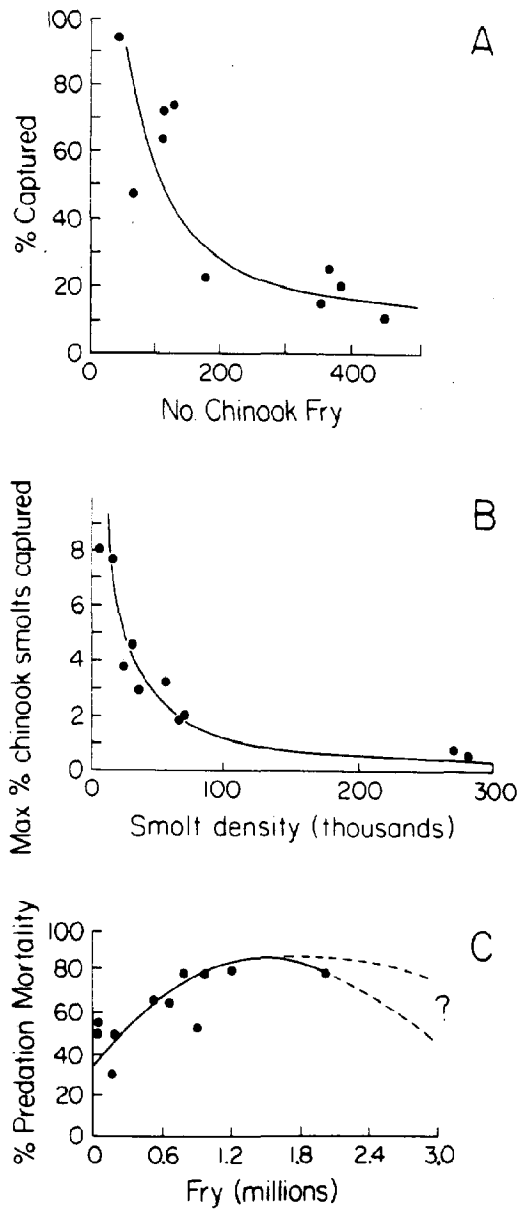

Figure 5. Examples of predation mortality rates of juvenile salmon. Percentage of chinook fry captured by (A) Bonaparte's gulls during 5-minute trials (after Mace 1983), and (B) mergansers on a daily basis. (C) Percent daily predation on pink salmon fry by coho salmon smolts and trout. Taken from Peterman (1987).

only 15% in unmanipulated pools. The survival of Atlantic salmon to adult stage was three times higher when smolts were released in the ocean rather than upstream in the river to bypass predation during downstream migration (Hvidsten and Mokkelgjerd 1987).

Similar reductions in predation mortality have been reported when avian predators were removed or reduced in abundance. Huntsman (1941) and Elson (1962) were able to increase Atlantic salmon smolt production by 200-500% by reducing the number of pisciverous birds (primarily mergansers). Avian predators such as gulls and mergansers are opportunistic foragers (MacDonald et al. 1988); if juvenile salmonids are abundant or otherwise conspicuous relative to other species, they become the preferred prey (Wood 1987). Further, bird predators congregate in favorable feeding areas, such as near hatchery release points (Mace 1983). In the Columbia River, ring-billed gulls flock to hydroelectric facilities during the spring to feed on migrating salmonids that are killed, wounded, or disoriented as the pass through or over the dams (Ruggerone 1986).

Dams on the Columbia River and other regulated streams of the Pacific Northwest have created conditions that are generally unfavorable for migrating salmonids. The number and diversity of piscivorous fishes has increased in mainstem reservoirs. Exotic species such as the walleye, smallmouth bass, and channel catfish - all predators of juvenile salmonids - have become prominent in reservoir fish communities (Maule and Horton 1984; Gray and Rondorf 1986). At the same time, reservoir refill operations and the backwater effects of dams have increased the length of time that smolts are exposed to predators during their seaward migrations.

The northern squawfish preys on both wild and hatchery juvenile salmonids in lower sections of the Columbia and Snake Rivers (Thompson 1959; Sims et al. 1977; Gray et al. 1983, 1984, 1986; Nigro et al. 1985; Palmer et al. 1986). Squawfish concentrate in tailrace areas of dams where they are able to feed on seaward migrants (Palmer et al. 1986; Faler et al. 1988). Sims et al. (1977) found salmonid remains in 21% of squawfish captured directly below Lower Granite Dam on the Snake River. Squawfish predation on salmonids was higher in fish collected near dams on the lower Columbia River than in those collected away from dams (Gray et al. 1983). Near stocking locations and during periods of hatchery releases, Thompson (1959) reported that juvenile salmonids made up 87% of the fish consumed by northern squawfish in the lower Columbia River. Buchanan et al. (1981), on the other hand, found salmonid remains in only 2% of the squawfish collected in free-flowing sections of the lower Willamette River.

As prey populations become more prolific, diverse, and stable in the Columbia and Snake River reservoirs, the abundance of predators will no longer be constrained by short-term annual supplies of outmigrating wild smolts. Shifts in predator type and abundance that come with altered species associations, and perhaps with increased hatchery production, have led to higher predation mortalities among wild juveniles during migration (Li et al. 1987). Theoretically, inflated predator populations can decimate wild stocks, either trapping them at low levels of abundance or pushing them toward extinction (Peterman and Gatto 1978; Ney and Orth 1986; Peterman 1987).

The effect of adding large numbers of hatchery fish to a basin, such as the Columbia River, on predation in the estuary and marine environments has not been studied to our knowledge. Mortality from predation is variable during the estuarine phase. Several North American workers reported that predation on salmonids in estuaries is low (Myers 1978; Simenstad et al. 1982; McCabe et al. 1983; Myers and Horton 1982). But in recent studies by Norwegian researchers, predation losses in estuaries ranged up to 25% of the smolt population (Hvidsten and Mokkelgjerd 1987; Hvidsten and Lund 1988). No significant difference was found in the predation rate (20%) on wild and hatchery-reared Atlantic salmon smolts in the estuary of the River Orkla, Norway. Piggins and Mills (1985), however, observed that hatchery-produced smolts survived less well at sea than wild smolts by a factor of four which the authors theorized was due in part to differences in predator avoidance behavior.

The intensity and magnitude of predation in estuaries depends in part on the duration of residence, the types and numbers of predators present, and the bathymetric and hydrographic properties of the estuary. For some species, the smaller the fish is upon reaching the estuary, the longer the duration of estuarine residence (Simenstad et al. 1982). Levings et al. (1986) reported that wild juvenile chinook fry remained in the Campbell River estuary for up to twice as long (2 months) as larger hatchery chinook. The stay in the estuary of some salmonid species may, in fact, last for a much shorter period. Healey (1979) estimated residence times of 0 - 18 d for chum fry in a small British Columbia estuary. Hvidsten and Mokkelgjerd (1987) suggested that Atlantic salmon smolts migrated through the River Surna (Norway) estuary in less than a day. Other authors (Fried et al. 1978; McCleave 1978) have reported relatively rapid estuarine migrations, with the direction and rate of seaward movement being strongly influenced by wind and tide-induced currents.

A negative correlation between abundance of pink salmon and the production of coho salmon in hatcheries in Hood Canal, Washington, was put forth as evidence of predation by the larger coho salmon on pink salmon fry shortly after their release (Ames 1981). Gunsolus (1978) suggested that predation of coho adults on coho smolts influences coho survival. Favorite and Laevastu (1979) proposed that sockeye salmon smolts are less vulnerable to predation when strong upwelling currents transport them offshore away from predators. Increased predation mortality among salmonids may occur during years when more preferred prey are scarce (Holtby 1988). Variations in predation mortality rather than decreased food supply has been suggested as the primary factor affecting Oregon coast coho salmon cohort strength (Fisher and Pearcy 1988).

Fishing Mortality

The relative susceptibility to angling of wild versus hatchery juvenile fish, and the effect of adding hatchery fish to a drainage on the harvest of wild fish varies with the situation. In some circumstances, hatchery fish are more vulnerable to angling than wild fish (Parker 1986; Marnell 1986; Boles 1960; Flick and Webster 1962; Calhoun 1966; Cordone and Frantz 1968; McLaren and Butler 1970; Rawstron 1972; Hunt 1979; Dwyer and Piper 1984). In others, such as for brook trout in several Michigan lakes, fishing mortality was greater for wild than for hatchery brook trout (Gowing 1978). Based on underwater observations of the faster reaction times by wild steelhead trout

compared to hatchery rainbow trout when presented with lures, Hillman and Chapman (1989) concluded that wild juvenile steelhead were more vulnerable to angling.

Hatchery trout stocked in areas with wild trout could theoretically play a variety of roles in influencing the harvest of the wild fish. Increased numbers of anglers may be attracted to streams where large numbers of hatchery steelhead smolts or catchable-size rainbow trout are released and overharvest juvenile wild steelhead unless they are protected by regulations that prevent their harvest. Pollard and Bjornn (1973) reported that the number of wild steelhead trout caught from Crooked Fork, Idaho, was unaffected by the presence of catchable-size hatchery trout; the wild trout were caught more readily than the hatchery trout, and the hatchery trout did not buffer harvest of the wild fish. Hazzard and Shetter (1938) reported that the catch of wild rainbow trout increased following the stocking of legal-size hatchery trout, presumably because of increased fishing effort. The harvest of larger anadromous presmolts by angling could lead to fewer adult returns due to reduced smolt production and greater mortality among the remaining, small smolts (Wagner 1968). Even if harvesting wild fish is prohibited, catch and release fishing can have negative consequences, including delayed hooking mortality (Wydoski 1977), increased susceptibility to natural mortality, and disruptions of existing social hierarchies (Lewynsky and Bjornn 1987).

The effect of supplementation on angling related mortality for adult wild salmonids can be severe if large numbers of hatchery fish are available for harvest and the wild fish are not protected in some way. Catch-and-release is commonly used to protect the wild fish, and can be quite effective, but even so angling-induced stresses and mortalities can be significant (Wydoski et al. 1976; Bouck and Ball 1966; Stringer 1967). Stress caused by hooking did not affect the homing accuracy of hatchery steelhead trout (Reingold 1975). Pettit (1977) found no difference in the viability and development of eggs from female steelhead that had been caught, released, and survived to enter the hatchery versus fish that had not been caught.

When hatchery fish are produced to supplement a natural run, a common management goal is to maximize harvest while maintaining a desired level of natural production. Fishing pressure usually increases as the total availability of fish increases, requiring careful regulation of exploitation rates and fishing seasons to avoid over-harvesting the wild stock (Evans and Smith 1986). Excessive harvest of the naturally-produced fish can be avoided either by restricting the catch (Reisenbichler 1986a), by marking all hatchery fish and requiring that unmarked wild fish be released (Reisenbichler 1986b), by adjusting the timing and distribution of harvest through stock selection and hatchery practices, by trapping and releasing hatchery adults into protected areas, and by establishing terminal (i.e., spatially distinct) fisheries (Evans and Smith 1986).

Disease

Disease must be considered within the framework of supplementation because of its role as a mortality agent. The is copious amounts of information on the incidence and effects of disease on salmonids within hatcheries. Our understanding of the effects of disease on free-ranging hatchery and wild fish is much more tenuous. Disease is thought to result in significant post-release

mortality among hatchery fish, being either directly responsible or predisposing fish to mortality from other causes. We have found little evidence to suggest that the transmission of disease from infected hatchery fish to wild salmonids is widespread. However, there has not been much research on this subject and since most disease-related losses probably go undetected (Goede 1986), we conclude that the full impact of disease on supplemented stocks is probably underestimated.

Fishery managers are generally aware of the potential for introducing infectious microparasites (defined to include viruses, fungi, bacteria, and many protozoans) and macroparasites (protozoans, helminths, and arthropods) into natural or wild salmonid stocks through the production and release of fish from hatcheries. Infectious diseases can theoretically be transmitted between two or more stocks, hatchery-produced or wild, having susceptible fish which come in contact with the pathogen. For example, hatchery stocks may be contaminated by fish, eggs, or water transported from other facilities. Surface water supplies used and discharged by hatcheries are rarely pathogen-free (Wolf 1972; Frantsi et al. 1975), so that water-borne diseases are not easily treated or contained. Hatcheries may act as reservoirs of infection due to conditions or practices which increase the vulnerability of fish to infection and maintain pathogen populations at infective levels (Goede 1986). Disease problems may persist in hatcheries as a consequence of contaminated water supplies and reproductive or vertical transmission of intracellular pathogens such as viruses. The perpetuation of infectious hematopoietic necrosis virus (IHNV) among many species of salmonids in Columbia River basin hatcheries is an example (Mulcahy et al. 1983; Groberg and Fryer 1983).

Hatchery stocks which show no outward sign of disease or parasitism may nevertheless contain fish carrying latent and infective doses of disease. Avoiding detection, subclinically infected fish are probably released into natural waters more often than is realized (Marnell 1986). Even under favorable conditions, latent infections may limit the success of hatchery fish released into natural habitats. At worst, virulent pathogens may be introduced into areas where they previously did not exist, causing catastrophic losses and the decimation of entire stocks of fish. Exposure to pathogens may potentially affect both hatchery and wild salmonids by (1) increasing levels of mortality, (2) increasing sensitivity to stressors, (3) impairing performance, and (4) modifying the genetic composition of the infected population. We direct the reader to Goede (1986) for an excellent summary of these problems.

