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ASSESSMENT & ANALYSIS OF SMOLT CONDITION IN THE COLUMBIA RIVER BASIN

Volume I: Evaluation of the Effect of a Modified Feeding Strategy on Growth & Smoltification Of Summer Steelhead (Oncorhynchus mykiss) At Dworshak National Fish Hatchery

Technical Report 1999

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Assessment and Analysis of Smolt Condition in the Columbia River Basin

Volume I: Evaluation of the Effect of a Modified Feeding Strategy on Growth and Smoltification of Summer Steelhead (*Oncorhynchus mykiss*) at Dworshak National Fish Hatchery

U. S. Department of the Interior
U. S. Geological Survey
Biological Resources Division
Columbia River Research Laboratory
Western Fisheries Research Center

U. S. Department of Energy
Bonneville Power Administration
Division of Fish and Wildlife

Technical Report, December 1999

Evaluation of the Effect of a Modified Feeding Strategy on Growth and Smoltification of Summer Steelhead (*Oncorhynchus mykiss*) at Dworshak National Fish Hatchery

A Technical Report of the Monitoring and Evaluation of Smolt Condition of Columbia River Basin Juvenile Salmonids Project 1999

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PREFACE

Monitoring and Evaluation of Smolt Condition of Columbia River Basin Juvenile Salmonids (Bonneville Power Administration, Project 8740100) is a continuation of Assessment of Smolt Condition for Travel Time Analysis project activities conducted from 1987-1996. The project was initiated in 1987 to investigate the relation between biological characteristics of juvenile salmon and steelhead, and estimates of survival during emigration. The project developed from the need to determine the effects of fish health and physiological condition on travel time and survival of anadromous salmonids in the Columbia and Snake Rivers. The goal of project 8740100 continues to focus on investigating and improving the understanding of the interactions of the physiological condition of wild and hatchery salmonid and steelhead stocks with the environment to further management actions that maximize survival from emergence through adult returns.

The ASCTTA project provided the Smolt Monitoring Program (SMP) of the Fish Passage Center (FPC) with fish condition and health information from 1987-1996, for Water Budget management of flows to enhance juvenile salmonid emigration. The project continually adapted by reorganizing monitoring and evaluation methods to answer the needs of regional fishery managers to understand the biological and environmental interactions that affect migration rates and survival. The project developed non-lethal methods to assess smolt condition of fish listed under the Endangered Species Act. Physiological evaluation support for the Smolt Monitoring Program of the Fish Passage Center for Water Budget Management ceased in1997, when flow and fish passage management became more prescriptive under the Biological Opinions of the National Marine Fisheries Service (NMFS).

Since 1997, the project has continued research of life history and environmental factors influencing juvenile salmonid physiology and survival with regional fishery agencies. This report is the first of a technical report series describing Assessment and Analysis of Smolt Condition in the Columbia River Basin resulting from collaborative work.

The report describes a cooperative pilot study conducted with the U.S. Fish and Wildlife Service, Idaho Fishery Resource Office (IFRO) and Dworshak National Fish Hatchery (NFH) to increase the proportion of hatchery summer steelhead (*Oncorhynchus mykiss*) that successfully outmigrate. Wide length frequency distributions, a common characteristic of juvenile steelhead at Dworshak NFH, reflect the presence of large precocious males and small parr that may residualize. Juvenile hatchery steelhead have been collected in several tributary streams below Dworshak NFH after production releases have emigrated; interactions and competition with native stocks is a concern.

The purpose of the study was to evaluate the effectiveness of reduced winter rations in producing a higher proportion of Dworshak summer steelhead that successfully smolt and emigrate. Our approach incorporated the known growth patterns, rearing temperatures, and feed consumption rates of the Dworshak summer steelhead stock to develop a feeding strategy to modulate growth and to promote smoltification in a larger proportion of the production. This stock- and site-specific design allowed testing at the production level as a model for future hatchery applications.

ABSTRACT

Objectives

The primary objective of the study was to increase the number of summer steelhead (*Oncorhynchus mykiss*) from Dworshak National Fish Hatchery that outmigrate by promoting smoltification in a larger proportion of the production release. To achieve this goal, growth was reduced during the winter to produce a smaller size range of fish to eliminate the production of large fish that residualize. A period of accelerated growth prior to release was designed to promote smoltification in all fish, regardless of size.

Results

Decreased winter growth was achieved with a combination of reduced ration and short, intermittent feeding periods. Growth rates were not reduced to the expected level in the modified feeding schedule treatment group, control group, or general production fish reared in the same system. Although significant differences in length, weight and condition factor developed between treatment and control groups during December and January, compensatory growth of the treatment fish after return to full rations resulted in fish of the same size from both groups for release. Migration rates of the treatment group were higher than that of the control group, although the difference was not significant. Growth and survival during extended seawater rearing did not differ between the two groups. Smoltification, as measured by gill Na^+, K^+-ATPase and seawater survival, were unaffected by a reduction in feed during winter months.

Recommendations

This study demonstrates the application of hatchery specific performance and holding condition records to develop a reduced ration, intermittent feeding method to modulate growth with no negative effects on smolt development. Future trials of reduced ration, intermittent feeding methods may be refined from this study to test the method during different rearing stages. The modified feeding schedule should be extended to produce a smaller size range of fish.

ACKNOWLEDGMENTS

This project was a cooperative pilot study of the following agencies and organizations: the Columbia River Research Laboratory (CRRL) and Marrowstone Marine Station (MMS) of the Western Fisheries Research Center, U.S. Geological Survey, Biological Resources Division; the Idaho Fishery Resource Office (IFRO), Dworshak National Fish Hatchery (NFH), and the Idaho Fish Health Center (IFHC), of the U.S. Fish and Wildlife Service; Dr. Anna Cavinato, Chemistry Program, Eastern Oregon State University (EOU); and Dr. Barbara Rasco, Department of Food Science, Washington State University (WSU). The project involved a number of complex activities requiring close coordination and cooperation that would not have been possible without the assistance of many people at these offices and agencies. Randy Bowen, Doug Burum, and Jill Olson at the IFRO assisted in PIT-tagging steelhead smolts. Billy Connor (IFRO) familiarized us with the PIT-tag interrogation-by-code facilities at Little Goose Dam, allowing us to collect out PIT-tagged steelhead in conjunction with another research project. The production and maintenance staffs at Dworshak NFH were responsible for rearing the steelhead and maintaining the facilities. Kathy Clemens of the IFHC provided diagnosis of a disease outbreak in seawater. Ron Spinek of MMS provided technical assistance during sampling. Student assistants were Todd Rogers and Melissa Wenz (EOU), Yiquin Huang (WSU) and Jim Meek (Student Conservation Association intern at MMS).

DISCLAIMER

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LIST OF ACRONYMS, UNITS, AND NOMENCLATURE

ASCTTA = Assessment of Smolt Condition for Travel Time Analysis
BP = Burrows pond
BPA = Bonneville Power Administration
BRD = Biological Resources Division of the USGS
BY = brood year
CON = control
CRRL = Columbia River Research Laboratory
EOU = Eastern Oregon University
FPC = Fish Passage Center
HFI = hundred-fish inventory
IFHC = Idaho Fish Health Center
IFRO = Idaho Fishery Resource Office
K = Condition factor
MFS = modified feeding schedule (reduced, intermittent feeding treatment)
MIS = monthly inventory summaries
MMS = Marrowstone Marine Station
MS-222 = tricaine methane sulfonate, anaesthetic
Na^+, K^+-ATPase = gill sodium, potassium-activated adenosine triphosphatase
NFH = National Fish Hatchery
NMFS = National Marine Fisheries Service
PIT-tag = passive integrated transponder tag
PS = physiology sampling
RIA = radioimmunoassay
RKM = river kilometers
SGR = specific growth rate
SMP = Smolt Monitoring Program
USFWS = United State Fish and Wildlife Service
USGS = United States Geological Survey
WSU = Washington State University

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INTRODUCTION

Steelhead (*Oncorhynchus mykiss*) from Dworshak National Fish Hatchery (NFH**)** are characterized by a wide length range at the time of release. A consequence of the wide size distribution is the production of three groups of fish: small parr that do not migrate, smolts that emigrate, and large sexually precocious males that residualize. Efforts to achieve size-at-release requirements, the use of demand feeders, and warm water temperatures may all contribute to an increase in the size range. Ultimately, failure of a substantial segment of the population to outmigrate results in competition with wild stocks, and a reduction in numbers of adult returns of both hatchery and wild stocks. In this report, we evaluate the effectiveness of a modified feeding schedule of reduced, intermittent rations on growth and development of steelhead. The goal was to decrease the mean size of Dworshak steelhead and create a period of rapid growth in the spring to stimulate smoltification in fish of all sizes.

Hatchery steelhead have been the subject of numerous studies designed to alter growth rates to achieve size-at-release goals. Bjornn et al. (1978, 1979) conducted extensive studies with steelhead at Dworshak NFH to determine how length at release, date of release, cold water conditioning, fungal infections, saltwater tolerance, and gill sodium, potassium-activated adenosine triphosphatase (Na^+, K^+-ATPase) activity affected seaward emigration, as measured by recapture at Lower Granite Dam and Little Goose Dam. Currently the goal is to release fish at 200 mm total length (TL) with a range of 180-250 mm. Recommended minimum release sizes for hatchery steelhead have been based on studies showing higher recapture rates of larger fish ($\geq$ 190 mm, fork length) after downstream migration over various distances (Tipping et al. 1995). The assumption drawn from these studies, that large size is a critical factor in smoltification, is contradicted by the smaller size of wild steelhead smolt emigrants (Beeman et al. 1990, 1991; Maule et al. 1994; Schrock et al. 1999).

Flow, rather than fish size, has been shown to be the primary predictor of migration rate in steelhead in other studies (Maule et al. 1994; Giorgi et al. 1997), but the mechanism for initiation of migration is still unexplained. Differences in smoltification indices between migrating and nonmigrating salmonids have been found, but in steelhead the timing of migration is not closely associated with changes in smolt indices. A study comparing the physiology of migrating and non-migrating rainbow trout found lower condition factor, plasma thyroxine, muscle and liver glycogen levels, and esterified fatty acid levels, and higher Na^+, K^+-ATPase levels in migrants. However, the peak of Na^+, K^+-ATPase activity in migrants did not correspond to the peak of emigration (Ewing et al. 1994a). Similarly, the timing of migration tendency in hatchery winter steelhead did not coincide with several indices of smoltification, including body silvering and gill Na^+, K^+-ATPase activity (Ewing et al. 1984).

Extensive reviews describe the many environmental variables that may be manipulated to modulate the timing and duration of smoltification (Wedemeyer et al. 1980; Folmar and Dickhoff 1980; Zaugg 1981, 1982; Hoar 1988; Maynard et al. 1995), but few methods are as practical at a large hatchery as feed modification. Some innovative efforts to increase adult returns, such as exercising fish, have been questioned due to the additional labor and expense needed to increase returns by only a small percentage (Evenson and Ewing 1993). Maynard et al. (1995) reviewed culture techniques that improve post-release survival, but did not consider that higher food availability in hatcheries than in the wild could be a factor in poorer post-release performance of hatchery fish.

Studies on the effect of alternative feeding strategies on size variation strongly suggest that the time of year, holding temperature, and even the stock of fish may influence the outcome of feeding trials (Smith 1987; Kindschi 1988; Klontz et al. 1991). Fish fed continuously on reduced rations showed greater size variation than intermittently-fed fish, but continuously-fed fish had the best feed conversion efficiency (Kindschi 1988). In that study, fish on the longest period of alternating four-week periods of starvation and feeding showed the least variation in length and weight. After return to full rations, compensatory growth allowed the starved fish to recover weight, although they were smaller at release than control fish. Another study investigated intermittent and reduced feeding schedules to prevent the production of large fish, alternating seven days of feeding with up to ten days of no feeding, to reduce growth of steelhead reared at 59º F (15º C) (Klontz et al. 1991). Feed reduction resulted in reduced final length and weight, but the percent reduction in length and weight did not correspond to the percent reduction in feeding intensity. A difference in size variation was not seen among the different feeding schedules. Reductions in feed to 50% of normal rations, regardless if fed continuously or intermittently, were found to reduce weight gain and to control the production of large fish that might residualize (Smith 1987). Fish size may also influence the relation between ration and growth: gross food conversion efficiency or food consumption decreases as ration increases in large fish. Demand feeding of steelhead allowed larger fish to feed to satiation, and if enough feed was available, smaller fish then fed (Wurtsbaugh and Davis 1977).

Several feeding studies have been conducted to investigate the effects of diet composition, ration rate, feeding frequency, and method of feeding on growth rates and smolt development in steelhead. Increased migration rates have been noted in steelhead fed reduced rations during the last month of hatchery rearing, but results differed at two study sites (Tipping and Byrne 1996). The study fish were smaller measured by both length and weight, and had lower condition factors than control fish but migration rates and recapture rates were higher in the treatment fish. Salmonids generally show reduced feeding levels and condition factor as they undergo the parr-smolt transformation, but other developmental changes--beyond the reduction in weight that affects condition factor--are necessary for smolt development. Only recently has manipulation of growth rate been investigated as a method of accelerating smoltification. Beckman et al. (1998), using temperature to control growth of spring chinook salmon (*O. tshawytscha*), reported that fish with higher spring growth rates emigrated earlier than fish with lower growth rates. The observation that steelhead may exhibit compensatory growth after periods of starvation, resulting in a higher size-specific growth rate than control fish after a return to normal ration levels (Dobson and Holmes 1984), was applied to our study as a method of enhancing smoltification.