Disease outbreaks are a relatively common occurrence in hatcheries, often requiring therapeutic treatment and sometimes the wholesale destruction of diseased fish. These efforts do not always meet with success. Recent results point to the failure of control methods to eliminate epizootics of bacterial kidney disease (BKD) among hatchery stocks of Columbia River spring chinook salmon (Elliott et al. 1989). Average rates of return of hatchery-produced spring chinook salmon adults were negatively correlated ($r = -0.72$; calculated from data presented in Table 2 of Raymond (1988)) with the number of hatchery smolts migrating past the uppermost dam on the Snake River during 1966-1984. During the same period, wild chinook salmon returned at an 80% higher rate than did hatchery fish (2.3% vs. 1.3% average rate of return). Even during years of improved in-river survival of hatchery smolts, the return of adults was lower than expected. From this, Raymond (1988) concluded that problems other than mortalities at dams were affecting hatchery stocks of

spring chinook salmon. Most researchers (e.g., Raymond 1988; Williams 1989) now believe that low stress tolerance coupled with a high incidence of BKD in yearling chinook salmon smolts is the major factor limiting spring chinook salmon production at Snake River basin hatcheries. Experimental evidence suggests that BKD interferes with the ability of salmonid smolts to acclimate to seawater, and that exposure to seawater actually accelerates mortality among infected fish (Fryer and Sanders 1981; Banner et al. 1983; Banner et al. 1986; Congleton et al. 1985). Banner et al. (1983, 1986) and Congleton et al. (1985) present data indicating that BKD-infected spring chinook smolts from several Oregon and Idaho hatcheries suffered heavy mortalities (up to 85%) after being held for several months in seawater. Many questions remain regarding the relationships between the incidence of disease in wild and hatchery stocks, physiological changes associated with smolt transformation, and survival in early ocean life.

Smoltification, the handling and confinement of fish during transportation, delays in downstream fish passage at dams, entry into saltwater and numerous other factors (e.g., temperature, pollution, etc.) all represent potential causes of stress in salmonids (Sanders et al. 1978; Wedemeyer et al. 1980; Specker and Schreck 1980; Fryer and Sanders 1981; Banner et al. 1983; Congleton et al. 1985; Li et al. 1987). The role of stress in reducing the ability of the salmonid immune system to respond to pathogens and other environmental stressors is well documented (Wedemeyer 1970; Wedemeyer and Wood 1974; Schreck 1981; Murphy and Kelso 1986). For example, stress-induced increases in plasma cortisol are known to lower the natural resistance of fish to disease pathogens (Pickering and Duston 1983; Angelidis et al. 1987). *Aeromonas hydrophila* epizootics are precipitated by stress conditions (Bullock et al. 1971); infections in salmonids are usually associated with stressful (i.e., elevated) water temperatures (Groberg et al. 1978).

Survival, growth, swimming ability, and other performance measures are compromised by the presence of disease, particularly in marginal habitats, after hatchery fish are released (Goede 1986). Smith and Margolis (1970) and Boyce (1979) found that juvenile sockeye salmon infested with tapeworm (*Eubothrium salvelini*) were more prone to exhaustion, lower growth rates, and higher mortalities than were unparasitized juveniles. Repeated measurements on two groups of brook trout, one carrying the IPN virus and the other not, 2.5 y after their release into a lake indicated that the carrier fish were smaller by 5 to 8% (Yamamoto 1975). However, size differences were not apparent 6 years after stocking (Yamamoto and Kilistoff 1979).

The generally poor ecological performance of hatchery fish following stocking (discussed in a previous section) may increase their vulnerability to diseases prevalent outside of the hatchery. Hatchery fish are presumably stressed by agonistic encounters with wild fish but to our knowledge no one has addressed the effects of such stress in epidemiological terms. Social interactions and status have a significant bearing on the severity of the stress response in salmonids (Li and Brocksen 1977; Ejike and Schreck 1980). Socially inferior hatchery fish may be more susceptible to infection following release. A similar argument can be made for situations in which wild trout are dominated by introduced hatchery fish. Petrosky and Bjornn (1988), however, saw no evidence of extended periods of stress in resident rainbow trout following the introduction of large numbers of hatchery trout.

In spite of the comparatively high incidence of disease among some hatchery fish stocks, there is little evidence to suggest that diseases or parasites are routinely transmitted from hatchery to wild fish. Work by Yamamoto and Kilistoff (1979) indicates that the IPN virus is not readily transmitted to noninfected brook trout in natural systems. Spread of BKD from heavily infected (100%) Atlantic salmon in the hatchery to wild fish was very limited (<1% infected; Pippy 1969). From experimental stocking of hatchery-reared brook trout infected with BKD and furunculosis, Allison (1961) and McDermott and Berst (1968), respectively, concluded that there was little or no communication of pathogens to resident wild brook trout. Mitchum et al. (1979) suggested that wild (feral) brook trout were infected with BKD by hatchery stocks, but did not provide conclusive evidence; hatchery trout last stocked in 1963 were inferred to have been the source of an epizootic among wild fish in 1976. Horizontal transmission of BKD from infected wild brook trout to stocked salmonids in natural waters has also been reported (Mitchum and Sherman 1981). Little is known of the prevalence of vertically transmitted diseases among progeny of naturally spawning hatchery or hatchery x wild salmonids.

The outcome of exposing wild stocks to infected hatchery stock - whether it is fatal, debilitating, or benign - depends on ecological parameters which influence the spread and pathology of the disease. If the incidence of wild salmonids being infected by hatchery fish is low, it may be due to a reduced probability of contact between individuals outside the confines of the hatchery, a greater natural resistance to pathogens among wild salmonids, and environmental conditions which are inimical to the survival and transmission of the pathogen. Marnell (1986) suggests that the constraining influence of high intermediate host-specificity among many fish parasites may limit their distribution and abundance.

Natural immunity to diseases and parasites appears to vary among species and stocks of salmonids (Sanders et al. 1970; Heggberget and Johnsen 1982; Babey and Berry 1989; LaPatra et al. 1990). For example, it has been postulated that members of the genus Onchorynchus may be more susceptible to BKD than are species of the former *Salmo* genus (Evelyn et al. 1988). Epizootics of the IHN virus occur in sockeye salmon, chinook salmon, and steelhead trout, but coho salmon are immune (Li et al. 1987). Winter et al. (1980) reported differences in BKD resistance among stocks of steelhead trout and coho salmon. They also found that individual stocks may be resistant to one disease (BKD) but highly susceptible to another (vibriosis). Variable susceptibility to infection by the protozoan *Ceratomyxa shasta*, and corresponding pre-spawning adult mortality, has been demonstrated for coho salmon (Sanders et al. 1972; Hemmingsen et al. 1986), chinook salmon (Zinn et al. 1977; Ratliff 1981) and summer-run steelhead (Buchanan et al. 1983). Infection frequencies in stocks of these species from the lower Columbia River and its tributaries appear to be much lower than in stocks from streams in which the protozoan is absent (Hemmingsen et al. 1986). Johnels (1984; cited by Stahl 1987) suggested that the introduction of hatchery-propagated Atlantic salmon from Sweden (Baltic Sea stocks) was responsible for the rapid spread of the skin parasite, Gyrodactylus salaris, in stocks of less resistant salmon in Norway (Eastern Atlantic stocks).

Evidence is accumulating that resistance to pathogens among salmonids is an inherited trait resulting from selection pressures. Immunity to several

diseases has been demonstrated to have a heritable basis in fish (Gjedrem 1983), although specific host cellular genes which confer a regulatory effect on the outcome of disease in fish have yet to be discovered. McIntyre and Amend (1978) demonstrated strong heritability for resistance to IHN in sockeye salmon. BKD resistance in coho salmon differs among transferring genotypes (Suzumoto et al. 1977; Winter et al. 1980).

As is true of other vertebrate species (O'Brien and Evermann 1989), salmonids have developed an elaborate array of immunogenetic defenses against pathogens with which they have co-evolved, but may be hypersensitive to exotic pathogens communicated by conspecifics and other closely related hosts (Barbehenn 1969; Marnell 1986). Widespread use of chemotherapy to control disease in hatcheries may result in the development of new, drug-resistant strains of viral and bacterial pathogens by natural selection. The consequences of exposing wild stocks to novel pathogens that are both virulent and readily transmitted may extend well beyond the economic impacts of the disease. Epizootics, if severe enough, can affect both the genetic structure and persistence of a species. Besides selecting for genotypes that confer immunity on surviving fish, disease outbreaks can alter the frequencies of alleles at loci affecting disease resistance (Allendorf et al. 1987), particularly when a large contraction in population size occurs. An inverse correlation between susceptibility to disease and genetic variability (allelic diversity) is suspected because immune system response appears to be coded by genes that are highly polymorphic (R. Waples, NMFS, pers. comm.). Significant losses of allelic diversity at loci associated with disease resistance are likely to increase a stock's susceptibility to epizootics.

Marnell (1986) has identified several conditions which, if met, increase the probability of damage to natural immune systems: (1) fish have no evolutionary association with a harmful pathogen present in the receiving water, (2) hybridization occurs between hatchery fish and the wild stock, and (3) long periods of time elapse between epizootics. The primary implication of using hatchery and wild stocks which have different genetically determined immune systems is that their progeny may be less resistant to endemic diseases. Hemmingsen et al. (1986) demonstrated that the susceptibility to infection by *C. shasta* by progeny of crossbred coho salmon was almost always intermediate between the susceptibilities of fish from the parental stocks.

The specificity of fish immunogenetic defense systems may dictate that only native or closely related stocks of salmonids be used for propagation. Regardless of the source of broodstock used, stocking programs should include monitoring and prophylactic treatment as needed to prevent the spread of potentially harmful diseases (Griffiths 1983; Murphy and Kelso 1986). Fish that are diagnosed as having a disease, or are even suspected of carrying a disease, should not be stocked into waters where that disease has never been detected (Evans and Smith 1986).

Supplementation Methodology

In this section we discuss various stocking variables that, through their effect on the interaction and survival of hatchery and wild fish, can strongly influence the success of supplementation programs. Supplementation

techniques that offer relatively easy and cost-effective means of regulating contact between hatchery and wild fish include, but are not limited to, stocking rates, size or age at release, and time and location of release. Successful supplementation requires knowledge of stock-specific life histories and habitat requirements; if the goal is minimize impacts to wild stocks, then hatchery fish should be produced that are qualitatively similar to those stocks.

Rearing and Stocking Procedures

The quality of fish released from hatcheries influences their subsequent survival and contribution as adults to the fishery and the spawning population (Burrows 1969). Insight into the effects of hatchery rearing and stocking procedures on the post-release survival of hatchery fish has been reported in several studies, but we were unable to locate quantitative information which describes the effects of various rearing and stocking procedures on wild or supplemented stocks. Our discussion, therefore, focuses primarily on the performance of hatchery fish.

Several abiotic and biotic factors affect the quality and production of salmonids in hatcheries (Table 8). Environmental conditions can be controlled within limits determined by site-specific factors (e.g., chemistry of water source, and physical facilities) and hatchery operations. Rearing and feeding (nutrition, frequency of feeding) techniques have improved to the point where hatcheries are able to produce better quality fish, minimize disease problems, and increase survival, without unduly sacrificing the quantity of fish produced. Nevertheless, much work remains to be done to define and develop optimum rearing strategies that conserve genetic resources and allow fish to survive, grow, and reproduce following their release into streams (Reisenbichler 1986a).

Table 8. Environmental factors known to affect the quality and production of salmonids in hatcheries (Parker 1986).

Physical	Chemical	Biological
Temperature	Dissolved Gases	Species
Pressure	pH	Genetics
Photoperiod	Nitrogenous wastes	Sex
Water Velocity	Inorganic Ions	Age
Cover	Hardness	Health
Substrate	Alkalinity	Physiological status
	Salinity	
	Contaminants	

Methods of stocking may affect the post-release survival of hatchery fish. In some cases the stocking is relatively easy on the fish, as when fish are released at the hatchery and allowed to leave the hatchery voluntarily. When fish are stocked away from the hatchery, the juveniles are captured at a hatchery, loaded into tank trucks, transported, and released into a lake or stream (Barton et al. 1980). Several components of the latter process may affect the subsequent performance and survival of hatchery-reared fish. Of

special concern is the amount and duration of stress which fish are subjected to by handling, confinement, transportation and release procedures. From the by Specker and Schreck (1980) and Barton et al. (1980) we believe that properly conducted stocking operations do not represent severe stressors to fish.

Environmental stressors, while not necessarily lethal in themselves, may disturb endocrine, metabolic, and osmoregulatory homeostasis (see Mazeaud et al. (1977) for a review), leading to reduced fitness and subsequent mortality. Handling and crowding can elicit a strong stress response in salmonids (Wedemeyer 1972; Schreck et al. 1977; Strange et al. 1978), and may be the most stressful aspects of the stocking operation (Specker and Schreck 1980; Barton et al. 1980; Barton and Peter 1982; Congleton et al. 1984). In a study of delayed mortality of stocked rainbow trout in Oregon, Horton (1956) observed a pattern of gradually increasing mortality until the third or fourth day, followed by a decrease and cessation by the end of a week's time. Average delayed mortality in Oregon stocking operations ranged as high as 10% of the fish transported.

Tagging operations are probably significant causes of stress (Yamada et al. 1979) and mortality. Berg (1977) reported that the additional step of weighing Atlantic salmon smolts at time of tagging reduced returns from 14% to 2.2%. Tagged fish, if their appearance or swimming abilities are altered by external marks, may not be able to interact normally in social and predatory situations.

The type of transport employed may influence stocking success. Air-dropped brook trout yearlings experienced lower survival than trout released at ground level in Ontario lakes (Fraser 1968). Congleton et al. (1984) reported that chinook salmon smolts transported by barge from collection facilities on the Snake River to the Columbia River estuary had significantly lower plasma cortisol concentrations than did smolts transported by truck.

Variations in loading density apparently have little effect on stress levels or mortality among transported salmonids, provided that water quality is not compromised. Congleton et al. (1984) found no difference in plasma cortisol concentrations in chinook salmon smolts held for up to 24 hours at three loading densities (0.12, 0.25, and 0.50 pound/gal in transportation collection facilities. Survival rates did not differ among test groups of coho salmon smolts confined at low (12 g/L) and high (120 g/L) densities following transportation (Specker and Schreck 1980).

Primary and secondary stress responses in salmonids associated with outplanting operations can be ameliorated by ensuring good water quality during shipment and avoiding excessive handling, crowding, and transit times. High dissolved oxygen levels, reduced water temperatures, and salt concentrations which help maintain osmotic balance are recommended for transport and recovery water (McCraren and Millard 1978; Nikinmaa et al. 1983; Parker 1986).

Because hatchery salmonids require prolonged periods, up to a week in some cases, to recover from a stressful situation (Strange et al. 1978; Barton et al. 1980), it may be necessary to provide a recovery area following transportation, particularly, if conditions in the receiving water would not allow the fish to recover (Parker 1986). In a study designed to evaluate the effects

of post-stocking acclimation on hatchery-reared brown trout released into three Welsh rivers, Cresswell and Williams (1982) observed less dispersal and higher percentages of recapture among acclimated fish, but only under low flow conditions. Miller (1954) found that hatchery-reared rainbow trout conditioned in a stream survived better than unconditioned, pond-reared fish. Shustov et al. (1981) attributed poor dispersal by hatchery Atlantic salmon released into the Kuzreka River (Kola peninsula, USSR) to poor physical conditioning and a lack of endurance.

Stocking Densities and Rates

Optimal stocking densities and rates depend on (1) the objectives of the project (e.g., enhancement vs restoration), (2) the distribution and carrying capacity of the habitats into which hatchery fish are to be introduced, (3) the proportion of limiting resources already used by resident fish, and (4) the viability (survival and reproductive success) of hatchery-produced fish. Determining the proper stocking rates for supplementation is more complicated than that for stock establishment or restoration in that consideration must be given to the abundance of wild fish relative to the carrying capacity of the stream.

Optimal stocking densities for steelhead fry and Atlantic salmon have been estimated by Hume and Parkinson (1987) and Cote and Pomerleau (1985; cited by Bley and Moring 1988). Symons and Heland (1978) refined stocking densities for hatchery-reared Atlantic salmon on the basis of age-specific habitat requirements. Because space, food, and cover requirements vary with fish size (e.g., Everest and Chapman 1972), the productivity and availability of size-specific habitats must be considered when supplementing species which spend more than one year in freshwater. Carrying capacities are higher and hatchery fish are more likely to learn to feed successfully in productive streams than in infertile streams (Bjornn 1986). Aquatic productivity is determined by a host of environmental factors, some of the more important being stream morphology, flow regime, water temperature, dissolved oxygen, acidity, allochthonous input, and the composition of the resident biota. In order to fully utilize the productive potential of the stream and to reduce energetic costs and predation losses, supplementation is probably best accomplished by releasing fish in small groups in several locations (Cote and Pomerleau 1985 - cited by Bley and Moring 1988; Hume and Parkinson 1987; Richards and Cernera 1989).

Hatchery managers should gauge the potential effects of releasing large numbers of presmolts or smolts on predator populations. Relatively high threshold densities of smolts may need to be released in order to significantly reduce the risk of predation (Peterman 1977; Ruggerone and Rogers 1984; McIntyre et al. 1989). Sufficient production of hatchery and wild fish combined with prudent harvest management is required to avoid depensatory losses to predators (including man), and to prevent the potential collapse and equilibration of wild stocks at relatively low population levels (Peterman 1987).

Age and Size at Release

Most anadromous hatchery fish, including those reared for supplementation purposes, are released as smolts with the expectation that they will migrate seaward soon after release (Bjornn 1986; Lichatowich and McIntyre 1987).

Alternate strategies include stocking underutilized habitats with eggs, fry, or parr (presmolts) and surplus adult fish. Each management approach is species and situation specific and involves economic and biological tradeoffs. Production costs are inversely related to the length of time that fish are reared at the hatchery, but fish grown to a larger size generally return at higher rates (Potter and Barton 1986). Production of wild salmonid smolts is less affected by raising hatchery fish to smolt size before outplanting (Wagner 1967). There are, however, genetic and disease burdens associated with prolonged hatchery residencies (see earlier sections).

Stocking strategies other than smolt stocking require that the hatchery juveniles rear in freshwater for a period before emigrating to the ocean (Bjornn 1986). Supplementation of natural stocks with presmolt life stages has become a valuable management tool because: (1) it allows for greater flexibility, efficiency, and volume in hatchery production, (2) more fish can be produced from natural rearing areas, and (3) the potential for detrimental genetic alteration is reduced. From a consideration of expected survival rates and production costs, Hume and Parkinson (1988) advised releasing smaller presmolts (fry) when the area to be stocked is small and a large number of eggs are available. Stocking larger fish may be the best supplementation technique when brood stock is scarce and a large amount of habitat is available. If the population size of wild fish is dangerously low (i.e., small relative to its potential), a conservative strategy might be to release smaller fish into underseeded habitats at densities which are unlikely to result in the displacement of the wild fish.

Several experiments have been reported or are currently underway to evaluate the effects of age and size at release on supplementation. Seidel et al. (1988) noted that poststocking survival-to-adult of fall chinook fingerlings raised in Washington hatcheries jumped from approximately 0.2% to 1.2% when mean size at release was increased from 4 to 6 g. Reimers (1979) reported that survival to return of yearling chinook salmon released from the Elk River hatchery (2.2%), although lower than that of wild salmon (4.3%), was substantially higher than survival of fish released as underyearlings (0.3%). Survival of fall-run chinook salmon from hatcheries on the Sacramento River also appears to be positively related to release size (Reisenbichler et al. 1982). Seelbach (1987) found that large yearling steelhead trout stocked in a Lake Michigan tributary in the fall survived to smolt stage at a much higher rate than did smaller fall-planted fingerlings and similar size, spring-planted yearlings. It is not clear whether the results apply to other hatchery programs since the experimental fish used in this study were first-generation offspring of wild steelhead.

It is difficult to differentiate the effects of size of release from time of release. Work by Bilton et al. (1982, 1984) indicated that release size and time jointly affect the survival and average size of salmon returning to coastal hatcheries. From an evaluation of survival rates for three graded size groups of juvenile coho salmon released simultaneously on four separate occasions during the spring and summer, Bilton et al. (1982) concluded that adult returns would be maximal for late June releases of large juveniles. For the range of release sizes and dates typically available to hatchery managers, time of release apparently has a greater effect on survival than does size (Bilton et al. 1982, 1984; Mathews and Ishida 1989).

Size at release may also affect the size of adults returning to the hatchery and, presumably, to spawn naturally; larger, faster growing smolts tend to return at an earlier age and are smaller in size (Hager and Noble 1976; Bilton et al 1982; Bilton 1984). Supplementation efforts may fail to produce the desired results if early-maturing hatchery fish are unable to compete effectively for wild mates or spawning sites.

Green (newly fertilized) or eyed eggs of hatchery-spawned anadromous salmonids are frequently stocked in streams and artificial incubation channels with the goal of augmenting natural production (Thomas 1975; Egglishaw and Shackley 1980; Kennedy and Strange 1980, 1981). Survival to the fry stage was lower for Atlantic salmon green eggs (1.4%) than for eyed eggs (10.3%) stocked in a Scottish stream (Kennedy and Strange 1981). Egg-to-fry survival varied inversely with stream gradient and resident fish densities (Kennedy and Strange 1980, 1984). Overwinter survival rates of embryos and yolk-sac larvae of wild and hatchery brook trout have been found to be similar (Flick and Webster 1964).

Egg planting reduces the exposure of fish to artificial selection in the hatchery but does not guarantee favorable results. Atlantic salmon from a Scottish hatchery that were stocked as eggs in two streams in northern Spain contributed significantly less to the adult in-river fishery than did native salmon. The lower performance of the non-native eggs was thought to have resulted from a combination of poor genetic adaptation and inadequate stocking methods (Garcia de Leaniz et al. 1989). Planting technique has been shown to affect the survival of salmonid eggs and embryos; direct plants of eyed eggs of brown trout produced more sac and swim-up fry than did Whitlock Vibert box plants (Harshbarger and Porter 1982).

Although substantial mortality of outplanted eggs can be expected even under the best conditions, optimal results are obtained when fertilization and stocking mimic natural spawning times. Foerster (1938) and Bjornn (1978) found no difference in the efficiency of supplementation of sockeye salmon and steelhead trout, respectively, using egg planting and releasing button-up fry.

A variation of the egg outplanting technique is the stocking of streamside incubation boxes with fertilized eggs of hatchery or wild stock origin. If a reliable supply of eggs from wild spawners can be obtained, egg boxes offer an attractive means of supplementing natural production, with less dependence on hatchery-propagated stocks of fish. Egg boxes require fewer resources, and are simpler and more portable than more conventional methods of artificial propagation, but do require reasonably good water quality.

Stocks can be supplemented successfully with age-0 salmonids, particularly in productive, underseeded habitats (Bjornn 1978). Fry fed for a short period before release may survive better than unfed fry (Stewart 1963), if the fry normally kept in the hatchery readily feed on the hatchery diet and do well. Slaney et al. (1980) reported substantial yields from stocking steelhead trout fry (mean weight 0.3 g) above migration barriers in a high-gradient stream. Results from other studies, however, indicate that stocking hatchery fish at the fry stage yields low survival rates and, consequently, low percentages of adult returns (Wagner and Stauffer 1978; Seelbach 1987; Hume and Parkinson 1988). Hume and Parkinson (1988) found that larger and presumably less vulnerable age-0 steelhead released late in the growing season almost always

survived better than did smaller fish released earlier. The relative importance of size and time-at-release could not be distinguished because they were highly correlated.

The average size of fry released from the hatchery relative to that of resident wild fry may affect the subsequent survival of both groups of fish. If hatchery fish are stocked or emerge earlier than wild fish, they may enjoy a competitive advantage (Fenderson et al. 1968) and reduce the survival of wild fish emerging at the normal time (Solazzi et al. 1983; Nickelson et al. 1986; Chandler and Bjornn 1988). Size-related effects can be avoided by imposing spawning, incubation, and feeding schedules that ensure that the hatchery fish are not present in the stream ahead of the wild fish and they are not larger than the wild fish (Reisenbichler 1986a).

Size at release has also been found to correlate with poststocking survival of older presmolts and smolts for steelhead (Larson and Ward 1954; Wagner 1968; Bjornn 1986; Seelbach 1987) Atlantic salmon (Meister 1969; Chadwick 1987) coho salmon (Hager and Noble 1976; Mahnken et al. 1982; Bilton et al. 1982) and chinook salmon (Hosmer et al. 1979; Seidel et al. 1988). Holtby (1988), however, reported that larger wild coho salmon smolts survived no better than smaller smolts from the same stock. Body size and smolt transformation status may influence the rate and path of migration taken by spring chinook salmon smolts released into the lower Columbia River (W. Zaugg, NMFS, pers. comm.). Larger fish tended to migrate in mid-river, whereas smaller fish remained close to shore. Migration rates were positively correlated with size at release.

Body size has an effect on the percentage of fish of a given age that become smolts and perhaps on the timing of seaward migration, particularly for species that normally spend more than one year in freshwater. Even in the presence of conducive exogenous stimuli (e.g., photoperiod), steelhead and Atlantic salmon are likely to remain in freshwater for additional periods of time if threshold sizes for smolting have not been attained (Bjornn 1986). For many species, hatchery programs have been successfully implemented to shorten the time required to reach smolt stage. Freshwater rearing periods for steelhead and Atlantic salmon, normally lasting two or more years, have been reduced to one year by providing increased temperatures and thereby growth rates in some hatcheries. Similar efforts to produce viable age-0, rather than yearling, coho and chinook salmon smolts have been less effective (Bilton and Jenkinson 1980; Bjornn 1986). Bilton et al. (1982) reported that "accelerated" age-0 coho salmon smolts returned at one-tenth the rate of age-1 (the normal smolting age) smolts that had been released on the same day. Bjornn (1986) observed that chinook salmon which normally became smolt as yearlings in the spring, became smolts and migrated downstream in the spring about 9 months after spawning if growth and development were accelerated in a hatchery, but returned at lesser rates than yearling smolts from the same population. In both cases, age-0 fish were smaller than the corresponding age-1 smolts; probably too small to survive in the ocean (Bjornn 1986).

Time and Location of Release

Time and location of release are important in supplementation of wild stocks because those two factors can help regulate the extent and magnitude of interactions between hatchery and wild fish. Smolt releases from anadromous

fish hatcheries are usually timed to coincide with the outmigration of wild conspecifics (Reimers 1979; Levings and Lauzier 1988). This practice yields conflicting results: it helps to preserve genetic integrity and ensures higher survival by mimicking natural outmigration, but it also increases the risk of density-related mortality and undesirable interactions between hatchery and wild fish. The objective and the result in most cases is the rapid movement of hatchery smolts to the ocean, where density-dependent effects are presumed to be less likely or less intense (Reisenbichler 1986a).

Chinook salmon and steelhead smolt releases from hatcheries in the Snake River drainage are also scheduled to coincide with flow (i.e., "Water Budget") releases and barge transportation schedules. Releases are timed to avoid overlap between the two species because the smaller chinook may be stressed by steelhead during transportation. Releases from Oregon hatcheries are based on time with size criteria; release times are hatchery and species specific (Nietzel and Fickeisen 1990).

Although smolt transformation is under the control of the seasonal photoperiod cycle (Clarke et al. 1981), considerable variability in the timing of the seaward migration of wild smolts occurs with fluctuation in temperature, flow, and other proximate factors in the environment (Grau 1981; Solomon 1981; Holtby et al. 1989). Rapid migration and a decreased risk of competition and predation may be facilitated by nighttime releases of larger fish under conditions of high turbidity and flow (Ginetz and Larkin 1976). Unfortunately, there are few data on ecological interactions between hatchery and wild smolts, so the impact of supplementation at this life stage remains poorly understood.

Time of release may affect the distribution of the fish in the marine environment (Irvine and Ward 1989) and the timing of adult returns (Evans and Smith 1986). For example, delayed smolt releases have been used to obtain "non-migrating" stocks of salmon in the Puget Sound (Mahnken and Joyner 1973). Delayed releases may have the benefit of hastening downstream migrations of hatchery smolts (Zaugg 1981, 1982; Zaugg et al. 1986), but also risk causing increased residualism, lower survival, and increased straying of returning adults if delayed for too long (Scholz et al. 1978). Fish released into the Columbia and Snake Rivers from upriver hatcheries after the spring runoff may have difficulty migrating through the reservoirs and be subjected to increased turbine-related mortality (Seidel et al. 1988).