Manipulation of diets, rations, or feeding regimes may negatively affect physiological processes that occur during the parr-smolt transformation. The lipid composition of steelhead is known to change during smoltification, with a decrease in total body lipids and changes in lipid classes found in specific tissues (Sheridan et al. 1983). Both diet and fasting may influence stress response and associated physiological responses, such as hyperglycemia in spring chinook salmon (Barton et al. 1988). Stress and its physiological consequences must be considered when altering feeding regimes of fish that may later be transported or face a long migration route. Fasting salmonids show negative effects such as increased mortality in as little as two weeks. After longer periods of starvation, mortality may continue, and survivors do not reach the size of controls even after a return to feed (Bilton and Robins 1973). However, in that study, sockeye salmon (*O. nerka*) starved for 1 to 3 weeks were able to compensate by utilizing feed more efficiently when presented with feed, and to reach the size of controls after return to full rations. Reduced, intermittent feed schedules are advantageous in that they control growth without the negative effects of extended fasting.

The goal of this study was to determine whether altered growth patterns could enhance smolt development in a wider size range of fish, especially smaller fish, while preventing production of large fish that are known to residualize. We attempted to reproduce growth patterns found in Dworshak steelhead during years when the stock had limited its own feed intake, resulting in release of small fish, but adult returns from the release were high. High adult returns from fish released smaller than size-at-release goals suggests that large size is not a prerequisite for smoltification. Our objectives were to: 1) reduce the length range while shifting the mode of lengths toward smaller sizes, and 2) increase the number of fish that migrate by promoting smoltification in a wider size range of fish, especially smaller fish. Wild steelhead were used as the model: wild migrating fish are smaller than hatchery fish, and feed availability in the wild during winter is lower than in the spring. Our study differs from other steelhead production studies in its use of the hatchery's monthly inventory records from the previous ten years (1986-1996) to design the modified feeding schedule. The minimum specific growth rate (by length and weight) for each month was determined from hatchery records, and ration amounts consumed during periods of minimal growth were chosen as the reference rates for the study. The stock- and site-specific study design allowed testing at the production level as a model for future hatchery applications.

METHODS

Experimental Fish

Dworshak NFH B-run summer steelhead progeny from the April spawning take 12, brood year 1997 (BY97) were used for the experiment. Fish were reared under routine hatchery production practices. Eggs were incubated in Heath trays until transfer to nursery tanks in May. In August 1997, fish were stocked at 95 to 100 fish per pound (~28,500 fish per raceway) into outdoor Burrows ponds in water reuse System II. The modified feeding schedule treatment group (MFS) and the production control group (CON) were each reared in duplicate ponds for a total of 4 Burrows ponds in System II. The density index was 0.1 on November 1, 1997. All ponds were supplied with ambient river water on a single-pass system until November 19, 1997, when System II ponds were put on reuse water. The following day fish were treated with formalin. Fish were held in the same raceways throughout the experiment.

On April 24, 1998, prior to release of fish from the hatchery, approximately 75 fish from each of the treatment and control ponds were transferred to the seawater rearing facilities at the Marrowstone Marine Station (MMS) in Puget Sound, Washington. The remaining fish in the raceways were released directly from the hatchery on April 29, 1998, when the entire System II production release occurred.

Feeding Methods and Calculations

Fish were hand-fed BioDiet Grower (2.5-mm feed) from the time of ponding until November 11, 1997. At that time, the fish were converted from hand feeding to Babington demand feeders, and were converted from BioDiet Grower to Nelson's Silver Cup steelhead diet (heat-extruded dry feed). Demand feeders were located at both ends of each pond, and were kept constantly full as per routine practice. Fish size at that time was about 25 fish per pound. The reduced ration, intermittent feeding period for the MFS fish (Burrows Ponds 16 and 18) began on November 26, 1997, while control fish (BP20 and 22) continued on full production rations.

The feeding rates for the MFS group were determined from hatchery MIS records for the System II production group for the years 1987-1996, using the following measurements: 1) total number of fish, 2) mean weight of fish, calculated from the number per pound, and 3) amount of feed fed. Monthly specific growth rates in length and weight were calculated for the ten-year period and were converted to percent per day ($\% \cdot day^{-1}$) (Figures 1 and 2; Appendices 1 and 2). Release years 1988 (BY87) and 1990 (BY89) were used as growth rate reference years based on the release of small fish compared to other years, and higher adult returns (Appendix 3). Monthly feed consumption rates were calculated (Table 1) for the previous ten years.

Based on the small fish size at release and mean temperatures of 52º F (11º C) for December and January 1993, the feeding rates for BY91 fish were selected as our goal, to achieve growth rates approximately half of that seen in other years. The two ponds designated for modified feeding (Ponds 16 and 18) were put on rations of 0.25 g feed $\cdot$ g $fish^{-1}$ per month based on the mean weight of fish from the November 1997 MIS (27 fish $\cdot$ lb^{-1}, 16.8g). Using the estimated number of fish in each MFS pond, the monthly ration for each pond was determined, and weekly rations calculated. For modified ration ponds, demand feeders were loaded on Monday, Wednesday, and Friday with one third of the calculated weekly ration. Monthly rations were recalculated for January based on the MIS mean fish weight on January 1, 1998. Pond 16 received a total of 528 lbs of feed from November 26 to December 31, and 561 lbs from January 1 to February 9; Pond 18 received 512 lbs and 544 lbs during the same time periods. On February 10, fish on the modified feed schedule were put back on full production rations.

Table 1. Consumption of grams of feed per gram fish for Dworshak National Fish Hatchery System II steelhead from 1987 to 1998 calculated from the Monthly Inventory Summaries.

Brood Year	Release Year	Dec	Jan	Feb	Mar
1987	1988	0.36	0.33		0.20
1988	1989	0.27	0.22	0.19	0.15
1989	1990	0.62	0.57	0.44	0.36
1990	1991	0.48	0.43	0.38	0.33
1991	1992	0.47	0.47	0.38	0.28
1992	1993	0.31	0.21	0.22	0.26
1993	1994	0.29	0.38	0.50	0.47
1994	1995	0.31	0.47	0.20	0.35
1995	1996	0.28	0.38	0.28	0.36
1996	1997	0.50	0.32	0.21	0.08

Table 2. Mean monthly temperatures (Celsius) at Dworshak National Fish Hatchery during 1986 – 1996. Derived from the Monthly Inventory Summaries.

Year	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
1986-87					12.5	12.4		10.4	5.6
1987-88	11.5	11.5	12.1		12.2	9.4	8.9	7.8	5.6
1988-89			11.9		12.3	12.2	12.4	12.8	11.1
1989-90	11.7	11.1	11.9		12.2	12.2	12.3	12.9	8.4
1990-91	8.2	9.8	11.9		11.9	12.2	12.3	12.2	9.3
1991-92		7.6	11.8		11.2	10.6	9.9	10.5	8.2
1992-93	12.2	11.9	11.7		12.7	8.7	8.7	12.4	11.0
1993-94	10.0	11.0	11.4		10.3	12.2	12.2	12.5	7.9
1994-95	11.7	12.2	10.6		12.2	12.3	12.1	12.3	7.3
1995-96		12.7	12.0		12.1	12.2	8.7	4.4	4.4

Table 3. Mean monthly temperatures (Fahrenheit) at Dworshak National Fish Hatchery during 1986 – 1996. Derived from the Monthly Inventory Summaries.

Year	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
1986-87					54.5	54.4		50.8	42.1
1987-88	52.7	52.7	53.7		53.9	49.0	48.0	46.0	42.0
1988-89			53.4		54.1	54.0	54.4	55.0	52.0
1989-90	53.1	52.0	53.5		54.0	54.0	54.2	53.5	47.1
1990-91	46.8	49.6	53.3		53.5	54.0	54.2	54.0	48.7
1991-92		45.7	53.2		52.2	51.0	49.9	50.9	46.7
1992-93	54.0	53.5	53.1		54.8	47.7	53.9	54.3	51.9
1993-94	50.0	51.7	52.6		50.6	54.0	53.9	54.5	46.3
1994-95	53.0	54.0	51.1		54.0	54.2	53.8	54.0	45.2
1995-96		54.8	53.6		53.8	54.0	47.6	39.8	39.85

Table 4. Food consumption by summer steelhead in the modified feeding schedule treatment (MFS 16 and 18) and control (CON 20 and 22) ponds at Dworshak National Fish Hatchery, Idaho, based on 100-fish inventories and Monthly Inventory Summaries (MIS).

Month	Pond	Pounds of Feed	Number of Fish	100-Fish Inventory (g feed·g fish^{-1})	100-Fish Inventory Weight of Fish (g)	MIS (g feed·g fish^{-1})	MIS Weight of Fish (g)
December	MFS 16	363	24057	0.26	26.0	0.19	36.0
	MFS 18	352	23126	0.26	26.7	0.19	37.1
	CON 20	520	25801	0.35	26.4	0.35	40.5
	CON 22	380	26487	0.23	27.7	0.43	44.0
January	MFS 16	429	23920	0.23	35.5	0.20	41.6
	MFS 18	416	22980	0.21	39.4	0.19	42.7
	CON 20	600	25656	0.25	43.2	0.24	49.1
	CON 22	800	26371	0.32	42.7	0.32	53.2
March	MFS 16	958	23249	0.32	57.9	0.32	58.2
	MFS 18	958	22050	0.32	61.9	0.32	61.3
	CON 20	958	24904	0.27	65.5	0.27	64.8
	CON 22	958	25885	0.26	65.7	0.23	72.0
April	MFS 16	672	22946	0.17	79.7	0.18	73.2
	MFS 18	672	21625	0.18	80.1	0.17	82.5
	CON 20	672	24506	0.16	78.7	0.16	75.6
	CON 22	672	26388	0.14	83.5	0.14	80.9

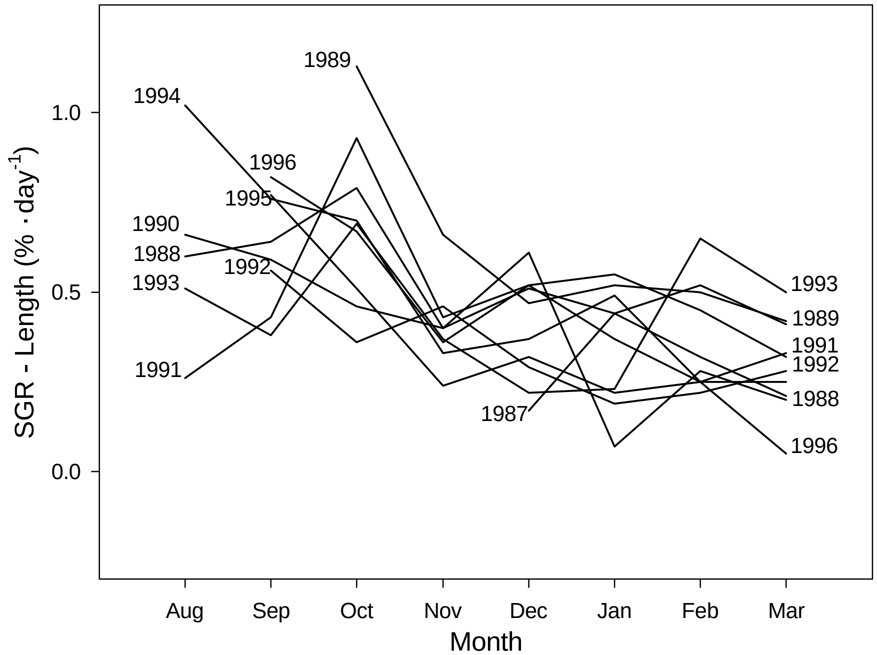

Figure 1. Mean specific growth rate (SGR, % · day^{-1}) in length (mm) of summer steelhead at Dworshak National Fish Hatchery, Idaho, derived from the production Monthly Inventory Summaries, 1987-1996.

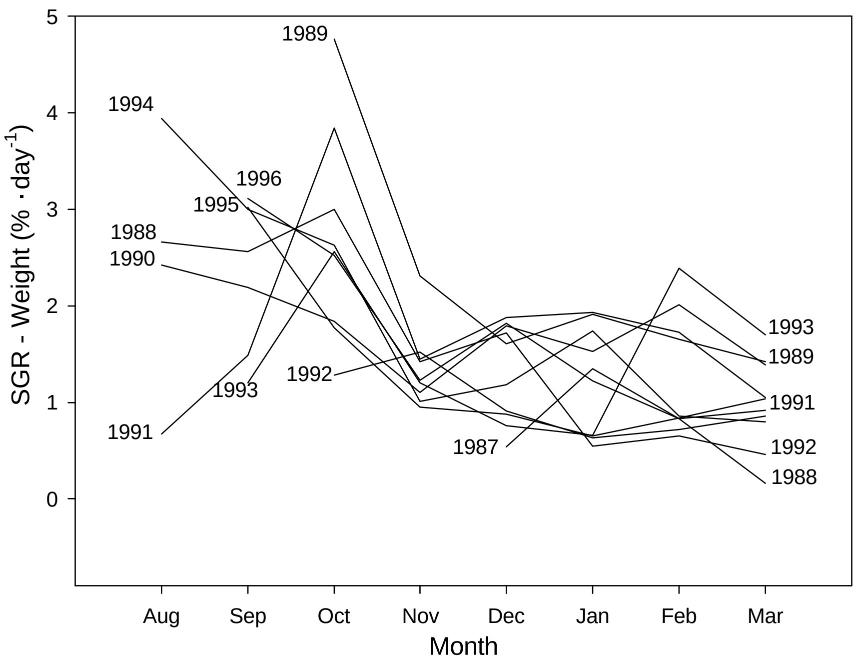

Figure 2. Mean specific growth rate (SGR, % · day^{-1}) in body weight (g) of summer steelhead at Dworshak National Fish Hatchery, Idaho, derived from the production Monthly Inventory Summaries, 1987-1996.