A portion of the hatchery fish released may either fail to emigrate or exhibit a protracted downstream migration lasting for weeks or months (Levings and Lauzier 1988). The survival of hatchery "residuals" is generally thought to be low (Seelbach 1987), although Reimers and Concannon (1977) recorded higher survival among chinook salmon that remained in the river for several months following a June release from an Oregon hatchery. Mitans (1970) recommended early spring stocking of smolt-age Atlantic salmon to allow non-migrants more rearing time in freshwater. Studies by Wagner (1968), however, suggest that early releases may be inappropriate; adult returns from smolt-size steelhead trout yearlings stocked in February and March were much lower than returns from releases in late April (the natural time of emigration). Hemmingsen et al. (1986) demonstrated a similar reduction in survival when the release date of coho salmon was advanced from July to May. Early releases of coho

salmon can increase predation on naturally-produced pink and chum fry (Johnson 1974).

Choices concerning the streams, stream reaches, and sites within a reach to be stocked depend on management goals, accessibility, and the characteristics of the receiving water. Release locations may be chosen with the aim of minimizing losses of hatchery fish to predation (Thompson and Tufts 1964), to dam-related mortality (Ebel 1970), and to lessening competition between hatchery and wild fish (Nietzel and Fickeisen 1990). Because anadromous salmonids generally home to the stream, and often to the release area, from which they emigrated as smolts (Wagner 1969; Hasler 1971; Power and McCleave 1980), release locations can be chosen to facilitate the segregation or mixing of hatchery and wild stocks, depending on program goals. Careful selection of release sites can help protect non-targeted wild stocks by minimizing interactions, by diverting fishing pressure away from vulnerable stocks, and by enhancing the opportunity to catch hatchery fish (Cramer 1981). Stocking programs set up solely to produce fish for harvest can lessen effects on wild fish by concentrating releases in streams outside sensitive natural production areas.

Integration of hatchery fish into wild stocks requires careful planning of the number and size of fish stocked, and the areas and time of stocking. Streams or reaches where natural spawning has been deficient are obvious choices for consideration. Stocking the fish in a single location may produce satisfactory results in small streams containing few wild fish (Elson 1957) or poor physical habitat (Bilby and Bisson 1987). Elson (1957) reported that stocked Atlantic salmon fry survived as well to smolt stage whether they were stocked in one location or scattered over 1/2 mile of stream. For streams possessing better quality habitat or significant wild fish populations, it is recommended that stocking sites be widely distributed to promote the equitable distribution of juveniles into available habitat and to lessen competition (Wentworth and LaBar 1984; Kennedy and Strange 1978; Bilby and Bisson 1987). Resident fish are less likely to be affected if stocking rates and locations are planned to exploit unused food and habitat resources without exceeding the carrying capacity of the stream.

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TECHNICAL REPORT 90-2

CONCEPTS FOR A MODEL TO EVALUATE SUPPLEMENTATION OF NATURAL SALMON AND STEELHEAD STOCKS WITH HATCHERY FISH

by

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Preface

This report was prepared as part of a Bonneville Power Administration (BPA) funded project to summarize information on supplementation of salmon and steelhead stocks with hatchery fish, Project No. 88-100. Tom Vogel was BPA project officer. The primary geographic area of concern was the northwestern United States with special emphasis on the Columbia River basin.

Three reports were prepared for the BPA project:

1. Analysis of Salmon and Steelhead Supplementation: Emphasis on Unpublished Reports and Present Programs, by W.H. Miller, T.C. Coley, H.L. Burge, and T.T. Kisanuki.

2. Supplementation of Salmon and Steelhead Stocks with Hatchery Fish: A Synthesis of Published Literature, by C.R. Steward and T.C. Bjornn.

3. Concepts for a Model to Evaluate Supplementation of Natural Salmon and Steelhead Stocks with Hatchery Fish, by T.C. Bjornn and C.R. Steward.

Reports 2 and 3 were prepared under contract with the Idaho Cooperative Fish and Wildlife Research Unit at the University of Idaho. The U.S. Fish and Wildlife Service, Office of Information Transfer helped fund the preparation of Report 2.

The overall objectives of the BPA funded project were to: (I) summarize and evaluate past and current supplementation of salmon and steelhead, (2) develop a conceptual model of processes affecting the results of supplementation, and (3) make recommendations relative to future supplementation research and needs.

Abstract.-Concepts and the basic components for a model that could be used to evaluate supplementation of native or naturally produced salmon and steelhead stocks with hatchery fish are presented and discussed with an example of a model in spreadsheet form. The example we developed, and the final model should be similar in form and function to the life-history model being used for system planning by the Northwest Power Planning Council, except that additional genetic groups of fish must be tracked through multiple generations. The number of genetic groups monitored should be held to less than 10, we suggest 6. Coefficients used for the system planning model will provide a basis for selecting coefficients for individual stocks. Managers should participate in determining the level of resolution desired from the model and the range of values for coefficients.

Supplementation of native stocks of salmon and steelhead with hatchery fish has occurred, and will occur more frequently in the Columbia River drainage with increased efforts to increase the size of the fish runs. The benefits and costs associated with supplementation are not easily assessed, in part because of our incomplete knowledge of the outcome of the many interactions that can occur between native and hatchery fish (see reviews by Miller et al 1990 and Steward and Bjornn 1990). There are numerous examples of large numbers of adult salmon and steelhead being produced from hatchery operations. In some cases, however, hatchery fish have been shown to be less fit in natural systems than the local native fish (Reisenbichler and McIntyre 1977; Chilcote et al. 1986), leading to offspring of native X hatchery crosses that may have reduced fitness (Kapuscinski and Lannan 1986) relative to native fish. The challenge is to maintain or improve the genetic quality of hatchery fish and determine the best ways to use natural and hatchery production to increase the abundance of anadromous fish in the Columbia River basin.

There are a number of terms used to describe groups of salmon and steelhead. Listed below are our definitions of most of the terms and their use in this report:

Species: a taxonomic unit that may be further divided into subspecies, races, demes, or stocks. Examples, chinook salmon *Oncorhynchus tschawytscha*, and steelhead *Oncorhynchus mykiss*.

Subspecies, race, deme, and *stock*: terms that we use synonymously to identify groups of fish that are reproductively isolated in space or time and that may have developed a unique genome. We prefer the term stock. Examples, the Lemhi River stock of the spring-run of Columbia River chinook salmon, and the Grande Rhonde stock of group-A steelhead.

Population and *run*: terms used to describe a group of fish usually of the same species that are together in a specific time or place. Examples, the spring-run of chinook salmon and the group-A run of steelhead as

they migrate up the Columbia River, and a population of juveniles in a stream or in the ocean. Note that populations or runs may be made up of individuals from one or more stocks.

Native, indigenous, and *endemic*: terms often used synonymously to identify the groups of fish that naturally colonized stream or lake systems and were present when man began to alter the habitat and biota of the Columbia River drainage in the 19th and 20th centuries. Examples, the native Warm River stock(s) (Deschutes River tributary) of spring-run chinook salmon, and the native upper Snake River stock of fall-run chinook salmon. We prefer and will use the term native when we wish to identify naturally produced fish of indigenous stock ancestry.

Wild and *natural*: terms used to identify fish that have been naturally produced (parents spawned naturally and fish grew up in streams or lakes and eventually the ocean) without regard to ancestry (native or alien or hatchery stock). The term wild is often used synonymously with native, and for that reason we will avoid use of the term wild, and use the term natural to describe naturally produced fish where that is the only distinction we wish to make, or where we are unsure of ancestry. Examples, the natural steelhead in the South Fork of the Clearwater River that may be offspring of: (1) adults from prior releases of hatchery smolts, (2) hatchery adults released to spawn naturally, or (3) crosses of hatchery and natural adults.

Hatchery: a term we will apply to fish that have spent any part of their life in a hatchery. On one end of the spectrum of hatchery fish is a fish that resulted from gametes taken from native parents, incubated in a hatchery only to the eyed-stage, and then placed back in its stream to complete its life cycle. The other extreme could be a hatchery program started with an alien stock where the fish were selected to perform best in the given hatchery environment or to meet other management goals, the fish are reared in the hatchery till the smolt stage, adults return to the hatchery, and the program has continued for many generations. Examples, steelhead returning to the Lochsa River that originally were stocked in the stream as fry or as smolts would be hatchery adults, perhaps with different abilities to produce viable offspring, but still hatchery fish as we define them.

To supplement the native stocks of salmon and steelhead with hatchery fish is to add production to, or make up for a deficiency in production of native fish. In general, the goal is to produce more adult fish that will be available in fisheries in preferred areas. More adults can be produced by more fully using the capacity of freshwater production areas (reduce the deficiency), and by releasing smolts to exceed that capacity (add production to that naturally possible). Natural production in freshwater could be limited in various habitats and life stages; the number of fry produced may be limited by the amount and quality of spawning and incubation areas rather than by the number of spawners, the number of smolts produced could be limited by habitat used in summer by feeding juveniles or by habitat used in winter by juveniles seeking security. If production by the native fish is significantly below the carrying capacity of the environment because there are too few spawners or too few juveniles produced, then supplementation by stocking hatchery adults, eggs,

fry, or sub-smolts should increase the number of smolts produced. Supplementation by stocking smolts could insure full use of the natural production capacity and could result in more adults produced than would be possible with full natural production because the number of hatchery smolts stocked is constrained by hatchery capacity and not the carrying capacity of a stream system.

Unfortunately, supplementation is not simply an additive process whereby the number of fish produced is equal to the normal native production plus the hatchery fish stocked. For the species that spend months or years in freshwater before going to the ocean, hatchery juveniles (and naturally produced offspring of hatchery origin) will compete with and displace some native juveniles. The number of fish displaced will depend on the proportion of the capacity that is unused, abundance of native fish, number of hatchery fish stocked or produced from hatchery adults, the size and time of stocking, and fitness (relative measure of adaptation to a particular environment) of the hatchery fish.

If there is little or no difference in fitness and other important characteristics between the stock of fish to be supplemented and the hatchery stock, then displacement of the native fish may be of little consequence. If there are differences between the native and hatchery fish, however, then supplementation may lead to reduced production of native fish, an overall reduced fitness of naturally produced fish, and less production of adults than anticipated.

A modelling approach to assessing the long-term effects of supplementation on genetic makeup and productivity of salmon and steelhead stocks has utility because the field studies to evaluate supplementation will be difficult to conduct (replication and length of time). Concepts, factors, and variables that should be included in a multi-generation, multi-genetic group model that can be used to predict the outcome and evaluate various supplementation scenarios are presented below. A discussion should be held with managers to decide which variables to include in a model and the degree of stock definition that is necessary.

Concepts for Consideration

Factors to Include in a Model

There are many factors that are explicitly or implicitly expressed in a life-history type model that can be used to predict and evaluate the effects of supplementation. Some factors are labelled and readily recognized in the model, but some are expressed through a coefficient or relation used to link components of the model. The following is a listing of factors that should be considered for inclusion in a model for evaluating supplementation.

A- Life history stages:

Spawner to eggs deposited,
Eggs to fry that emerge,
Fry to parr produced,
Parr to smolts produced,

Smolts to recruits, and
Recruits to spawners.

B- Types of fish:

Species of fish,
Native, endemic, or indigenous,
Naturally produced (wild) from native, hatchery, or mixed parents,
Hatchery fish.

C- Stock parameters:

Age structure,
Proportion females,
Eggs per female,
Survival rates and relations for each life stage,

D- Genetic factors:

Relative fitness of hatchery versus wild or native fish,
Rate of change in fitness over time in hatchery and streams,
Origin and history of hatchery broodstock,
Frequency of wild fish addition to hatchery broodstock,
Intensity of selection in the hatchery and natural environment,
Effective population size,
Gene flow between wild and hatchery stocks, and
Definition of a genetically distinct group,

E- Environment of the stocks:

Quality and quantity of habitat,
Presence of other species that are competitors or predators,
Carrying capacity for each life stage,
Recent changes in environment that affect genome of native fish,
Variability of factors affecting survival,

F- Supplementation methods:

Life stage of fish stocked,
Proportion of area stocked,
Duration of stocking,
Size and number of stocked fish relative to natural fish,
Time and method of release of hatchery fish,
Number of sub-smolts stocked relative to carrying capacity, and
Number of smolts stocked relative to carrying capacity.

G- Interactions between hatchery and wild or native fish:

Mating overlap in time and space,
Use of summer and winter habitat by juveniles,
Competition for food and space,
Predator-prey interactions,
Transmission of disease,

Alteration of fishing patterns and harvest rates,
Response of wild or native fish to hatchery fish, and
Differences in behavior of wild versus hatchery fish.

The relative importance of the various factors and variables listed above can only be estimated at the present time because of the lack of definitive data. Once a model has been constructed, sensitivity testing can be undertaken to determine which factors and interactions have the largest potential for changing the number and type of fish produced. For example, we suspect that releasing smolts will result in more adults returning and more interactions with native fish than if fry were stocked, but the outcome of the interactions depend on the fitness of the hatchery fish, number stocked, size of fish stocked, time of stocking, etc. and cannot be estimated easily without a model.

The reliability of the coefficients that are needed to run a model to evaluate supplementation strategies is fair, at best, but can be estimated with enough accuracy to use a model and feel confident that the predicted outcomes are likely within the 'ballpark', and certainly useful for relative comparisons. Attempting to operate the model will quickly reveal where there is little or no empirical data to use in developing values for the necessary coefficients, and thereby identify where research is needed.

The life history model that we propose herein can be illustrated as a series of linked relations that define the number of fish produced at each life stage (Figure 1). All of the variables that affect the production of fish and are to be included in the model must be expressed as a coefficient incorporated into one or more of the linked relations. For example, if hatchery fish produced offspring that were less likely to survive than wild fish because they spawned at a less optimum time, the fitness coefficient in the egg to fry life-stage relation should reduce the slope of the line in the relation and the number of fry produced.

Groups to Follow in the Model

The number of groups of fish of various genetic ancestries can become large when there is mating overlap and interbreeding between hatchery and native fish and the offspring are followed for more than a few generations. For example, if we started in generation 0 with spawning by native adults (N_0), and a release of hatchery fry at the time progeny from the N_0 spawners entered the stream, there would be two groups of spawners at the next generation (N_1 and H_1), assuming the hatchery fish survived and returned as adults. With continued stocking of fry, and interbreeding between the various genetic groups, there would be four groups by the generation 2, 11 by the third, 67 by the fourth (Table 1), 2,271 by the fifth, and 2,577,585 by the sixth (Figure 2). The foregoing numbers were calculated with sex of the native or hatchery fish ignored in interbreeding. If sex and genetic ancestry must be considered in the matings, the number of groups at each generation would be nearly double those presented.

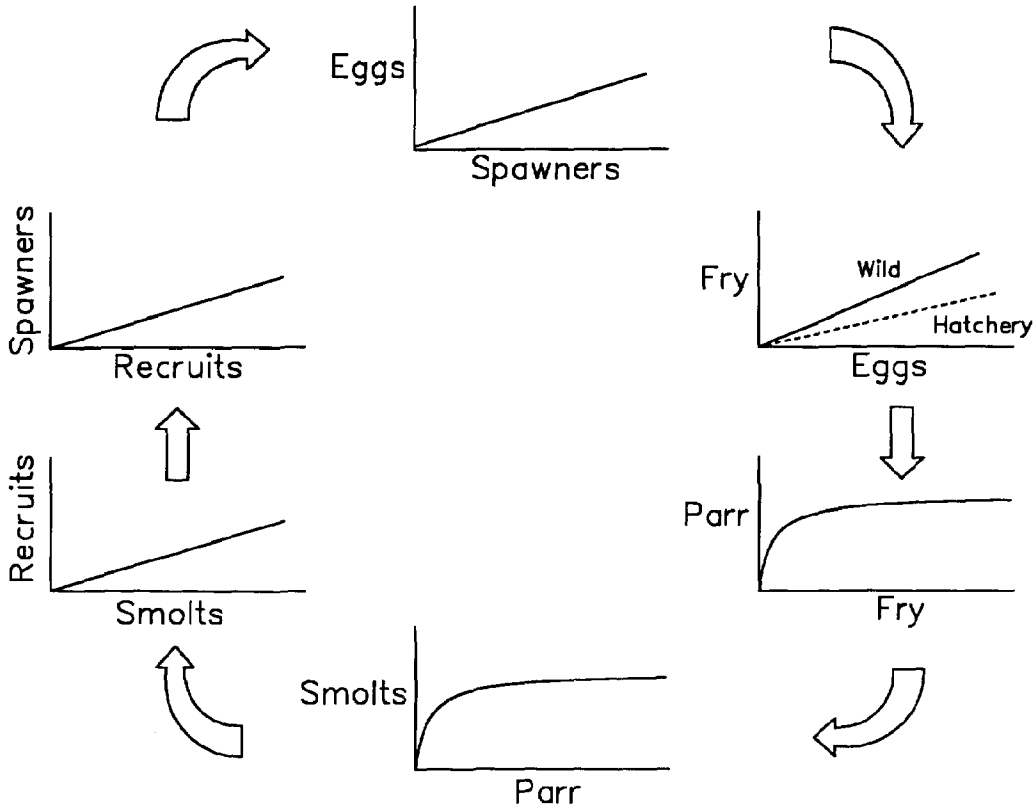

Figure 1. The life-history relations that would be the primary components of a model to evaluate strategies to supplement wild stocks of salmon and steelhead with hatchery fish. The dashed line in the egg-to-fry relation illustrates how the production of fry from hatchery spawners would be less than that from wild spawners if the hatchery fish were less fit.

The foregoing numbers also assume that all fish resulting from a brood year mature and spawn in the same year, which is not true. For example, adult chinook salmon from a single brood year usually return in three subsequent years after spending 1, 2, or 3 years in the ocean (Table 2). Steelhead adults from a single brood year could return in as many as 7 subsequent years, because they spend 1-4 years in fresh water before becoming smolts, and up to 4 years in the ocean (Table 3). If we tried to keep track of the groups resulting from interbreeding, by sex of spawners, and by the age of the spawners, the number of groups would be larger still.

In our opinion, it is not necessary to follow each and every group that could be identified through a number of generations in order to evaluate the outcomes of supplementation. Our present knowledge of the fitness of offspring of hatchery or native X hatchery crosses would not allow us to distinguish between anything but general groups. The primary issues of

general overall fitness, changes in fitness over time, and the number of fish with reduced fitness can be monitored and evaluated if the offspring from given matings were placed into general groups based on initial fitness generation, and then followed as a groups over time.

To illustrate the general grouping than might be undertaken, we have combined all of the genetic groups in Table 1 into six groups with viabilities of 0.50-0.59, 0.60-0.69, 0.70-0.79, 0.80-0.89, 0.90-0.99. and 1.00. Groups would be assigned a fitness equal to the mid-point of the range. The frequency distribution of the groups listed in Table 1 would be as listed in Table 4 when grouped into the general groups described above. With different assumptions from those used in preparing Table 1, the frequency distribution would change, as illustrated for the case where the gap in hatchery-native fish fitness is reduced by one-fourth with each generation of natural spawning and rearing (Table 4). The important point is that the number of groups is reduced to a manageable number.

The general functioning of a model to monitor supplementation results, with fitness groupings, is illustrated in the spreadsheet depicted in Table 5. Native fish in a particular drainage are assigned a fitness of 1.0 on a relative scale, and the fitness of hatchery fish at first natural spawning must be estimated. If only native fish were present, only the native column in the spreadsheet would be used because the fitness would always be 1.0. If hatchery fish with a fitness of less than 1.0 are added to the drainage, then other columns in the spreadsheet would be used. In the example presented in the Table 5 spreadsheet, hatchery fry equal in number to the initial number of native fry were added each year starting in generation 1.

When adults from the stocking of hatchery fry return to spawn they are placed in fitness groups based on their fitness and on the fitness of the fish they may mate with; sibling hatchery fish and native fish were the only options in generation 2 of the example. We assigned a fitness of 0.55 to the returning hatchery adults. If they mated with siblings, their offspring would have a fitness of $(0.55+0.55)/2 = 0.55$. If they mated with native fish, their offspring would have a fitness of $(1.0+0.55)/2 = 0.775$.

The number of adults involved in each type of mating (native X hatchery, etc.) depends on the number of adults in each group and the amount of mating overlap (full overlap in our example). At the end of generation 1, there were 1214 adults produced, 821 (67.63%) native adults and 393 (32.37%) adults from the stocking of hatchery fry. The number of native X native matings equal $(0.6763*0.6763)*1214 = 555$ spawners placed at the top of the native fish column of the spreadsheet for generation 2. The number of hatchery X hatchery matings equal $(0.3237*0.3237)*1214 = 127$ spawners placed in the fitness group 0.55 column. The number of hatchery X native matings equals $(0.3237*0.6763)*1214 = 532$ spawners placed in the fitness group 0.75 column. Sex ratios for native and hatchery fish were similar.

Fitness values for each life stage of the fish represented in the model, must be set so that the product of the individual values is equal to the overall fitness (spawners to adult progeny) value for the group (0.55, 0.65, etc.). In the example, we selected values for each stage that

Table 1. List of groups of adults available to spawn and their relative fitness in each generation with native (N) and hatchery (H) fish spawning in the first generation. Fitness of native fish = 1.0, first generation hatchery spawners = 0.5, and the gap in fitness between native and hatchery fish, or their crosses, is reduced by half with each generation of natural reproduction.

Generations / Genetic groups	Generations 1	2	3	4
Generation 1				
N_1		1.00		
H_{11}		0.50		
Generation 2				
N_2			1.00	
H_{12}			0.75	
H_{21}			0.50	
$N_1 \times H_{11}$			0.88	
Generation 3				
N_3				1.00
H_{13}				0.88
H_{22}				0.75
$(N_1 \times H_{11})2$				0.94
$N_2 \times H_{12}$				0.94
$N_2 \times H_{21}$				0.88
$N_2 \times (N_1 \times H_{11})$				0.97
$H_{12} \times H_{21}$				0.81
$H_{12} \times (N_1 \times H_{11})$				0.91
$H_{21} \times (N_1 \times H_{11})$				0.84
H_{31}				0.50
Generation 4				
N_4				1.00
H_{14}				0.94
H_{23}				0.88
$(N_1 \times H_{11})3$				0.97
$(N_1 \times H_{12})2$				0.97
$(N_2 \times H_{21})2$				0.94
$(N_2 \times (N_1 \times H_{11}))2$				0.98
$(H_{12} \times H_{21})2$				0.91
$(H_{12} \times (N_1 \times H_{11})2$				0.95
$(H_{21} \times (N_1 \times H_{11}))2$				0.92
H_{32}				0.75
$N_3 \times H_{13}$				0.97
$N_3 \times H_{22}$				0.94
$N_3 \times (N_1 \times H_{11})2$				0.98
$N_3 \times (N_2 \times H_{12})$				0.98
$N_3 \times (N_2 \times H_{21})$				0.97
$N_3 \times (N_2 \times (N_1 \times H_{11}))$				0.99
$N_3 \times (H_{12} \times H_{21})$				0.95
$N_3 \times (H_{12} \times (N_1 \times H_{11}))$				0.98

Table 1. continued

Generations Genetic groups	Generations 1	2	3	4	
N_3 X (H_{21} X (N_1 X H_{11}))					0.96
N_3 X H_{31}					0.88
H_{13} X H_{22}					0.91
H_{13} X (N_1 X H_{11})2					0.95
H_{13} X (N_2 X H_{12})					0.95
H_{13} X (N_2 X H_{21})					0.94
H_{13} X (N_2 X (N_1 X H_{11}))					0.96
H_{13} X (H_{12} X H_{21})					0.92
H_{13} X (H_{12} X (N_1 X H_{11}))					0.95
H_{13} X (H_{21} X (N_1 X H_{11}))					0.93
H_{13} X H_{31}					0.84
H_{22} X (N_1 X H_{11})2					0.92
H_{22} X (N_2 X H_{12})					0.92
H_{22} X (N_2 X H_{21})					0.91
H_{22} X (N_2 X (N_1 X H_{11}))					0.93
H_{22} X (H_{12} X H_{21})					0.89
H_{22} X (H_{12} X (N_1 X H_{11}))					0.91
H_{22} X (H_{21} X (N_1 X H_{11}))					0.90
H_{22} X H_{31}					0.81
(N_1 X H_{11})2 X (N_2 X H_{12})					0.97
(N_1 X H_{11})2 X (N_2 X H_{21})					0.95
(N_1 X H_{11})2 X (N_2 X (N_1 X H_{11}))					0.98
(N_1 X H_{11})2 X (H_{12} X H_{21})					0.94
(N_1 X H_{11})2 X (H_{12} X (N_1 X H_{11}))					0.96
(N_1 X H_{11})2 X (H_{21} X (N_1 X H_{11}))					0.95
(N_1 X H_{11})2 X H_{31}					0.86
(N_2 X H_{12}) X (N_2 X H_{21})					0.95
(N_2 X H_{12}) X (N_2 X (N_1 X H_{11}))					0.98
(N_2 X H_{12}) X (H_{12} X H_{21})					0.94
(N_2 X H_{12}) X (H_{12} X (N_1 X H_{11}))					0.96
(N_2 X H_{12}) X (H_{21} X (N_1 X H_{11}))					0.95
(N_2 X H_{12}) X H_{31}					0.86
(N_2 X H_{21}) X (N_2 X (N_1 X H_{11}))					0.96
(N_2 X H_{21}) X (H_{12} X H_{21})					0.92
(N_2 X H_{21}) X (H_{12} X (N_1 X H_{11}))					0.95
(N_2 X H_{21}) X (H_{21} X (N_1 X H_{11}))					0.93
(N_2 X H_{21}) X H_{31}					0.84
(N_2 X (N_1 X H_{11})) X (H_{12} X H_{21})					0.95
(N_2 X (N_1 X H_{11})) X (H_{12} X (N_1 X H_{11}))					0.97
(N_2 X (N_1 X H_{11})) X (H_{21} X (N_1 X H_{11}))					0.95
(N_2 X (N_1 X H_{11})) X H_{31}					0.87
(H_{12} X H_{21}) X (H_{12} X (N_1 X H_{11}))					0.93
(H_{12} X H_{21}) X (H_{21} X (N_1 X H_{11}))					0.91
(H_{12} X H_{21}) X H_{31}					0.83
(H_{12} X (N_1 X H_{11})) X (H_{21} X (N_1 X H_{11}))					0.94
(H_{12} X (N_1 X H_{11})) X H_{31}					0.85
(H_{21} X (N_1 X H_{11})) X H_{31}					0.84
H_{41}					0.50

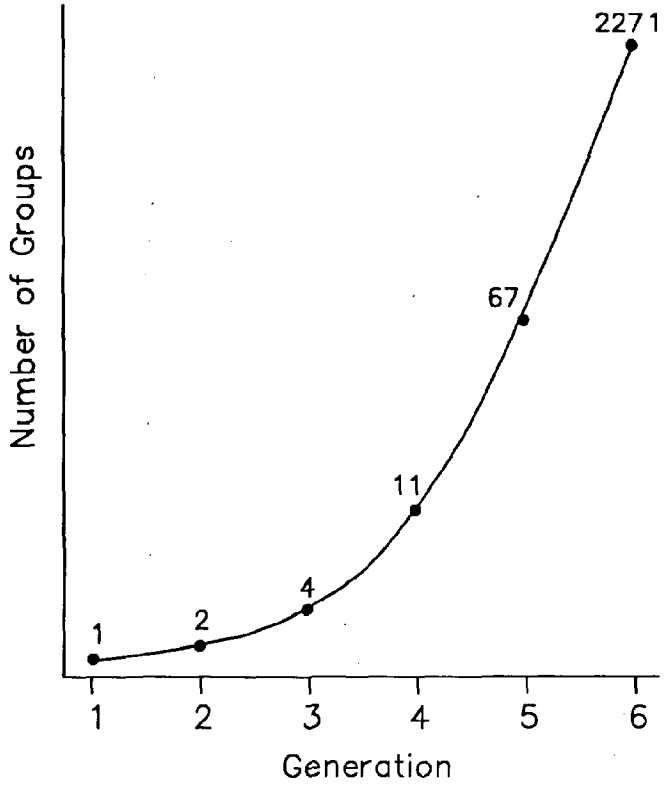

Figure 2. The number of genetic groups that would be present in each generation, starting with only native fish spawning in the first generation, hatchery adults spawning naturally at start of the second generation, and all potential crosses occurring in subsequent generations. Sex and age at spawning ignored.

represented our perception of where the largest fitness gap might exist.