Inventory and Sampling Methods

Three inventory methods were used at the hatchery during the experiment: the production MIS conducted by Dworshak NFH, the 100-fish inventory (HFI) conducted by the Idaho Fishery Resource Office (IFRO), and physiological sampling (PS) conducted by the Columbia River Research Laboratory (CRRL). Length and weight data from both the HFI and PS methods were analyzed and compared to determine sample numbers for further production studies. Results are presented based on monthly HFI data until February, when results for both HFI and PS are presented to allow comparison of results from the two methods. Statistical analyses were conducted on both sets of data.

Dworshak NFH conducted routine monthly inventories on the entire production, including the ponds used in the experiment, and provided us with the MIS records. Sampling consisted of dip-netting a random sample of fish from the pond, taking the total weight of the fish in the net, and counting the number of fish to estimate an average weight per fish. Mortalities collected from each pond were recorded daily.

The IFRO took monthly inventories of approximately 100 fish per pond from October 1, 1997 through release. Fish were measured for total length (mm) and weight (0.1 g).

Physiology samples (n = 20 fish per pond) were collected by CRRL staff at 1-month intervals from February 1998 (when the MFS fish were returned to full rations) until the time of release in April, and at 1 and 3 months after transfer to seawater. The number of fish sampled was limited by the time necessary to collect physiological measurements (see *Physiological Analyses* below). Fish were non-lethally anaesthetized using tricaine methanesulfonate (MS-222) at 80 $mg \cdot L^{-1}$ and were measured for fork length (mm) and weight (g). In order to compare the IFRO length samples with those taken by the CRRL staff, it was necessary to convert total length to fork length based on a calculated regression equation ($r^2 = 0.9926$, $n = 78$).

Physiological Analyses

Physiological assessment of the 20-fish samples included fork length (mm); weight (g); skin reflectance; mucus lysozyme ($\mu g \cdot mL^{-1}$, hen egg white lysozyme standard HEWL); gill ATPase activity ($\mu mol\ P_i \cdot mg\ protein^{-1} \cdot hr^{-1}$); short-wave near-infrared spectroscopy for lipids and protein; total body fat and tissue moisture analysis. Length and weight measurements were used to calculate condition factor (K) as [(weight $\cdot$ length^{-3}) $\cdot$ 10^5]. Gill Na^+, K^+-ATPase activity was assayed by the method described by Schrock et al. (1994).

Skin reflectance was measured with a modification of the technique described by Haner et al. (1995). Results were analyzed and are being reported separately by the IFRO and the Idaho Fish Health Center (IFHC).

Mucus lysozyme was analyzed by a microplate adaptation of Sankaran and Gurnani (1972) and Muona and Soivio (1992) modifications of a turbidimetric method (Litwack (1955). Results will be reported at a later date.

Short-wave, near-infrared readings and analysis for lipids and protein were performed by Eastern Oregon University (EOU) researchers by the method of Lee et al. (1992). Body fat analysis was completed by an acid hydrolysis method (method 948.15)**,** Cunniff (1997). Five fish from each experimental group were frozen and shipped to Washington

State University for chemical analysis. A core sample for analysis was taken from each fish in an area below the lateral line, centered just above the vent to correspond to the area where skin reflectance measurements were made. Moisture content was determined by drying a pre-weighed sample at 212 to 221º F (100 to 105º C) in a drying oven for 17 to 18 hr. All lipid data were reported on a dry weight basis. Tissue samples were analyzed in triplicate if sample size permitted, or in duplicate if inadequate sample was available. Drs. Cavinato (EOU) and Rasco (WSU) will report the combined results.

Transport to Marrowstone Marine Station

Approximately seventy-five fish from each experimental pond were transported in ten 45-gal (170 L) totes to MMS on April 24, 1998 for extended seawater rearing trials. Fish were netted from the raceways, transferred to 15-gal (57 L) totes, moved from the ponds to the truck, and poured into the 3 x 4 x 2.5 foot (0.9 x 1.2 x 0.8 m) transport totes. Each transport tote was equipped with an air stone to provide oxygen during the 12-hr trip. Water temperatures in the totes were maintained between 51.8 and 55.4º F (11 – 13º C) with ice. Both oxygen and temperature were monitored during transport. Four fish died when they were either washed out of the covered totes or suffocated in the plastic tote liners. Upon arrival at the facility, the fish were netted and transferred by bucket to separate circular tanks supplied with 55.4º F (13º C) freshwater.

Seawater Rearing

At MMS, fish were transferred to 480 gal (1820 L) tanks and allowed to acclimate in freshwater for three days. On May 3, conversion to seawater was initiated. Fish were held at 1/3 seawater for two days (9.5 ppt salinity), 2/3 seawater for two days (19.0 ppt salinity), and were converted to full strength seawater (27.0 to 29.5 ppt salinity) on May 7th. Different salinities were reached by controlling the flow of both freshwater and seawater to the experimental tanks. Fish were maintained at an average flow of 3 gpm (11 Lpm) with a temperature range of 50.0 to 54.5° F (10.0 – 12.5 º C) throughout the rearing period (April 25 to August 5). After conversion to seawater was completed, temperature and salinity in the tanks were ambient ocean conditions and were monitored daily.

Fish were fed ad libitum (to satiation) once daily. Feed was kept in a separate container for each tank. An initial feed weight was recorded and determined again at the end of each seven-day period to determine total weekly consumption. Mortalities were removed and recorded daily, measured for fork length and placed in appropriately labeled bag and stored in the freezer. Tanks were cleaned every two weeks or as needed. Separate brushes and nets were used for each tank.

An initial length and weight inventory was made of all fish on April 25. Tank length and weight inventories were conducted monthly during the seawater rearing period, after collection of the physiology samples in June and August.

In-River Migration and Survival

To measure migration rate, estimate survival during migration, and assess smolt development after release, 400 fish from one replicate treatment pond and one control pond were marked with PIT-tags (800 total) on April 22, 1998. To determine the effect of fish size, PIT-tags were injected into 200 small fish ($\leq$ 200 mm TL) and 200 large fish (> 200 mm) from each pond. Migration time was measured to Lower Granite, Little Goose, and Lower Monumental dams on the lower Snake River, and McNary Dam on the Columbia River. Survival to Lower Granite Dam during migration was estimated using the cumulative number of unique interrogations at each of the four dams. To compare smolt development before and after release, PIT-tagged fish from the study were recaptured in the National Marine Fisheries Service (NMFS) interrogation-by-code facilities at Little Goose Dam, and gill tissue was collected to determine Na^+, K^+-ATPase activity for comparison with pre-release activity levels.

Statistical Analysis

Statistical analysis was performed using SAS version 6.0. General linear model (GLM) tests and two sample t-tests were performed between replicate MFS groups (ponds 16 and 18) and replicate control groups (ponds 20 and 22). Tests were conducted by month comparing fork length (mm), weight (g), and condition factor. Gill Na^+, K^+-ATPase activities were analyzed for the 20 fish physiological samples. GLM analysis was used rather than analysis of variance (ANOVA) because of unequal sample sizes. It was determined that the replicate MFS groups and replicate control groups were not significantly different ($P < 0.05$); therefore the results were pooled to increase sample sizes. Pooled MFS and pooled control samples were then compared to each other, again using two sample *t*-test and GLM tests by month evaluating fork length (mm), weight (g), condition factor, and gill Na^+, K^+-ATPase (20 fish physiological samples). A significance level of $P = 0.05$ was used for all statistical tests.

For statistical analysis of results from the PIT-tag information, mean gill ATPase and mean condition factor were compared between treatments and controls (Bonferroni post-hoc procedure) to identify which ponds differed. For PIT-tagged steelhead recaptured at Little Goose Dam, mean gill ATPase was compared between the treatment and control groups using a two-sample *t*-test (Wilkinson, 1990). Mean migration rates were compared between treatments and controls using a chi-square test for differences in probabilities (Conover, 1971). A *P*-value of 0.05 was used to test for statistical significance.

RESULTS

Growth, Condition Factor, and ATPase

A statistically significant difference was seen between the mean fork lengths of treatment (MFS) and control (CON) fish one month after the modified feeding schedule began ($P < 0.05$), as measured by the HFI in January (Figure 3). The significant difference persisted and was measured in both the HFI and PS methods in February (Figure 3 and 4). Mean fork length data from the HFI and PS inventories are combined in Figure 5 to demonstrate differences in results from the two sampling methods. Significant differences were also seen between weights of the two groups (Figures 6 and 7), and combined results are presented in Figure 8. Mean lengths and weights did not differ between groups at the time of release (Figures 3 to 8).

During the first month after conversion back to production rations (March), the mean specific growth rate was much higher in the MFS than CON group, by both length (Figure 9) and weight (Figure 10).

A significant difference in condition factor was found between the MFS and CON groups in the first inventory after ponding (Figure 11), but the difference did not persist, and was attributed to measurement error due to the small size of fish (95-100 fish $\cdot lbs^{-1}$, ~4.6 grams) at the time of ponding. After treatment ponds were placed on the modified feeding schedule in late November, a significant difference in condition factor was seen between treatment and control groups ($P < 0.05$) at the next inventory, and the difference persisted until March (Figure 11). At the time of release, the difference in condition factor between the MFS and CON groups, as measured by the HFI, was negligible. However, there was a significant difference in condition factor between groups sampled for physiology (PS) in March and at the time of transfer to seawater (Figure 12). Between March and the time of release in April, both MFS and CON fish showed a decline in condition factor, although timing of the decrease differed between the two groups.

Gill Na^+, K^+-ATPase was monitored beginning February 12, 1998, during physiology sampling (n = 20). No significant differences in ATPase activity between the MFS and CON groups were found throughout the study (Figure 13). In both groups, mean ATPase values remained low in fresh water (< 5 μmol $P_i \cdot$ mg $protein^{-1} \cdot hr^{-1}$), but increased dramatically after transfer to seawater (~23 μmol $P_i \cdot$ mg $protein^{-1} \cdot hr^{-1}$ on June 1).

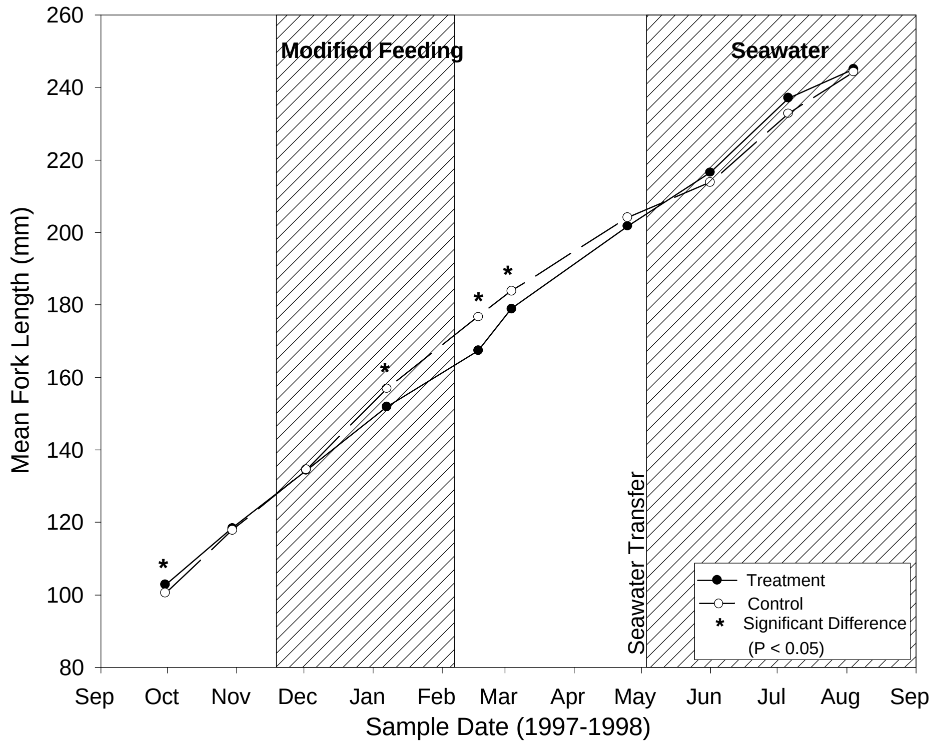

Figure 3. Mean fork length (mm) of summer steelhead in the modified feeding schedule treatment (MFS 16 and 18) and control (CON 20 and 22) groups at Dworshak National Fish Hatchery, Idaho, based on 100-fish and tank inventories at Marrowstone Marine Station, Washington.