In the spreadsheet example, we allowed fitness to increase by 10 units (from 0.55 to 0.65 for example) for each full generation of natural spawning and rearing. Fish that originated as hatchery fish became the same as native fish in terms of fitness when their combination of generations of natural reproduction and matings with fish of higher fitness resulted in fitness values of 1.

Fitness of Native and Hatchery Fish

Differences in fitness, the ability to live and develop under normal conditions, between native and hatchery fish can be large or small depending on the origin of the hatchery stock, number of generations of domestication, and the type and intensity of selection in the hatchery. For a given spawning and nursery area, the native stock would have the highest fitness, the result of generations of adaptation to environmental

Table 2. Examples of the age groups of chinook salmon that would contribute to spawning runs from each brood year.

	Years of return and age of adults					
Brood year	1985	1986	1987	1988	1989	1990
Fall and some summer chinook salmon, age 0 smolts						
1980	5					
1981	4	5				
1982	3	4	5			
1983	2	3	4	5		
1984		2	3	4	5	
1985			2	3	4	5
1986				2	3	4
1987					2	3
1988						2
Spring and some summer chinook salmon, age 1 smolts						
1980	6					
1981	5	6				
1982	4	5	6			
1983	3	4	5	6		
1984		3	4	5	6	
1985			3	4	5	6
1986				3	4	5
1987					3	4
1988						3

conditions in the natal area and the migration paths. In areas where the environment has been changed significantly, the fitness of native fish may be reduced, but would still be higher than non-native stocks that might be introduced, unless the environmental changes were so drastic that past adaptations were of no value or were even maladaptive.

Hatchery stocks developed from the stock to be supplemented would likely have the least difference in fitness, initially at least, from the native stock. Theoretically, the size of the gap in fitness between the native stock and the hatchery stock would depend on the type and severity of selection in the hatchery, the frequency of native stock additions to the hatchery stock that would improve the fitness of the hatchery stock, and the additions of hatchery fish to the native stock that may lower the fitness of the native stock. Hatchery stocks developed from nearby stocks with similar characteristics and environments would appear to be next in preference to use of the local stock for development of hatchery stocks used for supplementation because they would likely have less difference in fitness than distant stocks from different types of environments (Reisenbichler 1984).

Table 3. An example of the age groups of steelhead that could contribute to spawning runs from each brood year, and the number of years in which contributions would occur.

Brood year	Years of return and age of adults						
Smolt age	1986	1987	1988	1989	1990	1991	1992
1980							
1	6						
2	6	7					
3	6	7	8				
4	6	7	8	9			
1981							
1	5	6					
2	5	6	7				
3	5	6	7	8			
4		6	7	8	9		
1982							
1	4	5	6				
2	4	5	6	7			
3		5	6	7	8		
4			6	7	8	9	
1983							
1	3	4	5	6			
2		4	5	6	7		
3			5	6	7	8	
4				6	7	8	9
1984							
1		3	4	5	6		
2			4	5	6	7	
3				5	6	7	8
4					6	7	8
1985							
1			3	4	5	6	
2				4	5	6	7
3					5	6	7
4						6	7
1986							
1				3	4	5	6
2					4	5	6
3						5	6
4							6
1987							
1					3	4	5
2						4	5
3							5
4							

Table 4. Frequency distribution of genetic groups by fitness groupings in each generation from Table 1 with fitness of native fish = 1.0, first generation hatchery spawners = 0.5, and the gap in fitness between native and hatchery fish or their crosses reduced by half with each generation of natural reproduction, and where the gap is reduced by one-fourth.

Generations Groups	Fitness range	Gap reduced by half (Table 1)	Gap reduced by one-fourth
Generation 1			
Group 1	1.00	1	1
Group 2	0.90-0.99	0	0
Group 3	0.80-0.89	0	0
Group 4	0.70-0.79	0	0
Group 5	0.60-0.69	0	0
Group 6	0.50-0.59	1	1
Generation 2			
Group 1	1.00	1	1
Group 2	0.90-0.99	0	0
Group 3	0.80-0.89	1	1
Group 4	0.70-0.79	1	0
Group 5	0.60-0.69	0	1
Group 6	0.50-0.59	1	1
Generation 3			
Group 1	1.00	1	1
Group 2	0.90-0.99	4	1
Group 3	0.80-0.89	4	5
Group 4	0.70-0.79	1	2
Group 5	0.60-0.69	0	1
Group 6	0.50-0.59	1	1
Generation 4			
Group 1	1.00	1	1
Group 2	0.90-0.99	52	10
Group 3	0.80-0.89	12	35
Group 4	0.70-0.79	1	17
Group 5	0.60-0.69	0	3
Group 6	0.50-0.59	1	1

To date, the difference in fitness between native or natural and hatchery stocks of salmon and steelhead has been only partially assessed in a few cases (Reisenbichler and McIntyre 1977; Chilcote et al. 1986). The results of these studies have raised the concern about supplementing native stocks of fish with hatchery stocks if the fitness of the hatchery fish is significantly less than the native stock. In the examples we provide, we have assigned the native stock a fitness of 1.0 and a lesser rate to the hatchery fish. The fitness of the progeny of native X hatchery matings depends primarily on the fitness of the parents.

Table 5. An example of a spreadsheet model with life history stages and the necessary coefficients for each stage to estimate the numbers of fish produced by each fitness group in each generation.

					Generation 1
Parameters:	Values	Symbols	B–H parameters		
Proportion females	0.67	pf			
Eggs/female	6000	f			
Egg–fry survival	0.5	Ef			
Parr capacity	1000000	Cp	1.00E–06	=a1	
Parr prod rate	0.2	Po	5	=b1	
Smolt capacity	500000	Cs	2.00E–06	=a2	
Smolt prod rate	0.1	So	10	=b2	
Smolt–rec survival	0.112	Sr			
Recr–spawn survival	0.33	Ra			

Life stages				Natural fish fitness groups						
Variables	Symbol	Native	Stocked hatchery	0.95	0.85	0.75	0.65	0.55	0.45	0.35
Spawners–eggs deposited										
Number of spawners	A	1000								
Fitness–spawners	Fs	1		1	0.98	0.97	0.96	0.95		
Eggs deposited	E	4020000	0	0	0	0	0	0	0	0
Eggs–fry emerged										
Fitness–eggs	Fe	1		0.99	0.98	0.96	0.95	0.9		
Fry emerged/stocked	F	2010000	2010000	0	0	0	0	0	0	0
Fry–parr										
Fitness–fry	Ff	1	0.7	0.98	0.95	0.92	0.88	0.85		
Adjusted fry number		2010000	1407000	0	0	0	0	0	0	0
Parr produced/stkd	P	238802	167162	0	0	0	0	0	0	0
Parr–smolt										
Fitness–parr	Fp	1	0.8	0.99	0.96	0.93	0.9	0.89		
Adjusted parr number		238802	133729	0	0	0	0	0	0	0
Smolts produced/stkd	S	22224	12446	0	0	0	0	0	0	0
Smolt–recruit										
Fitness–smolts	Fs	1	0.9	0.99	0.98	0.96	0.94	0.9		
Adjusted smolt number		22224	11201	0	0	0	0	0	0	0
Recruits produced	R	2489	1255	0	0	0	0	0	0	0
Recruit–spawner										
Fitness–recruits	Fr	1	0.95	1	0.99	0.98	0.97	0.94		
Adjusted recruit no.		2489	1192	0	0	0	0	0	0	0
Spawners produced	A	821	393	0	0	0	0	0	0	0
Relative overall fitness										
Adult to adult		0.82		ERR	ERR	ERR	ERR	ERR	ERR	ERR
Fry to adult		0.0004	0.4788	ERR	ERR	ERR	ERR	ERR	ERR	ERR
Smolt to adult		0.0370	0.8550	ERR	ERR	ERR	ERR	ERR	ERR	ERR
Total smolts produced		33425	Percent native		66					
Total adults produced		1215	Percent native		68					

Table 5. Continued.

Generation 2

Parameters:		Symbols	B–H parameters	
Proportion females	0.67	pf		
Eggs/female	6000	f		
Egg–fry survival	0.5	Ef		
Parr capacity	1000000	Cp	1.00E–06	=a1
Parr prod rate	0.2	Po	5	=b1
Smolt capacity	500000	Cs	2.00E–06	=a2
Smolt prod rate	0.1	So	10	=b2
Smolt–rec survival	0.112	Sr		
Recr–spawn survival	0.33	Ra		

Life stages / Variables	Symbol	Native	Stocked hatchery	Natural fish fitness groups 0.95	0.85	0.75	0.65	0.55	0.45	0.35
Spawners–eggs deposited										
Number of spawners	A	555		0	0	532	0	127	0	0
Fitness–spawners	Fs	1		1	0.98	0.97	0.96	0.95		
Eggs deposited	E	2232946	0	0	0	2074121	0	486307	0	0
Eggs–fry emerged										
Fitness–eggs	Fe	1		0.99	0.98	0.96	0.95	0.9		
Fry emerged/stocked	F	1116473	2010000	0	0	995578	0	218838	0	0
Fry–parr										
Fitness–fry	Ff	1	0.7	0.98	0.95	0.92	0.88	0.85		
Adjusted fry number		1116473	1407000	0	0	915932	0	186012	0	0
Parr produced/stkd	P	129440	163123	0	0	106190	0	21566	0	0
Parr–smolt										
Fitness–parr	Fp	1	0.8	0.99	0.96	0.93	0.9	0.89		
Adjusted parr number		129440	130498	0	0	98757	0	19193	0	0
Smolts produced/stkd	S	12034	12133	0	0	9182	0	1784	0	0
Smolt–recruit										
Fitness–smolts	Fs	1	0.9	0.99	0.98	0.96	0.93	0.9		
Adjusted smolt number		12034	10920	0	0	8814	0	1606	0	0
Recruits produced	R	1348	1223	0	0	987	0	180	0	0
Recruit–spawner										
Fitness–recruits	Fr	1	0.95	1	0.99	0.98	0.97	0.94		
Adjusted recruit no.		1348	1162	0	0	967	0	169	0	0
Spawners produced	A	445	383	0	0	319	0	56	0	0
Relative overall fitness										
Adult to adult		0.80		ERR	ERR	0.75	ERR	0.55	ERR	ERR
Fry to adult		0.0004	0.4788	ERR	ERR	0.8049	ERR	0.6400	ERR	ERR
Smolt to adult		0.0370	0.8550	ERR	ERR	0.9408	ERR	0.8460	ERR	ERR
Total smolts produced		33374	Percent native		36					
Total adults produced		1203	Percent native		37					

Table 5. Continued.

Generation 3

Parameters:		Symbols	B–H parameters	
Proportion females	0.67	pf		
Eggs/female	6000	f		
Egg–fry survival	0.5	Ef		
Parr capacity	1000000	Cp	1.00E–06	=a1
Parr prod rate	0.2	Po	5	=b1
Smolt capacity	500000	Cs	2.00E–06	=a2
Smolt prod rate	0.1	So	10	=b2
Smolt–rec survival	0.112	Sr		
Recr–spawn survival	0.33	Ra		

Life stages / Variables	Symbol	Native	Stocked hatchery	Natural fish fitness groups 0.95	0.85	0.75	0.65	0.55	0.45	0.35
Spawners–eggs deposited										
Number of spawners	A	555		218	38	511	18	125	0	0
Fitness–spawners	Fs	1		1	0.98	0.97	0.96	0.95		
Eggs deposited	E	2232946	0	876154	150060	1994430	70382	478591	0	0
Eggs–fry emerged										
Fitness–eggs	Fe	1		0.99	0.98	0.96	0.95	0.9		
Fry emerged/stocked	F	1116473	2010000	433696	73529	957327	33432	215366	0	0
Fry–parr										
Fitness–fry	Ff	1	0.7	0.98	0.95	0.92	0.88	0.85		
Adjusted fry number		1116473	1407000	425022	69853	880740	29420	183061	0	0
Parr produced/stkd	P	122534	154419	46646	7666	96662	3229	20091	0	0
Parr–smolt										
Fitness–parr	Fp	1	0.8	0.99	0.96	0.93	0.9	0.89		
Adjusted parr number		122534	123535	46180	7360	89895	2906	17881	0	0
Smolts produced/stkd	S	11324	11417	4268	680	8308	269	1653	0	0
Smolt–recruit										
Fitness–smolts	Fs	1	0.9	0.99	0.98	0.96	0.93	0.9		
Adjusted smolt number		11324	10275	4225	667	7976	250	1487	0	0
Recruits produced	R	1268	1151	473	75	893	28	167	0	0
Recruit–spawner										
Fitness–recruits	Fr	1	0.95	1	0.99	0.98	0.97	0.94		
Adjusted recruit no.		1268	1093	473	74	875	27	157	0	0
Spawners produced	A	419	361	156	24	289	9	52	0	0
Relative overall fitness										
Adult to adult		0.75		0.95	0.85	0.75	0.65	0.55	ERR	ERR
Fry to adult		0.0004	0.4788	0.9605	0.8848	0.8049	0.7145	0.6400	ERR	ERR
Smolt to adult		0.0370	0.8550	0.9900	0.9702	0.9408	0.9021	0.8460	ERR	ERR
Total smolts produced		36203	Percent native		31					
Total adults produced		1309	Percent native		32					

Table 5. Continued.

					Generation 4
Parameters:		Symbols	B-H parameters		
Proportion females	0.67	pf			
Eggs/female	6000	f			
Egg-fry survival	0.5	Ef			
Parr capacity	1000000	Cp	1.00E-06	=a1	
Parr prod rate	0.2	Po	5	=b1	
Smolt capacity	500000	Cs	2.00E-06	=a2	
Smolt prod rate	0.1	So	10	=b2	
Smolt-rec survival	0.112	Sr			
Recr-spawn survival	0.33	Ra			

Life stages				Natural fish fitness groups						
Variables	Symbol	Native	Stocked hatchery	0.95	0.85	0.75	0.65	0.55	0.45	0.35
Spawners-eggs deposited										
Number of spawners	A	653		197	85	446	18	108	0	0
Fitness-spawners	Fs	1		1	0.98	0.97	0.96	0.95		
Eggs deposited	E	2626764	0	790028	334620	1739676	70275	413849	0	0
Eggs-fry emerged										
Fitness-eggs	Fe	1		0.99	0.98	0.96	0.95	0.9		
Fry emerged/stocked	F	1313382	2010000	391064	163964	835044	33381	186232	0	0
Fry-parr										
Fitness-fry	Ff	1	0.7	0.98	0.95	0.92	0.88	0.85		
Adjusted fry number		1313382	1407000	383243	155766	768241	29375	158297	0	0
Parr produced/stkd	P	142522	152681	41588	16903	83366	3188	17178	0	0
Parr-smolt										
Fitness-parr	Fp	1	0.8	0.99	0.96	0.93	0.9	0.89		
Adjusted parr number		142522	122145	41172	16227	77530	2869	15288	0	0
Smolts produced/stkd	S	13153	11273	3800	1498	7155	265	1411	0	0
Smolt-recruit										
Fitness-smolts	Fs	1	0.9	0.99	0.98	0.96	0.93	0.9		
Adjusted smolt number		13153	10145	3762	1468	6869	246	1270	0	0
Recruits produced	R	1473	1136	421	164	769	28	142	0	0
Recruit-spawner										
Fitness-recruits	Fr	1	0.95	1	0.99	0.98	0.97	0.94		
Adjusted recruit no.		1473	1079	421	163	754	27	134	0	0
Spawners produced	A	486	356	139	54	249	9	44	0	0
Relative overall fitness										
Adult to adult		0.74		0.95	0.85	0.75	0.65	0.55	ERR	ERR
Fry to adult		0.0004	0.4788	0.9605	0.8848	0.8049	0.7145	0.6400	ERR	ERR
Smolt to adult		0.0370	0.8550	0.9900	0.9702	0.9408	0.9021	0.8460	ERR	ERR
Total smolts produced		36913	Percent native		36					
Total adults produced		1337	Percent native		36					

Table 5. Continued.

Generation 5

Parameters:		Symbols	B–H parameters	
Proportion females	0.87	pf		
Eggs/female	6000	f		
Egg–fry survival	0.5	Ef		
Parr capacity	1000000	Cp	1.00E–06	=a1
Parr prod rate	0.2	Po	5	=b1
Smolt capacity	500000	Cs	2.00E–06	=a2
Smolt prod rate	0.1	So	10	=b2
Smolt–rec survival	0.112	Sr		
Recr–spawn survival	0.33	Ra		

Life stages / Variables	Symbol	Native	Stocked hatchery	Natural fish fitness groups 0.95	0.85	0.75	0.65	0.55	0.45	0.35
Spawners–eggs deposited										
Number of spawners	A	641		186	73	451	16	105	0	0
Fitness–spawners	Fs	1		1	0.98	0.97	0.96	0.95		
Eggs deposited	E	2576365	0	747193	289301	1758214	60111	400228	0	0
Eggs–fry emerged										
Fitness–eggs	Fe	1		0.99	0.98	0.96	0.95	0.9		
Fry emerged/stocked	F	1288183	2010000	369861	141758	843943	28553	180103	0	0
Fry–parr										
Fitness–fry	Ff	1	0.7	0.98	0.95	0.92	0.88	0.85		
Adjusted fry number		1288183	1407000	362463	134670	776427	25126	153087	0	0
Parr produced/stkd	P	140832	153822	39627	14723	84884	2747	16736	0	0
Parr–smolt										
Fitness–parr	Fp	1	0.8	0.99	0.96	0.93	0.9	0.89		
Adjusted parr number		140832	123057	39230	14134	78942	2472	14895	0	0
Smolts produced/stkd	S	13007	11366	3623	1305	7291	228	1376	0	0
Smolt–recruit										
Fitness–smolts	Fs	1	0.9	0.99	0.98	0.96	0.93	0.9		
Adjusted smolt number		13007	10229	3587	1279	6999	212	1238	0	0
Recruits produced	R	1457	1146	402	143	784	24	139	0	0
Recruit–spawner										
Fitness–recruits	Fr	1	0.95	1	0.99	0.98	0.97	0.94		
Adjusted recruit no.		1457	1088	402	142	768	23	130	0	0
Spawners produced	A	481	359	133	47	254	8	43	0	0
Relative overall fitness										
Adult to adult		0.75		0.95	0.85	0.75	0.65	0.55	ERR	ERR
Fry to adult		0.0004	0.4788	0.9605	0.8848	0.8049	0.7145	0.6400	ERR	ERR
Smolt to adult		0.0370	0.8550	0.9900	0.9702	0.9408	0.9021	0.8460	ERR	ERR
Total smolts produced		36553	Percent native		36					
Total adults produced		1323	Percent native		36					

Table 5. Continued.

Generation 6

Parameters:		Symbols	B–H parameters	
Proportion females	0.67	pf		
Eggs/female	6000	f		
Egg–fry survival	0.5	Ef		
Parr capacity	1000000	Cp	1.00E–06	=a1
Parr prod rate	0.2	Po	5	=b1
Smolt capacity	500000	Cs	2.00E–06	=a2
Smolt prod rate	0.1	So	10	=b2
Smolt–rec survival	0.112	Sr		
Recr–spawn survival	0.33	Ra		

Life stages / Variables	Symbol	Native	Stocked hatchery	Natural fish fitness groups 0.95	0.85	0.75	0.65	0.55	0.45	0.35
Spawners–eggs deposited										
Number of spawners	A	638		186	71	455	15	107	0	0
Fitness–spawners	Fs	1		1	0.98	0.97	0.96	0.95		
Eggs deposited	E	2563737	0	749352	279013	1774354	58065	407612	0	0
Eggs–fry emerged										
Fitness–eggs	Fe	1		0.99	0.98	0.96	0.95	0.9		
Fry emerged/stocked	F	1281869	2010000	370929	136716	851690	27581	183425	0	0
Fry–parr										
Fitness–fry	Ff	1	0.7	0.98	0.95	0.92	0.88	0.85		
Adjusted fry number		1281869	1407000	363510	129881	783555	24271	155911	0	0
Parr produced/stkd	P	140156	153838	39745	14201	85672	2654	17047	0	0
Parr–smolt										
Fitness–parr	Fp	1	0.8	0.99	0.96	0.93	0.9	0.89		
Adjusted parr number		140156	123070	39348	13633	79675	2388	15172	0	0
Smolts produced/stkd	S	12945	11367	3634	1259	7359	221	1401	0	0
Smolt–recruit										
Fitness–smolts	Fs	1	0.9	0.99	0.98	0.96	0.93	0.9		
Adjusted smolt number		12945	10230	3598	1234	7065	205	1261	0	0
Recruits produced	R	1450	1146	403	138	791	23	141	0	0
Recruit–spawner										
Fitness–recruits	Fr	1	0.95	1	0.99	0.98	0.97	0.94		
Adjusted recruit no.		1450	1089	403	137	775	22	133	0	0
Spawners produced	A	478	359	133	45	258	7	44	0	0
Relative overall fitness										
Adult to adult		0.75		0.95	0.85	0.75	0.65	0.55	ERR	ERR
Fry to adult		0.0004	0.4788	0.9605	0.8848	0.8049	0.7145	0.6400	ERR	ERR
Smolt to adult		0.0370	0.8550	0.9900	0.9702	0.9408	0.9021	0.8460	ERR	ERR
Total smolts produced		36538	Percent native		35					
Total adults produced		1323	Percent native		36					

Changes in Fitness over Time

If the fitness of hatchery fish used to supplement a native stock is less than the native fish, then one of the questions that arises is the rate at which the fitness of natural progeny of hatchery fish (or crosses) converges on the fitness of native fish. Theoretically, with each succeeding generation that progeny of hatchery fish reproduce naturally their fitness should increase through natural selection (Figure 3).

In the example provided in Table 1, we assumed that half the gap in fitness between native fish and hatchery or crosses with hatchery fish had been closed with each generation completed in the natural environment. Thus hatchery fry stocked in the example and returning to spawn as adults (group H_{11} in Table 1) had a fitness of 0.5 at the start of the first generation, a fitness of 0.75 (group H_{12}) at the start of the second generation if they were the progeny of a H_{11} X H_{11} mating, a fitness of 0.88 (group H_{13}) at the start of the third generation if they were the progeny of a H_{12} X H_{12} mating, and a fitness of 0.94 (group H_{14}) at thestart of generation 4 if they were the progeny of a H_{13} X H_{13} mating. In a model to evaluate supplementation, a procedure to adjust the fitness coefficients (overall and for each life stage) must be included to account for changes due to cross breeding, repeated natural reproduction, and changes that may occur in the hatchery stock.

Operational Time Frame for Model

Models to evaluate supplementation could be set up to operate on year-to-year or generation-to-generation time frames. If it were important to track the contribution of each age group in every brood year, then the year by year approach would be necessary. If we can assume, for modeling purposes, a relatively constant age and sex ratio at maturity, a generation-to-generation model could be used. The model should probably be able to monitor all groups for 20 or more generations, to allow ample time to reach equilibrium levels for given conditions, and the opportunity to evaluate mid period changes in conditions.

Life-Stage Compartments of Model

A life-history type model appears to be the most logical approach to estimating the abundance of salmon and steelhead resulting from supplementation, because hatchery fish of more than one life stage will be added to streams. Relations can be developed for each of the life stages to allow estimation of fish numbers of each type (native, hatchery, and those from each fitness group) at each stage and to incorporate the effects of various conditions through stage-specific coefficients, including those for fitness. With life stage modeling, an assessment of the effects of supplementation can be made for any stage, including number of fish produced and overall fitness.

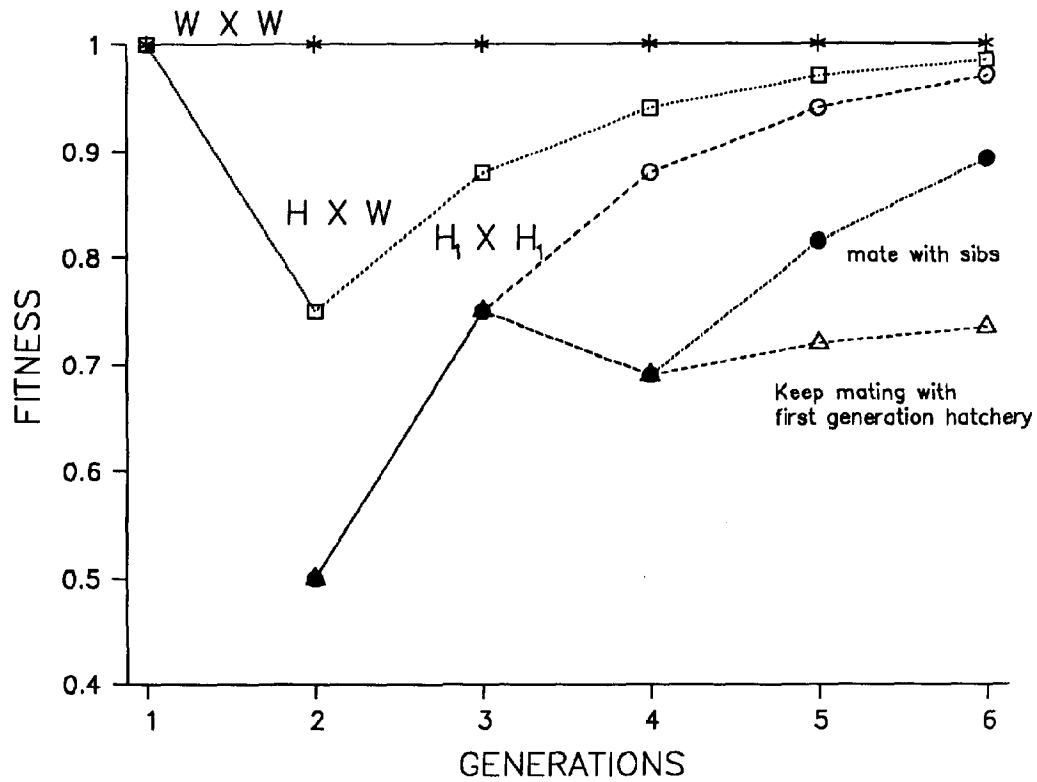

Figure 3. Examples of fitness values for fish with various genetic backgrounds and changes over time depending on parentage and rate of improvement in fitness with each succeeding generation of natural reproduction. In this example, the assumptions are as listed for groups in Table 1.

For the salmon and steelhead stocks of the Columbia River, the life cycle can be divided into many stages, but the stages listed below are probably the ones needed to evaluate supplementation:

1. Adult to deposited egg: the stage that incorporates the number, sex ratio, fecundity, and fitness of the spawners, mating overlap between groups, and the limitation, if any, of available spawning area in estimating the number of eggs deposited in redds by each group of fish or type of mating. This would be the starting stage for all naturally produced fish and the start when supplementation is done with hatchery adults.

2. Deposited egg to emergent fry: the stage that includes the number and fitness of the eggs deposited and quality of the redd environment (survival rate) to estimate the number of fry of each group that would emerge from the redds. The initial generation for hatchery fish

would start with this stage if supplementation was done with newly fertilized or eyed eggs.