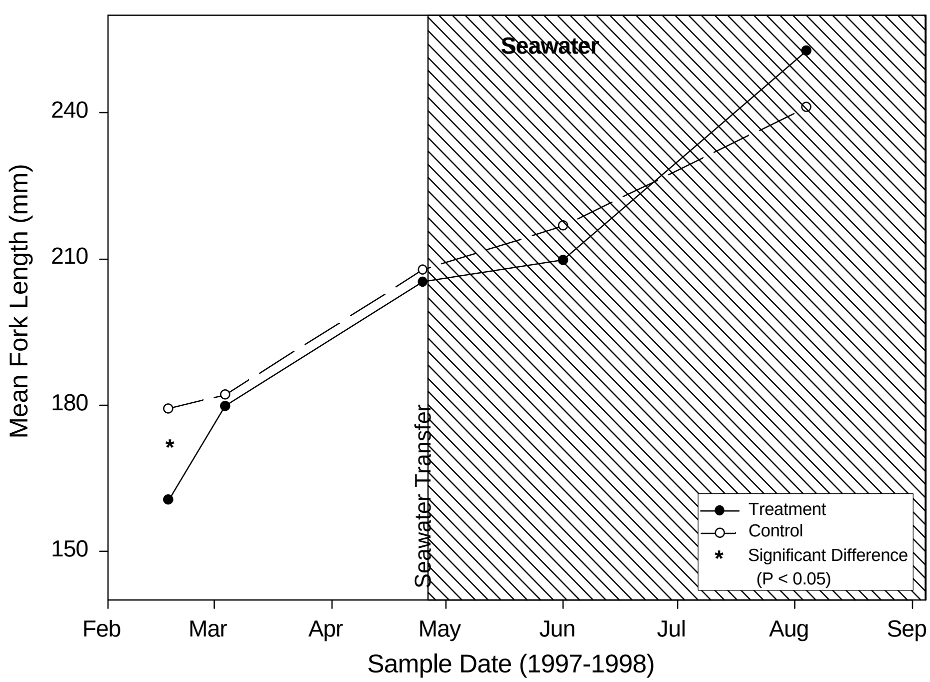

Figure 4. Mean fork length (mm) of summer steelhead in the modified feeding schedule treatment (MFS 16 and 18) and control (CON 20 and 22) groups at Dworshak National Fish Hatchery, Idaho, based on 20-fish physiology samples.

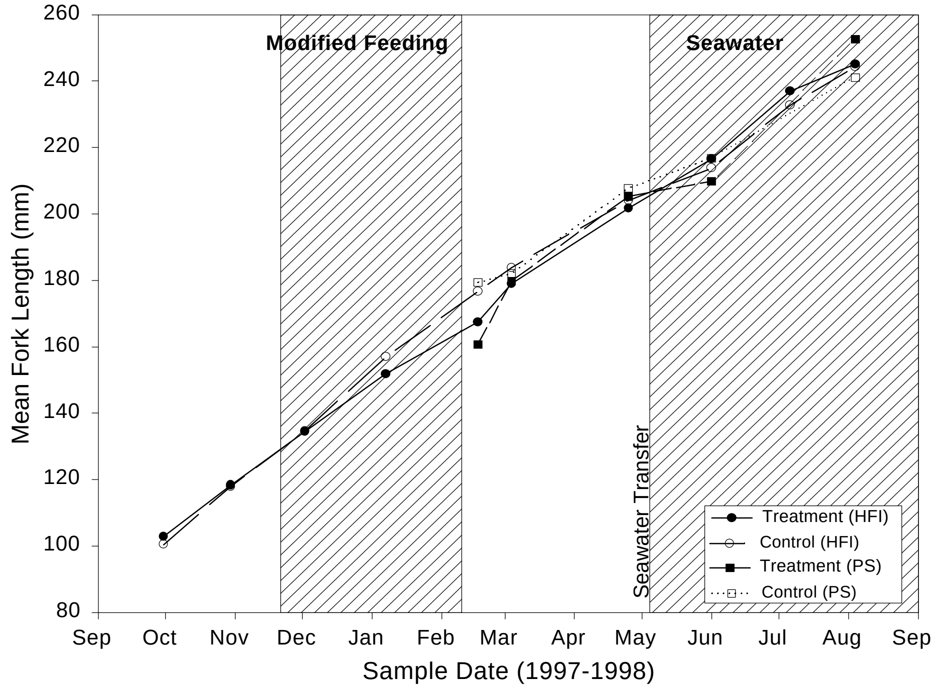

Figure 5. Mean fork length (mm) of summer steelhead in the modified feeding schedule treatment (MFS 16 and 18) and control (CON 20 and 22) groups at Dworshak National Fish Hatchery, Idaho, based on 100-fish and tank inventories at Marrowstone Marine Station, Washington (HFI) and 20-fish physiology samples (PS).

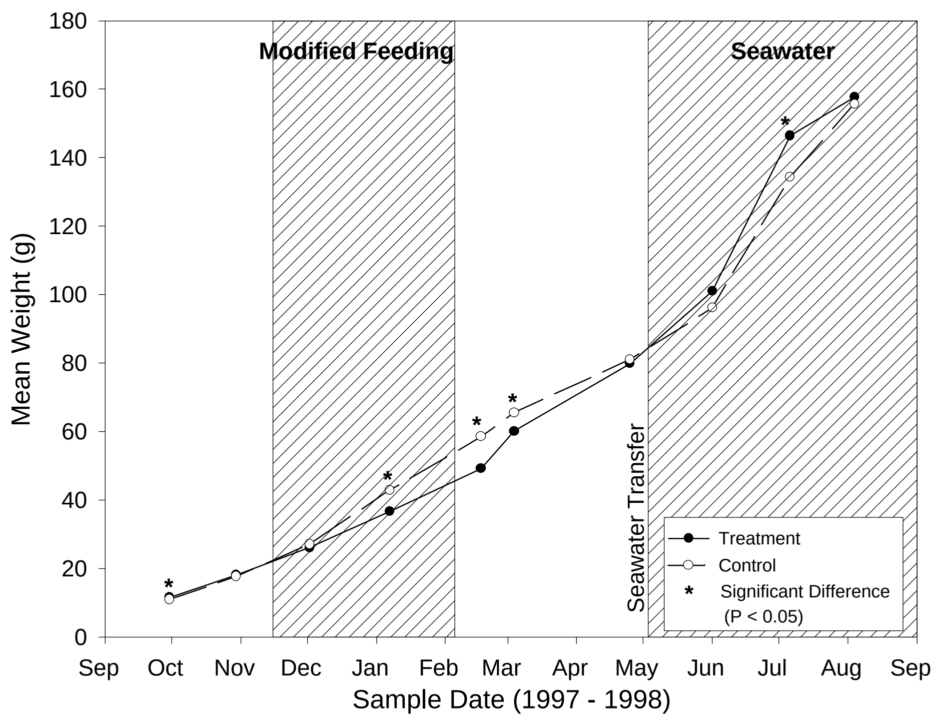

Figure 6. Mean weight (g) of summer steelhead in the modified feeding schedule treatment (MFS 16 and 18) and control (CON 20 and 22) groups at Dworshak National Fish Hatchery, Idaho, based on 100-fish inventories and tank inventories at Marrowstone Marine Station, Washington.

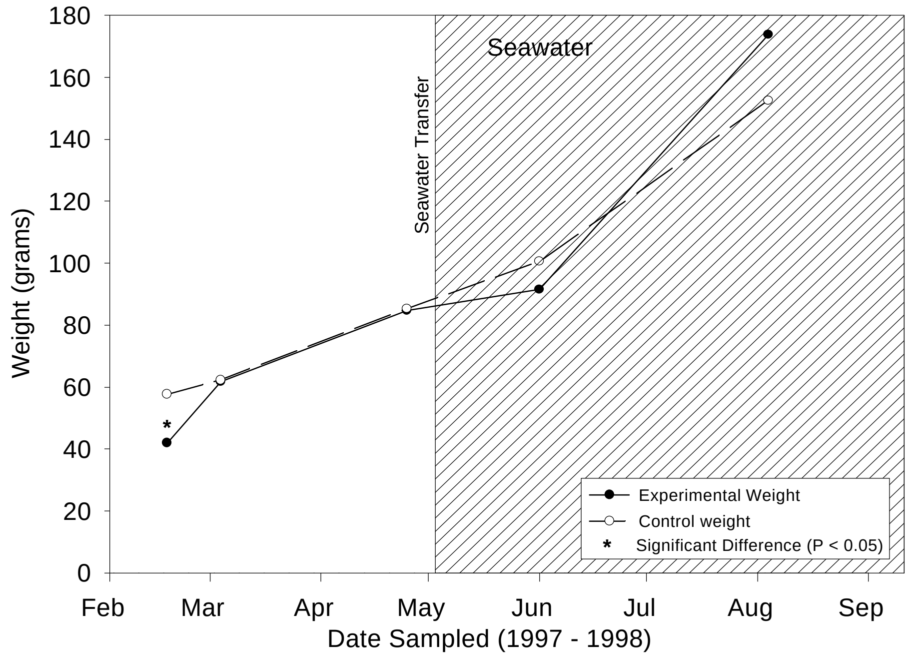

Figure 7. Mean weight (g) of summer steelhead in the modified feeding schedule treatment (MFS 16 and 18) and control (CON 20 and 22) groups at Dworshak National Fish Hatchery, Idaho, based on 20-fish physiology samples.

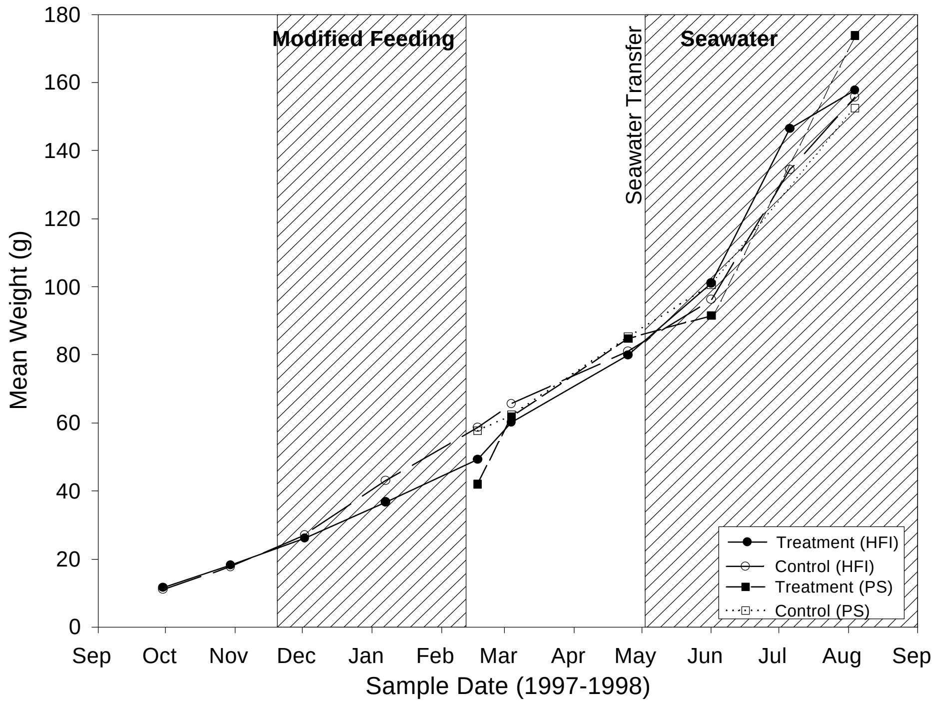

Figure 8. Mean weight (g) of summer steelhead in the modified feeding schedule treatment (MFS 16 and 18) and control (CON 20 and 22) groups at Dworshak National Fish Hatchery, Idaho, based on 100-fish inventories and tank inventories at Marrowstone Marine Station, Washington (HFI) and 20-fish physiology samples (PS).

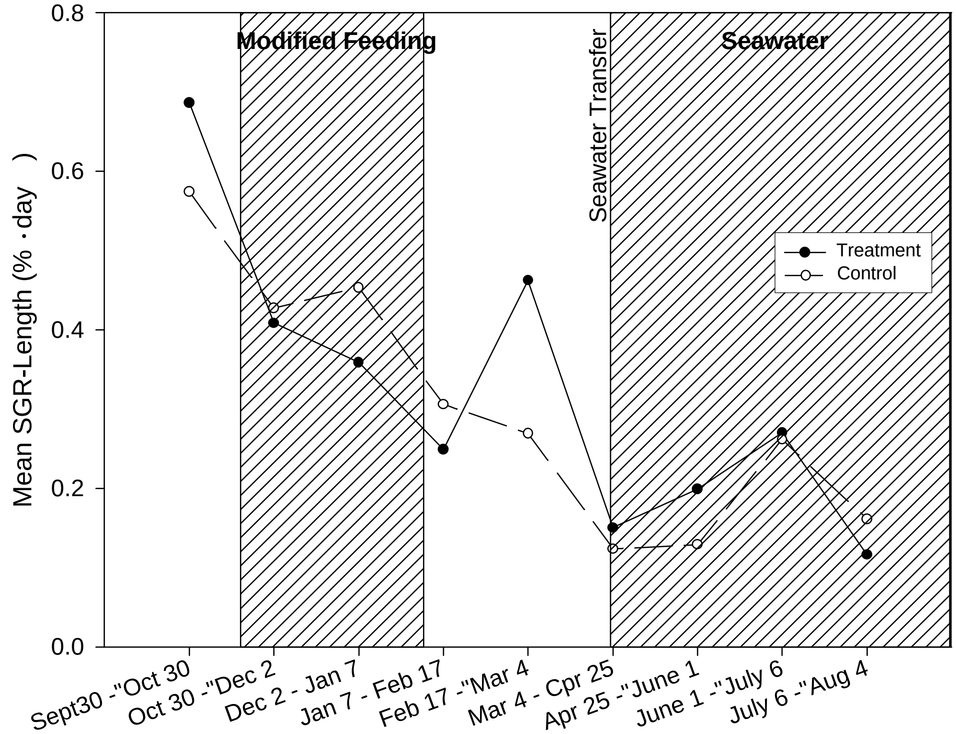

Figure 9. Mean specific growth rate (SGR, % · day $^{-1}$) in fork length (mm) of summer steelhead in the modified feeding schedule treatment (MFS 16 and 18) and control (CON 20 and 22) groups at Dworshak National Fish Hatchery, Idaho, based on 100-fish inventories and tank inventories at Marrowstone Marine Station, Washington.

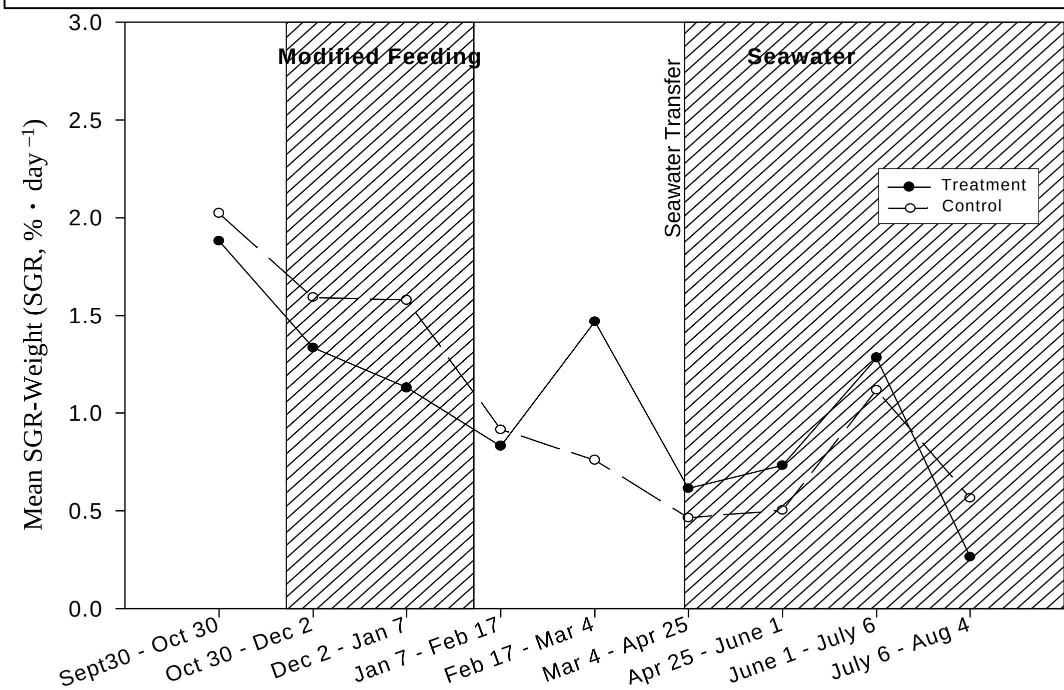

Figure 10. Mean specific growth rate (SGR, % · day $^{-1}$) in body weight (g) of summer steelhead in the modified feeding schedule treatment (MFS 16 and 18) and control (CON 20 and 22) groups at Dworshak National Fish Hatchery, Idaho, based on 100- fish inventories and tank inventories at Marrowstone Marine Station.

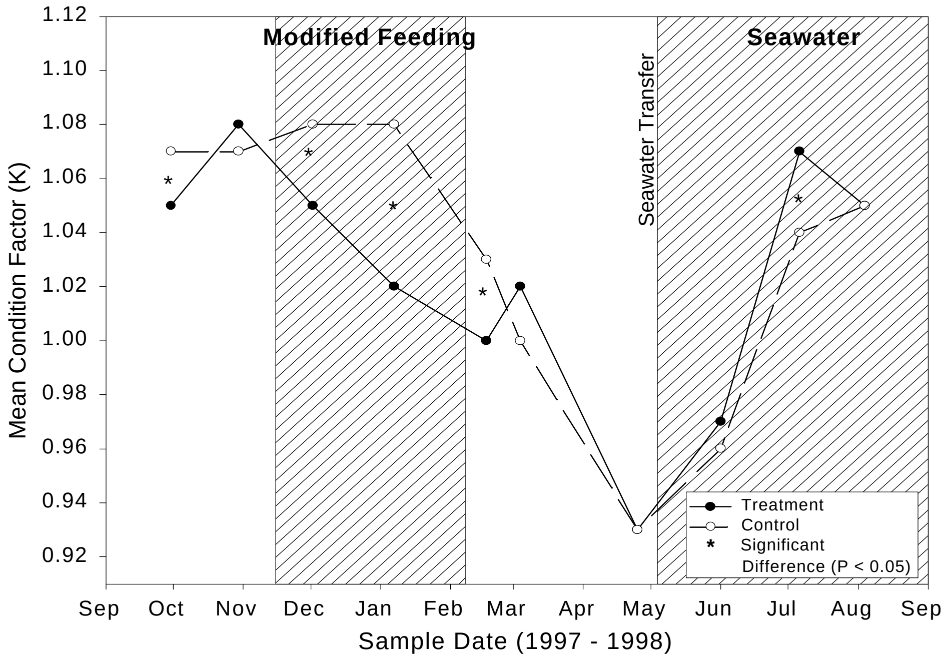

Figure 11. Mean condition factor (K) of summer steelhead in the modified feeding schedule treatment (MFS 16 and 18) and control (CON 20 and 22) groups at Dworshak National Fish Hatchery, Idaho, based on 100-fish inventories and tank inventories at Marrowstone Marine Station, Washington.

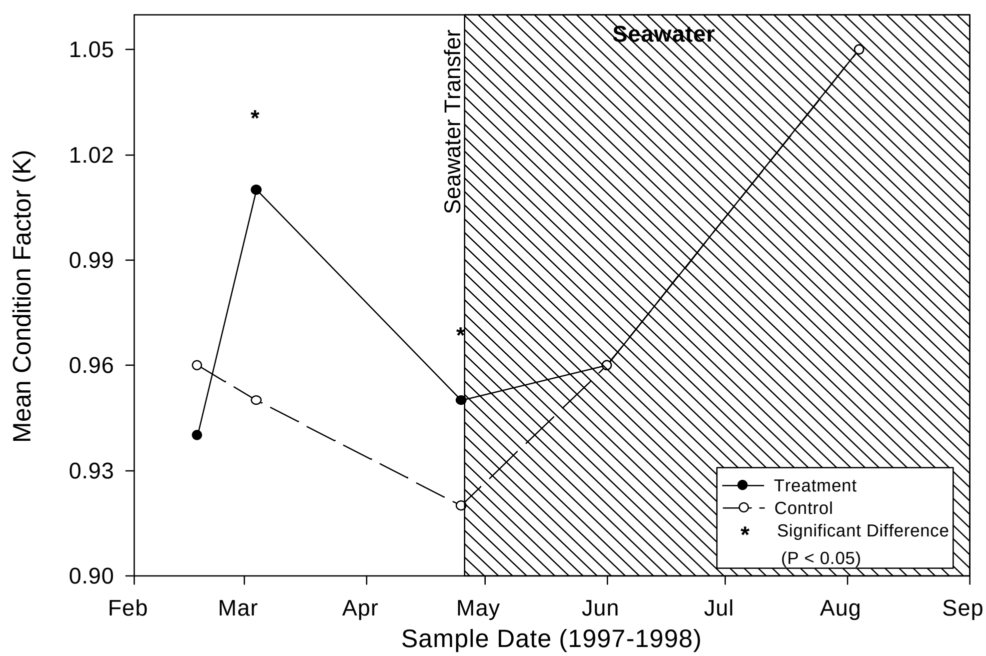

Figure 12. Mean condition factor (K) of summer steelhead in the modified feeding schedule treatment (MFS 16 and 18) and control (CON 20 and 22) groups at Dworshak National Fish Hatchery, Idaho, based on 20-fish physiology samples.

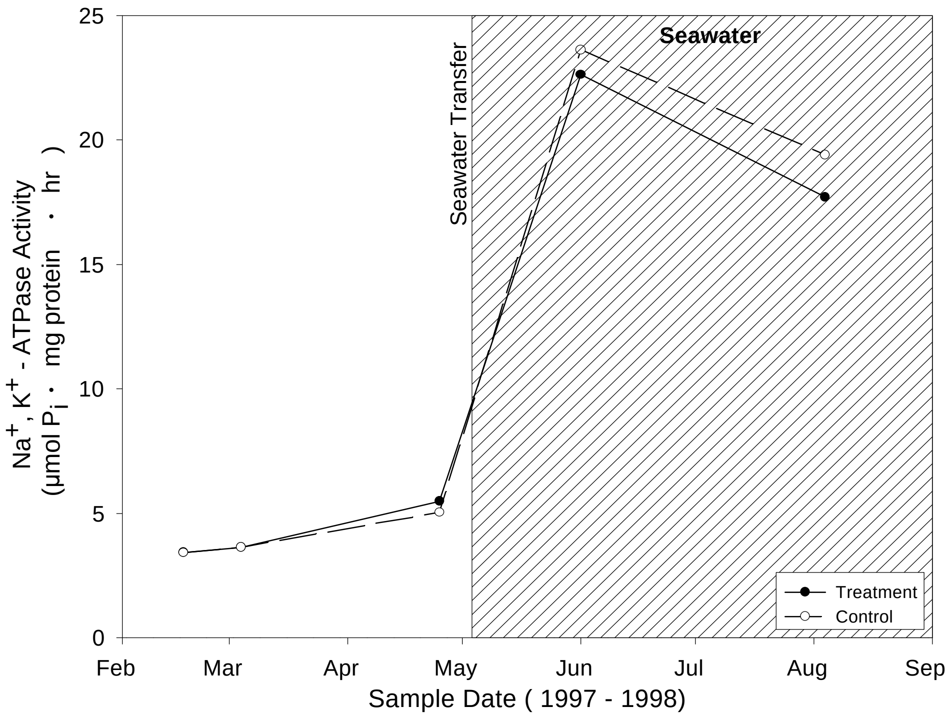

Figure 13. Mean Na^{+}, K^{+} -ATPase activity (μmol P_i · mg $protein^{-1}$ · hr^{-1}) of summer steelhead in the modified feeding schedule treatment (MFS 16 and 18) and control (CON 20 and 22) groups at Dworshak National Fish Hatchery, Idaho.

Feed Consumption

Feed consumption (g feed · g $fish^{-1}$) by System II production fish during the study was low, as determined from the MIS (excluding data from MFS ponds 16 and 18) compared to prior years (Table 1), with the exception of the 1989 release (BY87). Feed consumption by System II production fish was 0.27 g feed · g $fish^{-1}$ per day in December 1997, and decreased to 0.22 g feed · g $fish^{-1}$ in January 1998. Feed consumption for fish in the experiment was calculated using both HFI and MIS data (Table 4). In December, fish on the modified ration schedule consumed an estimated 0.26 or 0.19 g feed · g $fish^{-1}$ based on weights from the HFI and MIS, respectively, and in January consumed 0.19 g feed · g $fish^{-1}$ calculated from both inventory methods. Control fish consumed 0.39 (HFI) or 0.24 (MIS) g feed · g $fish^{-1}$ in December, and 0.28 (HFI) or 0.24 (MIS) g feed · g $fish^{-1}$ in January. Feed consumption by MFS fish was 68 to 79% of feed consumption by CON fish during the same period.

Seawater Performance

Specific growth rates (% · day^{-1}) for the MFS fish were higher than for CON fish for the first two months in seawater, but the difference was not significant (Figure 9 and 10). A significant difference in condition factor in seawater was seen only in the July inventory results (Figure 11), after a disease episode resulted in high mortality in one of the MFS tanks (Figure 14). A presumptive diagnosis of a *Pseudomonas* infection in fish from that tank was made by the IFHC (K. Clemens, personal communication).

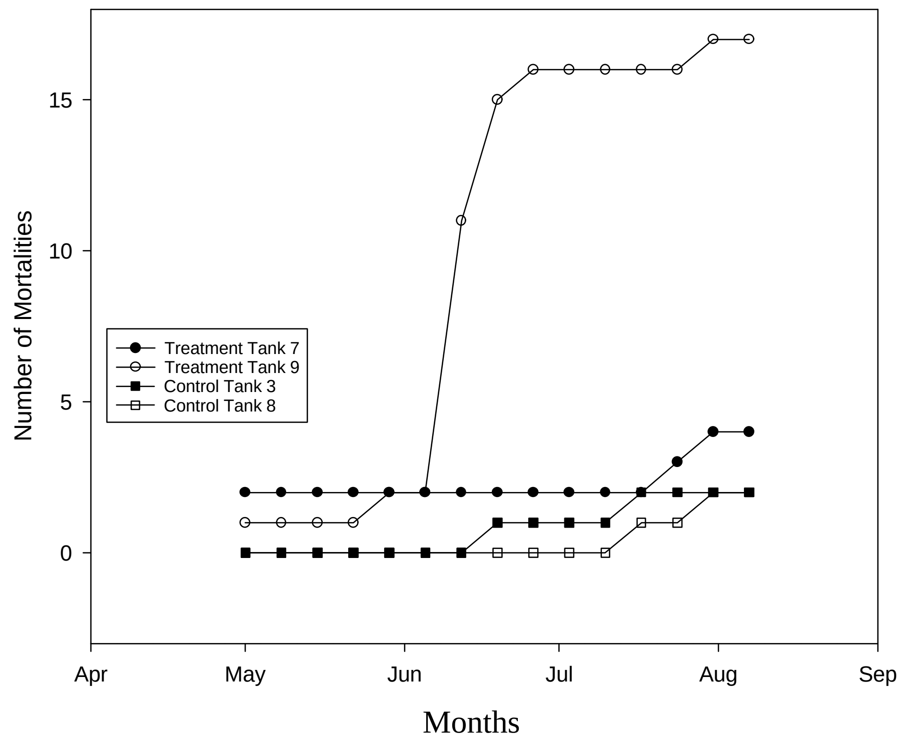

Figure 14. Number of mortalities of summer steelhead in the modified feeding schedule treatment (MFS 16/Tank 7 and 18/Tank 9) and control (CON 20/Tank 3 and 22/Tank 8) groups at Marrowstone Marine Station, Washington.