3. Fry to fingerling pre-smolt: the number and fitness of emergent-fry is related to the carrying capacity, density dependent, and density independent mortality factors of the environment to estimate the number of fish that reach the fingerling pre-smolt (parr) stage. The pre-smolt stage is a user defined point in the life cycle between emergent fry and smolt, that would correspond with the time when pre-smolts might be stocked to supplement the native stock. For spring chinook salmon that migrate to the sea as yearlings in the spring, a pre-smolt stage might be the middle or end of the first summer. For steelhead, it might be the end of the first, second, or third summer, depending primarily on the time pre-smolts are stocked and on the age of fish at smolting. When supplementation is done with fry, this stage would be the start of the initial generation for the hatchery fish.

4. Pre-smolt to smolt: the stage that is created to facilitate evaluation of supplementation with pre-smolts. It is necessary to estimate the number of naturally produced pre-smolts produced so that a comparison with hatchery pre-smolts can be made. The number and fitness of the pre-smolts must be related to the carrying capacity and mortality factors in the environment.

5. Smolt to recruit: the stage that includes the number and fitness of natural and hatchery (if stocked) smolts, mortality rates during the seaward migration, and mortality at sea up to the time the fish are first recruited to the fisheries. If smolts are used for supplementation, this stage would be the start of the initial hatchery generation.

6. Recruit to spawner: the periods from first recruitment to the fisheries, migration upstream to the spawning areas, and the holding time prior to spawning are included in this stage.

The relations for each of the life stages would be based on information available from prior studies, or lacking that, on the judgement of experts. For example, there is information available on the sex ratios, age composition, and fecundity of many of the stocks of fish that would be supplemented and those used for supplementing. Information on survival relations for each of the life stages is not generally available, especially for each and every stock, but there is enough information to make reasonable estimates of the relations. Relations and coefficients used in the system planning model (Monitoring and Evaluation Group 1989) developed by the Northwest Power Planning Council (NPPC) could be used as a starting point.

Coefficients used to express the effects of fitness of the offspring of each type of mating (native X native, hatchery X native, etc.), the amount of mating overlap, and of such factors as size and health of fish used for supplementation would be developed for each life stage (see example in Table 5 spreadsheet). Native fish might be assigned a fitness coefficient of 1.0, for example, and hatchery fish a lower value if less fit or a higher value if more fit for survival

than the native fish. Relative fitness of the hatchery fish or progeny of hatchery X native matings may vary by life stage.

Incorporating survival relations for each of the life stages provides the flexibility to take into account the special conditions that might be present in spawning areas, streams used for rearing, river and reservoir migration routes, and fisheries for each stock. For example, survival to

the smolt stage of spring chinook salmon rearing in headwater streams appears to be a density-dependent asymptotic relation, whereas the relation for fall chinook rearing in mainstem reservoirs could be a linear relation if density-independent predation was the major cause of mortality.

Probability of Mating

The probability of mating between native and hatchery fish depends on the number of native and hatchery adults, the sex ratio of both groups, and the degree of overlap in time and location of spawning. Other factors could affect the probability of mating, such as size of fish, general health, and willingness to compete for mates, but we have assumed such factors will be similar for both native and hatchery fish.

If only native fish were present, then the probability of mating between two native fish would be 1.0 X 1.0 = 1.0. If equal numbers of native and hatchery fish were present, the age and sex ratios were equal for both groups, and there was full overlap in time and location of spawning the probability for each of the four possible matings would be 0.25 (example 2, Table 6). If all else stayed equal, but the numbers of each group changed, to say, three-fourths native females and one-fourth hatchery, the probabilities would change to 0.563 for the NF X NM cross, 0.188 for the NF X HM and HF X NM crosses, and 0.063 for the HF X HM cross (example 3, Table 6). As long as the sex ratios were similar for each of the groups being considered, the proportion of the population of males used in the calculations would be the same as for females. It would not matter if there were more or less males than females, as long as the ratio was the same for both groups.

If there were differences in the sex or age ratios between native and hatchery groups, the probabilities of mating would be affected as illustrated in example 4 in Table 6. In this example, native females continued to make up 75% of the females, but the sex ratio of the native fish was set at 0.667 females and 0.333 males, and that of hatchery fish at 0.5 females and 0.5 males. In the total population of males then, native fish made up 0.6 and hatchery fish 0.4. The proportion of N X H crosses increased relative to example 3, because there were more hatchery males available to spawn.

If the degree of overlap in time or location of spawning is less than complete, the probabilities of N X H crosses decreases because the fish are not all together when spawning occurs. In example 5 (Table 6), we setoverlap at 50%; only half of the native and hatchery fish were spawning at the same time or place. The matings between native females and native males includes those from the half of the population that did not spawn at the same time or place as the hatchery fish (probability 0.375) and those from fish that had the opportunity to mate with hatchery fish, but didn't because of chance (0.281).

Table 6. Probabilities of mating for native and hatchery fish with varying degrees of overlap in spawning time and location.

Example	Proportion in group Female	Male	Over-lap	Non-overlap	Prob-abilities
1. All native or all hatchery fish (sex ratio unimportant)					
NF X NM =	1.00 X	1.00 X	1.00		1.000
HF X HM =	1.00 X	1.00 X	1.00		1.000
2. Half native and half hatchery fish (equal sex ratio, full overlap)					
NF X NM =	0.50 X	0.50 X	1.00		0.250
NF X HM =	0.50 X	0.50 X	1.00		0.250
HF X NM =	0.50 X	0.50 X	1.00		0.250
HF X HM =	0.50 X	0.50 X	1.00		0.250
3. Females: 3/4 native and 1/4 hatchery (sex ratio same, full overlap)					
NF X NM =	0.75 X	0.75 X	1.00		0.563
NF X HM =	0.75 X	0.25 X	1.00		0.188
HF X NM =	0.25 X	0.75 X	1.00		0.188
HF X HM =	0.25 X	0.25 X	1.00		0.063
4. Females: 0.75 native and 0.25 hatchery, males: 0.6 native and 0.4 hatchery, (full overlap)					
NF X NM =	0.75 X	0.60 X	1.00		0.450
NF X HM =	0.75 X	0.40 X	1.00		0.300
HF X NM =	0.25 X	0.60 X	1.00		0.150
HF X HM =	0.25 X	0.40 X	1.00		0.100
5. Females and males: 0.75 native and 0.25 hatchery (50% overlap)					
NF X NM =	0.75 X			0.5	0.375
NF X NM =	0.75 X	0.75 X	0.50		0.281
NF X HM =	0.75 X	0.25 X	0.50		0.094
HF X NM =	0.25 X	0.75 X	0.50		0.094
HF X HM =	0.25 X	0.25 X	0.50		0.031
HF X HM =	0.25 X			0.5	0.125
6. Females and males: 0.75 native and 0.25 hatchery (10% overlap)					
NF X NM =	0.75 X			0.9	0.675
NF X NM =	0.75 X	0.75 X	0.10		0.056
NF X HM =	0.75 X	0.25 X	0.10		0.019
HF X NM =	0.25 X	0.75 X	0.10		0.019
HF X HM =	0.25 X	0.25 X	0.10		0.006
HF X HM =	0.25 X			0.9	0.225

Methods of Supplementation

The methods of supplementation will be dictated by each manager's perception of the best way to increase production, and by the factors regulating the availability of fish from hatcheries. Unless the native stock has been reduced to low levels of abundance, the best way to minimize the potential for genetic damage to the supplemented stock is to use the local stock as the source for the hatchery stock, add native/natural fish to the hatchery broodstock periodically, avoid hatchery practices that select for a segment of the population, and do not overwhelm the native stock with hatchery fish. Hatchery fish from a genetically sound supplementation program should have higher fitness values than those from hatchery stocks that are not so managed.

Hatchery fish at many life stages have been used to supplement or restore salmon and steelhead populations. Adults from hatcheries have been released in streams or spawning channels to spawn naturally, newly fertilized and eyed eggs have been placed in streams or incubation

channels, unfed fry and other pre-smolt juveniles have been released in streams to continue rearing, and smolts have been released to migrate seaward and then return to spawn in the stream of release. The model must accommodate the addition of hatchery fish at all of these life stages, which is a reason for the recommended life-stage compartments.

The size and health of hatchery fish relative to the natural fish, season and location of supplementation, and the effect of other species on the hatchery fish can be accounted for in the fitness coefficient. If the hatchery fish are more vulnerable to predation or angling, or less able to secure favorable living space than their native counterparts, the reduced survival could be expressed in a lower fitness coefficient.

Supplementation and the Carrying Capacity of Streams

For all forms of supplementation where the hatchery fish are expected to spend a significant period of time in the natural environment before spawning or becoming a smolt, the concept of a carrying capacity for fish must be considered. There may be a limited number of spawning sites in a stream or lake shore. Most streams and perhaps some large rivers or reservoirs have an upper limit on the number (or biomass) of fish that can be supported during the summer. The winter carrying capacity of streams may be different than that in summer because of the factors involved.

Carrying capacities become important for species like chinook and coho salmon and steelhead that spend a significant period of time in streams before migrating to the ocean. During the freshwater phase density-dependent forms of mortality limit the number of smolts that can be produced in a given natural environment. If a habitat is fully seeded by native fish and hatchery fish are added, there will be a reduction in the number of native smolts produced to compensate for the number of hatchery fish that compete successfully and become smolts. A more critical concern is the case where there is a relatively small number of native fish, a large number of hatchery fish are added, and the

native fish become further depressed because of the added competition they must endure.

In a supplementation model the number of native, hatchery, and other genetic types of smolts produced is a function of the initial numbers of each type of fish, their relative fitness, and the carrying capacity of the environment. Non-native fish can be equated to native fish by multiplying their abundance by their fitness coefficients. This adjusted initial number of non-native fish would then be added to the number of native fish to obtain the effective initial number of fish at the beginning of a life stage. The number of native and non-native fish produced at the end of the life stage would then be the total number produced multiplied by the proportion of each type at the beginning.

Effects of Supplementation on Other Species

Hatchery fish released in a stream to supplement one species may affect other species. To assess the effect of supplementation on non-target species the model must be able to track each of the species of interest through each life stage and generation, and there must be a way to express the results of the interactions that occur between the species. The severity of the interaction effect would depend on the degree of niche overlap between two or more species, what factors limit production, and the abundance of the fish relative to the carrying capacity. A coefficient could be attached to each of the relations for each life stage to modify the survival rate according to the effect of interspecific interactions.

Deterministic versus Stochastic Models

A deterministic model would be used to evaluate the effects of supplementation without the confounding effects of environmental variability. A stochastic model would be useful to determine if environmental variability would affect the outcome of supplementation, or to determine the likelihood of extermination of stocks with marginal levels of abundance.

General Model Structure

A model (as described above) to evaluate supplementation of salmon and steelhead stocks could be designed and constructed on a computer spreadsheet (as the preliminary example in Table 5), or it could be a model constructed with program code in the manner of the system planning model. In either case, the basic components (life stages) of the model would be similar to those of the system planning model, but the model would differ in the need to keep track of selected genetic groups over time. At present, the system planning model used by the NPPC keeps track of hatchery and native fish throughout their life cycle, but only for the first generation. A spreadsheet model used by Byrne and Bjornn (1988) to evaluate supplementation for a steelhead population was constructed to keep track of hatchery and native fish for many generations, but all fish with a hatchery origin were combined in a single group regardless of the length of time since coming from the hatchery.

The ultimate model to evaluate supplementation would be able to track each genetic group generated by matings between native, hatchery, and hatchery X

native parents; with age and sex of spawners considered. With such a model, we would have more than 5,000 groups to monitor by the sixth generation, and more than 5 million by the seventh generation. We might be able to program present-day computers to monitor that many groups, but we would likely have trouble providing coefficients that would be sufficiently discriminating for each of the groups. From a practical viewpoint, it is probably not necessary to monitor a large number of genetic groups to adequately assess the success of a supplementation program.

Outputs of the model must include the number of fish of each genetic group at the end of each life stage for each generation.

Coefficients for Variables

The coefficients provided with the documentation for the NPPC's system planning model (Monitoring and Evaluation Group 1989) are a good starting point in providing values needed for a supplementation model. Additional information has been developed for many of the subbasins in the Columbia River drainage as part of the system planning process. It will probably be necessary to develop stock specific coefficients, which may or may not be readily available, for use in a supplementation model. The coefficients developed for the system planning process will at least be helpful in selecting coefficients that are reasonable and similar to those found or used for other stocks of fish.

In addition to survival rates for each life stage, fitness values for each of the genetic groups must be assigned as a modifier of the survival rates. Unfortunately there are few measures of relative fitness for the various stocks of native and hatchery salmon and steelhead. In most cases, the progeny of hatchery or hatchery X native parents would likely have a fitness coefficient equal to or less than 1.0 if native fish were assigned a value of 1.0. Theoretically, the fitness values for the introduced fish could range from 0.0 to larger than 1.0. There have been cases where introduced fish did not survive and reproduce. Conceivably, excellent hatchery smolts could have a higher fitness coefficient than native fish for the first generation, if for example, the larger size they attained in the hatchery allowed them to survive at a higher rate than native smolts. Such benefits would not continue into succeeding generations when their offspring would be limited in the same ways as other naturally produced fish. We have not discussed heterosis or the breakdown of coadapted genetic systems that might affect fitness in complex ways, because we do not know how they might operate or how to include them in the model at this stage.

Recommendations

We recommend that a model be developed soon to help in the assessment of the effects of supplementation of wild stocks of salmon and steelhead with hatchery fish. The model could be developed to run as a spreadsheet program, similar to the example we provided, or it could be developed as a stand alone program similar to the sub-basin planning model, perhaps even a modification of that model.

We recommend that meetings be held, as needed, with a group of managers to review progress on model development, to determine the resolution required, and to evaluate the coefficients used in the model. These meetings are needed to insure that the model and its components meet the needs of the managers and that the predictions are as close to reality as possible.

Once the model is functional, it should be distributed to those interested, it should be used to conduct sensitivity tests, and various supplementation senerios should be run on a comparative basis to provide estimates of the relative outcomes of various management strategies.

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