In-river Migration and Survival

PIT-tag Interrogation Rates. Of the 800 tagged fish, 632 unique interrogations were made, for a recovery rate of 79.0% (Table 5). This interrogation rate was among the highest recorded for Dworshak steelhead, with the exception of the 85 % rate for the 1993 release (Table 6).

The CON smolts were interrogated at a slightly higher rate at downriver dams than MFS smolts, with 81% versus 77%, respectively (Table 5). Large smolts (> 200 mm) had a higher interrogation rate than small smolts ($\leq$ 200 mm) in both the CON and MFS groups. The percent of PIT-tags detected for small and large smolts (MFS and CON groups combined) was 78% and 80%, respectively. Small smolts were detected at a rate of 81% for the CON group and 75% for the MFS group (Table 5).

A comparison of the number of PIT-tag recoveries by 10-mm length groups showed little difference between the MFS and CON groups (Table 7). Generally, those length groups nearest the center of the distribution had the highest rates of interrogation. However, chi-square analysis found no significant difference between the two groups.

Migration Time. Mean migration time to Lower Granite Dam was less than six days, and mean migration time to Lower Monumental Dam was less than 14 days. Only 11 fish were interrogated at McNary Dam (Table 8). Smolts in the MFS treatment group traveled significantly ($P < 0.05$) faster to Lower Granite Dam than smolts in the control group. Small smolts in the MFS treatment group also traveled more quickly to Lower Granite Dam; however, the difference in mean migration time was not significant.

Table 5. Number of small and large steelhead smolts from modified feeding treatment (MFS 16) and control (CON 20) groups at Dworshak National Fish Hatchery, Idaho, that were PIT-tagged, released, and detected at lower Snake and Columbia River dams in 1998.

Treatment Group	Small Smolts[1]			Large Smolts[2]			Total		
	Marked	Detected	%	Marked	Detected	%	Marked	Detected	%
MFS 16	199	149	75	201	159	79	400	308	77
CON 20	200	162	81	200	162	81	400	324	81
Combined	399	311	78	401	321	80	800	632	79

[1] Smolts ≤ 200 mm fork length
[2] Smolts > 200 mm fork length

Table 6. Summary of PIT-tag release and interrogation data for steelhead released from Dworshak National Fish Hatchery, Idaho, and interrogated at lower Snake and Columbia River dams from 1992 through 1997.

Year of Release	Number Released	Number Interrogated	Percent Interrogated
1992	2969	2119	71
1993	1471	1254	85
1994	1468	985	67
1995	5118	3798	74
1996	5088	3321	65
1997	5589	4215	75

Table 7. Number of steelhead that were PIT-tagged and released at Dworshak National Fish Hatchery, Idaho, and interrogated at lower Snake and Columbia River Dams, presented for each 10-mm length group released from MFS 16 and CON 20 in 1998.

Length Group	MFS 16			CON 20		
	No. Released	No. Interrogated	Interrogation Rate	No. Released	No. Interrogated	Interrogation Rate
130	0	0	0.00	1	0	0.00
140	4	1	0.25	1	1	1.00
150	3	1	0.33	3	3	1.00
160	7	5	0.71	7	3	0.43
170	8	5	0.62	4	3	0.75
180	29	24	0.83	22	17	0.77
190	62	50	0.81	51	44	0.86
200	86	63	0.73	111	90	0.82
210	95	77	0.81	100	79	0.79
220	63	47	0.74	55	43	0.78
230	31	26	0.84	36	31	0.86
240	10	8	0.80	8	8	1.00
250	1	1	1.00	1	1	1.00
260	1	0	0.00	0	0	0.00

Table 8. Mean migration time of small and large steelhead smolts from treatment pond 16 and control pond 20 at Dworshak National Fish Hatchery that were PIT-tagged, released, and detected at lower Snake and Columbia River dams in 1998.

Dam Site	Experimental Group	Mean Migration Time (days)		
		Small Smolts[1]	Large Smolts[2]	Combined
Lower Granite	MFS 16	4.6	5.2	4.9
	CON 20	6.1	5.1	5.6
Little Goose	MFS 16	9.1	7.7	8.4
	CON 20	11.2	8.1	9.1
Lower Monumental	MFS 16	11.8	11.4	11.6
	CON 20	14.1	12.0	13.2
McNary	MFS 16	13.9	12.5	13.0
	CON 20	13.0	21.0	17.0

[1] Smolts < 200 mm fork length
[2] Smolts > 200 mm fork length

DISCUSSION

Interactions between hatchery and wild fish are a concern as more species are listed under the Endangered Species Act. Potential interactions include displacement, competition for food, and behavioral effects (Viola and Schuck 1995, McMichael et al. 1997). The wide length frequency distribution of Dworshak National Fish Hatchery summer steelhead at the time of release results in both large and small fish that residualize and are found in tributaries after release (Bigelow 1995, 1997). Reducing the number of hatchery fish that may residualize and interact negatively with endangered Snake River fall, spring and summer chinook and threatened steelhead has become a priority as wild stocks reach critically low numbers. Feeding studies offer an efficient and cost saving method of regulating growth in hatchery fish to control the rate of development and size at release. This study is unique in its application of extended stock specific feeding, growth, and temperature profiles to feeding regimen design, to manipulate growth to promote outmigration in a larger proportion of Dworshak steelhead.

Growth

A reduction in growth was seen after one month in the fish fed reduced rations, as indicated by significantly lower mean length and weight in the MFS fish from January through March (Figures 3 and 6). Slower growth during periods of reduced, intermittent feeding has been demonstrated in other studies (Klontz et al. 1991). During the period of reduced ration, fish of the MFS treatment emptied the demand feeders on the day they were filled, resulting in 1-day fasting periods (Tuesday and Thursday) and 2-day fasts on the weekends. The periods of fasting in our study were short compared to a previous study where fish reached a non-feeding mode after extended periods of fasting (Smith 1987). Dobson and Holmes (1984) found that compensatory growth in rainbow trout after longer, 3-wk periods of alternating fasting and feeding was manifested as an increase in length rather than gut fat deposits or water uptake. With conversion back to production rations in February, fish that had been on the reduced, intermittent rations demonstrated compensatory growth and achieved the same mean length and weight in April as control fish (Figures 3 to 8). We noted no detrimental effects on growth or smolt development.

Condition Factor

Mean condition factor was significantly lower in the MFS fish than in controls from December through February. The simultaneous decrease in condition factor of treatment and control groups starting in early January (Figure 11 and 12) has several possible explanations. Reduced feeding was seen in the treatment group, the control group, and the entire System II production group, therefore the length-weight relationship likely reflected this change. This voluntary reduction in feeding might be explained by a disease episode, although none was documented during routine health screenings (K. Clemens, IFHC, personal communication). In previous years, growth rates for Dworshak steelhead decreased in January or February, although in some years the decrease followed an increase in length or weight in December (Figures 1 and 2). However, a reduction in feeding and condition factor may be associated with smoltification (Wedemeyer et al. 1980; Ewing et al. 1984). The concurrent decrease in condition factor in all groups in early winter was too early to be attributed to smoltification that has been documented in the spring in this stock (Beeman et al. 1990, 1991; Maule et al. 1994; Schrock et al. 1999). After full rations were resumed for MFS fish, condition factor increased for a short period in March (Figure 11). This initial increase in condition factor, due to compensatory growth in weight, was followed by a decrease that was likely attributable to smoltification based on timing of the decrease compared with other years (Appendix 12). The decrease in condition factor was seen in both the MFS and CON groups between March and the time of release in April, when gill Na^+, K^+ ATPase levels were also similar between the two groups (Figures 11, 12, and 13).

Condition factor is known to decrease in hatchery fish during the parr-smolt transformation when fish decrease or cease feeding (Wedemeyer et al. 1980; Ewing et al 1984), even when satiation rations are available from demand feeders, as for controls in our study (Figures 11 and 12). Tipping and Byrne (1996) found that reduced rations during the last month of rearing, with a resultant reduction in condition factor, enhanced emigration rates. Treatment fish in our study fed reduced winter rations emigrated more quickly than control fish. We presented reduced rations during periods when fish may voluntarily limit feeding and when decreases in growth rates have not been associated with smoltification (Ewing and Rodgers 1998). The significant reductions in steelhead growth from reduced winter feeding intensity in our study occurred with no negative effects on migration behavior.

Size Range and Smoltification

The unanticipated voluntary reduction of feed consumption in the control group during the winter, coupled with the high compensatory growth in MFS fish during the spring, resulted in treatment and control fish of similar size at release. Our study achieved the intended pattern of growth in treatment fish, reduced growth in December and January followed by accelerated (compensatory) growth prior to release. However, a population of relatively smaller sized fish upon which to test the use of growth modification for enhancement of smoltification was not produced. Control and MFS fish had similar migration rates, seawater performance, and seawater survival, indicating no difference in smolt condition after release. Bigelow (1995, 1997) found that steelhead at Dworshak NFH display a wide length frequency distribution that persists throughout rearing, resulting in a high percentage of fish that residualize. Our results suggest that a reduced ration, intermittent feeding regime that utilizes a longer period of reduced feeding or a more aggressive reduction in rations may further reduce the number of large fish produced that residualize, thereby increasing the proportion that outmigrate. Based on the faster migration rates of fish fed the reduced, intermittent ration, migration rates in a larger proportion of the release may also be increased.

Feed Consumption

The small difference in feeding rates and therefore growth between the experimental groups was evidenced by few differences in physiological or migration performance.

Estimation of the target feed rate from the previous ten years' records did not anticipate the low feeding rate of the production group as a whole. After recalculation of actual feeding rates of both MFS and CON fish from the amount of feed fed and inventory weights of the fish, feed consumption rates in the MFS fish were found to be between 21 and 32% below that of CON fish. When the feed rate of the entire System II production was recalculated for the study period, it was found to be 0.27 and 0.23 g feed · g fish^{-1} during December and January, respectively. These rates were low compared to other years (Table 3), and were near the minimum levels selected for the MFS fish from December and January of 1993, based on fish size and water temperature (Tables 1, 2, and 3). Dworshak NFH steelhead show marked variability in feed consumption rates among months and years which is not always explained by differences in temperatures (Tables 2 and 3). Another factor was that fish from spawning take 12 used for the experiment were larger on average than the System II production fish, based on the Dworshak NFH Monthly Inventory Summaries. It has been shown that maintenance requirements may decrease in larger fish (Brown 1946), but it was not within the scope of this study to determine if the larger size of take 12 fish influenced feed consumption. We did not achieve the reduction in ration of 50% compared to the production fish that would be necessary to produce a significant reduction in growth (Smith 1987).

Seawater Performance

Control and MFS fish demonstrated similar seawater performance. After transfer to seawater, no differences in weight, condition factor, or mortality were found between the treatment groups (Figure 14, Table 4). After 1 month in seawater, both groups had achieved the same level of smoltification as measured by gill Na^+, K^+-ATPase, and ATPase levels remained similar after three months (Figure 13). Fast presmolt growth in the hatchery does not necessarily predict fast seawater growth in hatchery fish, although in steelhead, presmolt growth may explain approximately one-third of the variation in seawater growth (Johnsson et al. 1997). Our results indicated no difference in seawater growth, although the presmolt winter growth patterns differed between treatment and control fish.

The direct transfer of the experimental fish to the seawater facility, eliminating the opportunity for smolt development during in-river migration, was a limitation of the study and must be considered in interpretation of the seawater survival results as an indicator of potential ocean survival after in-river emigration. Survival of all fish after the abrupt transition to seawater, in effect a seawater challenge, demonstrated osmoregulatory competence of both the treatment and control group.

In-river Migration and Survival

Faster migration rates of the MFS fish may be interpreted as an indication of smoltification, when smolt indices such as gill ATPase are too low to distinguish between groups. In our study, the MFS fish arrived approximately 1 to 2 days sooner at the first three detection sites (Lower Granite, Little Goose, and Lower Monumental dams) than control fish, and 4 days sooner at the fourth site (McNary Dam) (Table 8). Larger fish also appeared to migrate slower as the distance from the hatchery increased, as indicated by the longer migration time to McNary Dam. Earlier comparisons of migration performance in wild and hatchery steelhead demonstrated that wild steelhead, smaller in size than their hatchery counterparts, had higher ATPase levels and shorter travel times than hatchery fish (Maule et al. 1994). Previous studies at Dworshak NFH have investigated holding conditions and characteristics of production steelhead that appear to affect seaward emigration (Bjornn et al. 1978, 1979). Size has been found to be an important factor determining emigration in other hatchery steelhead stocks, with fish of large sizes (> 190 mm) migrating at higher rates than small fish (Tipping et al. 1995), but the size comparison of hatchery to wild fish questions that result. A review of hatchery records at Dworshak NFH revealed higher adult returns during years when smaller fish were released from the hatchery (Appendix 3), challenging the advantage of large size.

Bjornn et al. (1978) determined that greater length at release was the single most important factor determining recapture at dams, yet even small fish conditioned in cold water prior to an early release, as in our study, were recaptured in large numbers. A review of data from that study shows that among fish released in May, smaller fish were recaptured at higher rates than larger fish. Tipping and Byrne (1996) also found that smaller fish were recaptured at higher rates than larger fish in a feed reduction study, but had specified a minimum size for fish before the feed reduction was applied. The results of numerous studies of recapture at dams caused us to consider the implications of the effect of size on recapture and possible mechanisms. Recapture rates for fish may depend on several interacting factors, such as size selectivity of dam recapture systems, river conditions such as flow, and physiological, or behavioral differences between fish of the same size on different release dates. During substantially decreased flows in the Snake River in 1977, only 5 to 15% of Dworshak steelhead were recaptured at Lower Granite Dam (Bjornn et al. 1979), rates far below those reported in this study. Therefore future approaches should include volitional or serial releases to determine differences among fish migrating at different times under differing river conditions.

Comparison of Inventory Methods

Results of the HFI for controls, used to monitor production growth, did not alert us to the reduced feeding rate of the System II production group as a whole. New guidelines for inventory procedures for hatchery fish should be incorporated into future production studies (Ewing et al. 1998). Discrepancies between results as calculated from the inventory or physiology samples may be explained by differences in sample size and the level of variation among individuals. By all measurements, reduced ration fish were the same size at release as the control fish, and showed the same acclimation, growth rate and smolt development after seawater transfer. Comparison of the three sources (MIS, HFI, PS) of measurements for length, weight, condition factor, and specific growth rate reveal that evaluations of production fish must provide appropriate sampling methods. Ewing et al. (1994b) found that variability in fish size affected the minimum error associated with estimates of fish size, and errors of 2 to 5% are expected. In that study, seven to nine random samples from a raceway were recommended to reduce error. Our study results indicate that sample sizes for physiological indices should be increased. Furthermore, HFI results did not duplicate MIS-calculated estimates of length and weight during the months of the study. We will continue to evaluate discrepancies between different sampling methods and sample sizes to determine appropriate methods for future production studies.

Conclusions

Hatchery production records provided the information necessary to design a study to achieve a reduced growth pattern in winter, and to produce fish physiologically comparable, at the time of release, to those on full production rations. Compensatory growth allowed the modified feeding schedule fish to reach the same size at release as control fish. Migration rates were enhanced in smaller fish in the modified feeding treatment group. Performance during seawater rearing, as measured by growth rates and gill ATPase, was similar in both the treatment and control groups. Future trials will include longer periods of reduced ration and intermittent feeding, with the goal of producing smaller fish in the treatment group. This will allow us to determine if hatchery fish can smolt at the same size as wild fish. Results of our study indicate that calculations of rations based on stock specific feeding rates, growth rates, and holding conditions provides the potential benefits of prevention of overfeeding and reductions in feed costs.

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APPENDICES

Appendix 1. Mean specific growth rate (SGR, % · day^{-1}) in length (mm) of summer steelhead at Dworshak National Fish Hatchery, Idaho, based on the Monthly Inventory Summaries, 1986-1996.

Brood Year	Mean SGR-Length (% · day^{-1})							
	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
1987					0.17	0.44	0.32	0.21
1988	0.62	0.64	0.79	0.40	0.61	0.07	0.28	0.20
1989				0.66	0.30	0.70	0.50	0.42
1990	0.66	0.61	0.54	0.34	0.51	0.44	0.58	0.41
1991		0.45	0.93	0.44	0.52	0.55	0.50	0.32
1992			0.36	0.46	0.29	0.19	0.22	0.28
1993		0.38	0.69	0.37	0.22	0.23	0.65	0.50
1994	1.02	0.76	0.70	0.32	0.37	0.49	0.25	0.25
1995		0.77	0.51	0.30	0.26	0.22	0.25	0.33
1996		0.82	0.67	0.36	0.52	0.37	0.25	0.05

Appendix 2. Mean specific growth rate (SGR, % · day^{-1}) in weight (g) of summer steelhead at Dworshak National Fish Hatchery, Idaho, based on the Monthly Inventory Summaries, 1986-1996.

Brood Year	Mean SGR-Weight (% · day^{-1})							
	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
1987					0.60	1.17	0.94	0.90
1988	2.64	2.56	2.96	1.43	1.73	0.55	0.65	0.47
1989				2.34	1.56	1.91	1.65	1.42
1990	2.41	2.16	1.82	1.11	1.77	1.53	2.01	1.39
1991		1.58	3.73	1.46	1.89	1.94	1.73	1.05
1992			1.26	1.52	0.91	0.62	0.72	0.89
1993		1.15	2.58	1.21	0.74	0.67	2.37	1.70
1994	4.21	3.00	2.58	1.03	1.19	1.72	0.86	0.80
1995		3.01	1.76	0.96	0.87	0.65	0.84	1.05
1996		3.04	2.53	1.24	1.82	1.22	0.83	0.16

Appendix 3. Mean total length (mm) and weight (g) at release and adult returns for Dworshak National Fish Hatchery summer steelhead *(Oncorhynchus mykiss)* from coded wire tag rack returns at Dworshak National Fish Hatchery, 1986-1997.

Brood Year	Release Year	Release Total Length (mm)	Release Weight (g)	Recovery Year	Return Rates
1986	1987			1990	.393
1987	1988	187	64.8	1991	.318
1988	1989	213	91.3	1992	.160
1989	1990	179	56.0	1993	.530
1990	1991	199	76.8	1994	.144
1991	1992	204	82.5	1995	
1992	1993	175	51.4	1996	.043
1993	1994	209	87.7	1997	

Appendix 4. Number of mortalities for summer steelhead for the treatment (MFS 16/Tank 7 and 18/Tank 9) and control (CON 20/Tank 3 and 22/Tank8) ponds in the modified feeding schedule study at Marrowstone Marine Station, Washington

Experimental Group	Number of Mortalities in Seawater			
	5/1/98 to 6/8/98	6/8/98 to 7/6/98	7/6/98 to 8/5/98	Total
MFS 16 Tank 7	2	0	1	3
MFS 18 Tank 9	2	17	2	21
CON 20 Tank 3	0	1	1	2
CON 22 Tank 8	0	0	2	2

Appendix 5. Mean, standard deviation (SD), minimum, and maximum fork length (mm) for summer steelhead based on 100-fish in the modified feeding schedule treatment (MFS 16 and 18) and control (CON 20 and 22) ponds at Dworshak National Fish Hatchery, Idaho and tank inventories at Marrowstone Marine Station, Washington.

Month	Pond	Sample Size	Fork Length (mm)			
			Mean	SD	Minimum	Maximum
September	MFS 16	100	101	9.5	60	122
	MFS 18	99	104	8.6	70	122
	CON 20	100	100	6.0	85	114
	CON 22	100	101	6.5	86	115
October	MFS 16	136	119	8.6	87	139
	MFS 18	127	118	9.5	67	138
	CON 20	97	116	8.4	95	138
	CON 22	124	119	8.1	86	134
November	MFS 16	99	134	12.6	96	153
	MFS 18	119	134	11.7	81	158
	CON 20	90	133	10.8	100	158
	CON 22	112	135	11.7	103	165
December	MFS 16	132	151	13.3	105	174
	MFS 18	61	153	15.7	113	185
	CON 20	115	157	15.3	97	190
	CON 22	95	156	16.9	99	180
January	MFS 16	102	167	16.2	100	201
	MFS 18	147	167	20.2	107	206
	CON 20	134	177	14.6	115	208
	CON 22	126	176	19.9	95	220
February	MFS 16	83	177	19.1	119	215
	MFS 18	110	180	15.4	134	215
	CON 20	102	184	19.4	115	228
	CON 22	93	183	24.2	95	220
April	MFS 16	75	202	22.0	121	248
	MFS 18	75	201	26.9	110	255
	CON 20	75	202	20.2	113	243
	CON 22	75	206	18.9	125	249
Seawater Transfer						
May	MFS 16	52	216	19.3	152	258
	MFS 18	52	217	18.2	167	264
	CON 20	54	212	22.2	116	252
	CON 22	55	215	18.0	124	243
June	MFS 16	52	237	21.7	155	280
	MFS 18					
	CON 20	52	231	19.6	157	268
	CON 22	55	234	18.5	133	262
July	MFS 16	30	245	20.4	195	280
	MFS 18					
	CON 20	32	241	19.1	192	279
	CON 22	33	247	15.4	203	280

Appendix 6. Mean, standard deviation (SD), minimum, and maximum fork length (mm) for summer steelhead based on 20-fish physiological in the modified feeding schedule treatment (MFS 16 and 18) and control (CON 20 and 22) ponds at Dworshak National Fish Hatchery, Idaho and Marrowstone Marine Station, Washington.

Month	Pond	Sample Size	Fork Length (mm)			
			Mean	SD	Minimum	Maximum
February	MFS 16	20	154	23.5	113	185
	MFS 18	20	167	17.8	125	195
	CON 20	20	177	15.9	135	205
	CON 22	19	182	20.8	129	205
March	MFS 16	20	176	29.7	113	219
	MFS 18	20	184	13.9	162	215
	CON 20	20	186	20.8	131	212
	CON 22	20	179	31.6	115	220
April	MFS 16	20	205	20.8	158	235
	MFS 18	20	206	25.9	130	243
	CON 20	20	199	23.8	160	233
	CON 22	20	217	14.3	186	250
Seawater Transfer						
May	MFS 16	20	211	17.5	173	248
	MFS 18	20	209	30.6	132	253
	CON 20	19	211	18.9	187	248
	CON 22	20	223	19.3	185	265
July	MFS 16	20	253	19.3	211	294
	MFS 18					
	CON 20	20	237	25.8	164	275
	CON 22	20	245	25.7	145	266

Appendix 7. Mean, standard deviation (SD), minimum and maximum weight (g) for summer steelhead based on 100-fish in the modified feeding schedule treatment (MFS 16 and 18) and control (CON 20 and 22) ponds at Dworshak National Fish Hatchery, Idaho and tank inventories at Marrowstone Marine Station, Washington.

Month	Pond	Sample Size	Weight (g)			
			Mean	SD	Minimum	Maximum
September	MFS 16	100	10.9	2.5	1.6	16.2
	MFS 18	99	12.3	2.8	3.8	18.8
	CON 20	100	10.8	1.9	6.7	15.9
	CON 22	100	11.2	2.1	6.9	16.1
October	MFS 16	136	18.1	3.9	6.7	29.1
	MFS 18	127	18.2	4.1	3.9	28.3
	CON 20	97	17.3	3.5	9.7	26.8
	CON 22	124	18.1	3.5	7.2	25.8
November	MFS 16	99	26.0	7.0	8.3	38.0
	MFS 18	119	26.2	7.1	5.6	44.2
	CON 20	90	26.4	6.9	11.1	41.6
	CON 22	112	27.7	7.8	11.3	51.7
December	MFS 16	132	35.5	9.5	9.7	54.3
	MFS 18	61	39.4	12.1	11.6	68.5
	CON 20	115	43.2	11.1	8.1	73.2
	CON 22	95	42.7	13.9	8.3	68.0
January	MFS 16	102	48.0	13.0	9.2	87.0
	MFS 18	147	50.2	17.2	8.8	83.0
	CON 20	134	57.7	13.7	12.0	91.7
	CON 22	126	59.4	18.9	8.5	116.2
February	MFS 16	83	57.9	18.1	12.0	103.0
	MFS 18	110	61.9	15.9	16.9	109.1
	CON 20	102	65.5	19.3	11.0	119.6
	CON 22	93	65.7	23.2	7.3	112.6
April	MFS 16	75	79.7	23.6	15.0	148.0
	MFS 18	75	80.1	27.8	10.0	174.0
	CON 20	75	78.9	20.7	11.0	126.0
	CON 22	75	83.5	20.4	20.0	135.0
Seawater Transfer						
May	MFS 16	52	99.6	25.8	38.0	169.0
	MFS 18	52	102.4	26.9	46.0	196.0
	CON 20	54	94.3	24.4	15.0	134.0
	CON 22	55	98.0	19.9	21.0	146.0
June	MFS 16	52	146.4	38.0	43.0	243.0
	MFS 18					
	CON 20	52	128.8	30.3	41.0	174.0
	CON 22	55	139.6	27.5	23.0	214.0
July	MFS 16	30	157.7	41.0	63.5	245.6
	MFS 18					218.8
	CON 20	32	146.4	38.2	51.7	255.9
	CON 22	33	164.8	33.1	86.6	

Appendix 8. Mean, standard deviation (SD), minimum, and maximum weight (g) for summer steelhead based on 20-fish physiological sampling in the modified feeding schedule treatment (MFS 16 and 18) and control (CON 20 and 22) ponds at Dworshak National Fish Hatchery, Idaho and Marrowstone Marine Station, Washington.

Month	Pond	Sample Size	Weight (g)			
			Mean	SD	Minimum	Maximum
February	MFS 16	20	36.2	17.7	10.2	64.4
	MFS 18	20	47.8	15.7	12.3	77.3
	CON 20	20	55.9	14.8	16.7	79.7
	CON 22	19	59.6	19.3	13.9	84.3
March	MFS 16	20	57.7	25.9	12.2	105.0
	MFS 18	20	65.9	15.8	43.8	105.7
	CON 20	20	64.2	20.1	14.2	91.4
	CON 22	20	60.3	27.8	9.6	103.7
April	MFS 16	20	84.5	24.3	34.2	126.2
	MFS 18	20	85.2	26.3	17.8	138.1
	CON 20	20	76.3	26.3	37.9	120.3
	CON 22	20	94.2	19.4	58.4	150.6
Seawater Transfer						
May	MFS 16	20	89.9	23.3	51.2	146.4
	MFS 18	20	93.2	32.7	23.0	148.1
	CON 20	19	92.3	26.5	60.1	155.6
	CON 22	20	108.4	27.9	58.0	167.7
July	MFS 16	20	173.8	44.8	94.1	283.0
	MFS 18					
	CON 20	20	141.7	41.6	46.6	212.8
	CON 22	20	163.4	38.8	30.0	212.0

Appendix 9. Mean, standard deviation (SD), minimum and maximum condition factor (K) for summer steelhead based on 100-fish in the modified feeding schedule treatment (MFS 16 and 18) and control (CON 20 and 22) ponds at Dworshak National Fish Hatchery, Idaho and tank inventories at Marrowstone Marine Station, Washington.

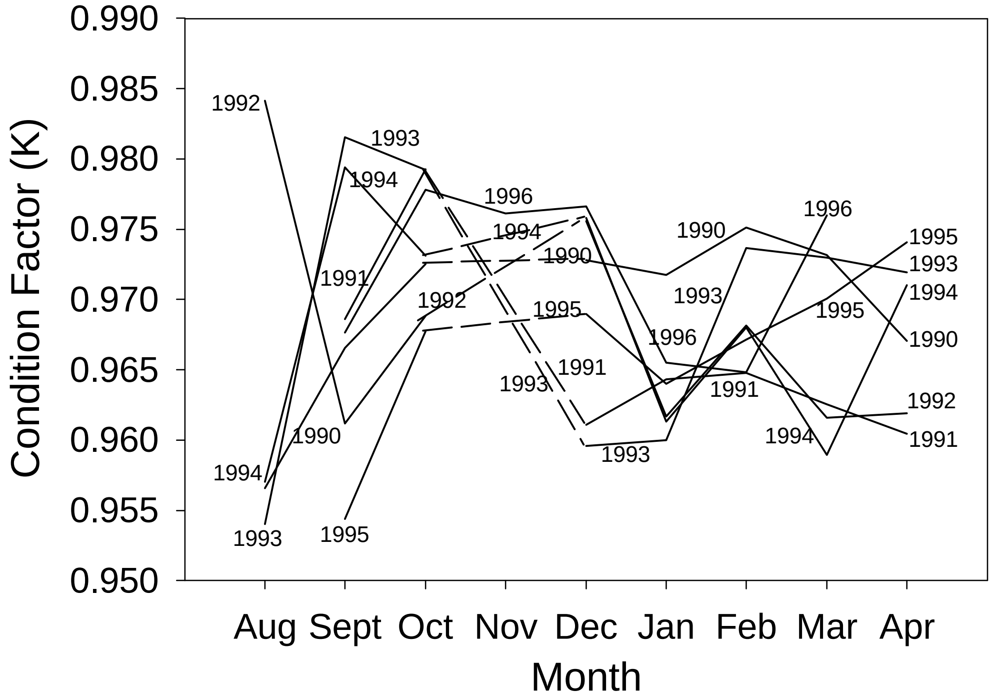
Month	Pond	Sample Size	Condition Factor (K)			
			Mean	SD	Minimum	Maximum
September	MFS 16	100	1.04	0.09	0.74	1.39
	MFS 18	99	1.05	0.07	0.86	1.20
	CON 20	100	1.07	0.06	0.94	1.21
	CON 22	100	1.08	0.08	0.68	1.33
October	MFS 16	136	1.07	0.07	0.94	1.53
	MFS 18	127	1.08	0.07	0.92	1.31
	CON 20	97	1.09	0.08	0.71	1.50
	CON 22	124	1.06	0.05	0.93	1.35
November	MFS 16	99	1.04	0.07	0.86	1.17
	MFS 18	119	1.05	0.13	0.83	2.08
	CON 20	90	1.08	0.09	0.83	1.32
	CON 22	112	1.09	0.09	0.90	1.52
December	MFS 16	132	1.00	0.10	0.66	1.52
	MFS 18	61	1.05	0.08	0.81	1.20
	CON 20	115	1.08	0.18	0.59	2.09
	CON 22	95	1.07	0.13	0.67	1.43
January	MFS 16	102	0.99	0.07	0.72	1.13
	MFS 18	147	1.01	0.10	0.60	1.29
	CON 20	134	1.01	0.07	0.62	1.18
	CON 22	126	1.04	0.09	0.64	1.28
February	MFS 16	83	1.00	0.08	0.70	1.20
	MFS 18	110	1.03	0.07	0.71	1.39
	CON 20	102	1.00	0.08	0.61	1.13
	CON 22	93	1.00	0.10	0.63	1.14
April	MFS 16	75	0.92	0.05	0.83	1.07
	MFS 18	75	0.94	0.05	0.75	1.11
	CON 20	75	0.93	0.08	0.76	1.49
	CON 22	75	0.93	0.03	0.86	1.04
Seawater Transfer						
May	MFS 16	52	0.96	0.05	0.85	1.11
	MFS 18	52	0.98	0.05	0.88	1.16
	CON 20	54	0.96	0.05	0.82	1.06
	CON 22	55	0.97	0.05	0.82	1.12
June	MFS 16	52	1.07	0.06	0.94	1.22
	MFS 18					
	CON 20	52	1.0	0.1	0.78	1.15
	CON 22	55	1.1	0.1	0.93	1.19
July	MFS 16	30	1.1	0.1	0.86	1.16
	MFS 18					
	CON 20	32	1.0	0.1	0.73	1.14
	CON 22	33	1.1	0.1	0.86	1.17

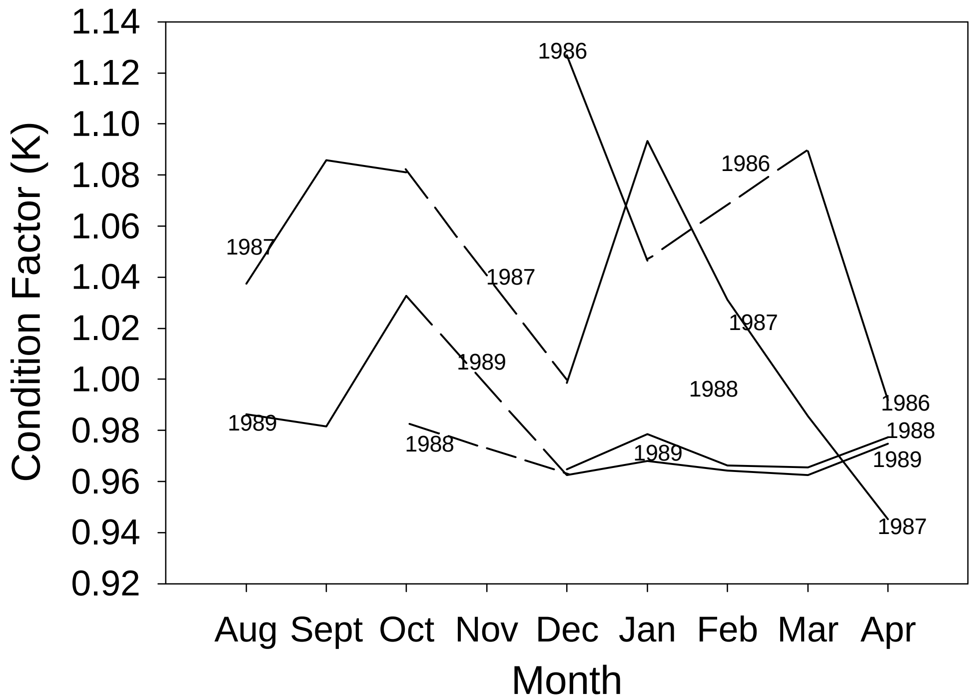
Appendix 10. Mean, standard deviation (SD), minimum, and maximum condition factor (K) for summer steelhead based on 20-fish physiological sampling in the modified feeding schedule treatment (MFS 16 and 18) and control (CON 20 and 22) ponds at Dworshak National Fish Hatchery, Idaho and Marrowstone Marine Station, Washington.

Month	Pond	Sample Size	Condition Factor (K)			
			Mean	SD	Minimum	Maximum
February	MFS 16	20	0.90	0.14	0.61	1.02
	MFS 18	20	0.98	0.09	0.63	1.08
	CON 20	20	0.98	0.08	0.68	1.09
	CON 22	19	0.94	0.11	0.65	1.04
March	MFS 16	20	0.98	0.07	0.79	1.08
	MFS 18	20	1.04	0.05	0.94	1.15
	CON 20	20	0.96	0.09	0.63	1.03
	CON 22	20	0.94	0.14	0.56	1.07
April	MFS 16	20	0.95	0.04	0.87	1.04
	MFS 18	20	0.94	0.06	0.81	1.07
	CON 20	20	0.93	0.04	0.87	0.99
	CON 22	20	0.92	0.04	0.86	1.05
Seawater Transfer						
May	MFS 16	20	0.94	0.04	0.88	1.02
	MFS 18	20	0.97	0.05	0.82	1.07
	CON 20	19	0.96	0.04	0.89	1.04
	CON 22	20	0.96	0.05	0.86	1.03
July	MFS 16	20	1.05	0.06	0.94	1.24
	MFS 18					
	CON 20	20	1.03	0.07	0.92	1.17
	CON 22	20	1.07	0.05	0.98	1.16

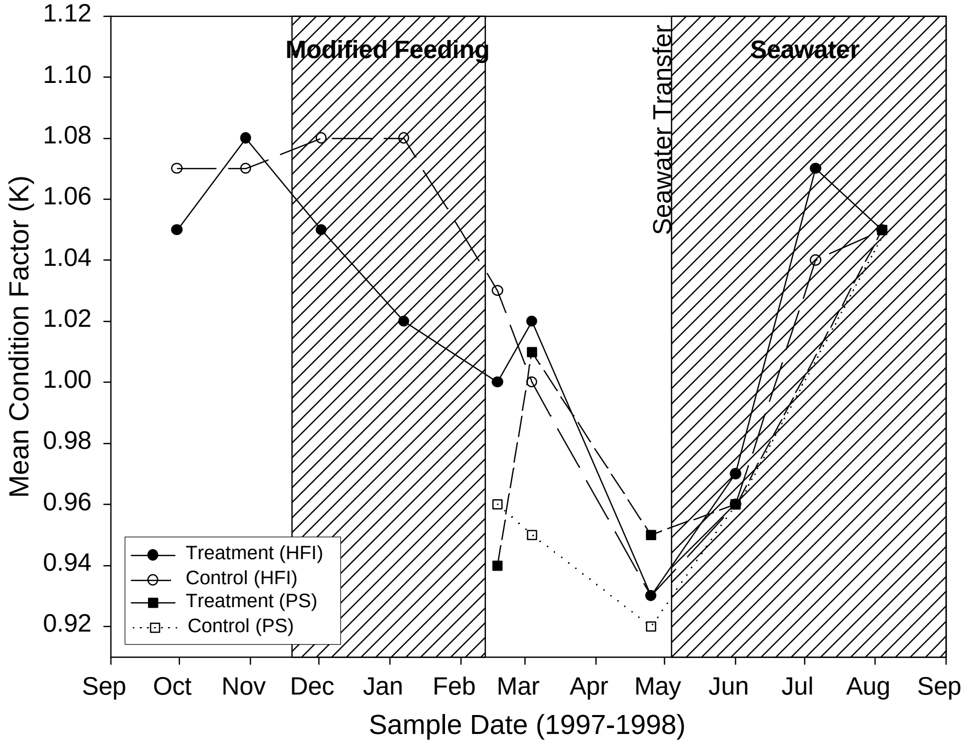
Appendix 11. Mean, standard deviation (SD), minimum, and maximum Na^+, K^+-ATPase (μmol $P_i \cdot$ mg protein$^{-1} \cdot$ hour^{-1}) for summer steelhead based on 20-fish physiological sampling in the modified feeding schedule treatment (MFS 16 and 18) and control (CON 20 and 22) ponds at Dworshak National Fish Hatchery, Idaho and Marrowstone Marine Station, Washington.

Month	Pond	Sample Size	Na^+, K^+-ATPase (μmol $P_i \cdot$ mg protein$^{-1} \cdot$ hour^{-1})			
			Mean	SD	Minimum	Maximum
February	MFS 16	20	3.4	1.4	0.7	6.2
	MFS 18	20	3.4	0.9	1.6	6.0
	CON 20	20	3.3	0.9	1.7	4.8
	CON 22	19	3.5	0.6	2.8	4.8
March	MFS 16	20	3.5	1.0	1.8	5.6
	MFS 18	20	3.8	0.9	2.1	5.3
	CON 20	20	3.3	0.9	1.8	5.2
	CON 22	20	3.9	1.1	1.5	6.5
April	MFS 16	20	5.4	1.6	2.9	8.6
	MFS 18	20	5.6	1.7	2.8	8.2
	CON 20	20	5.2	1.5	2.1	7.6
	CON 22	20	4.9	1.3	1.5	7.4
Seawater Transfer						
May	MFS 16	20	22.9	6.2	11.1	39.0
	MFS 18	20	22.3	4.0	15.7	31.1
	CON 20	19	24.3	3.4	17.0	30.3
	CON 22	20	23.0	4.4	17.4	34.4
July	MFS 16	20	17.7	5.8	7.5	31.2
	MFS 18					
	CON 20	20	20.9	7.3	9.9	43.2
	CON 22	20	17.9	5.2	9.0	28.4





Appendix 12. Condition factor (K) for summer steelhead at Dworshak National Fish Hatchery, Idaho, from Monthly Inventory Summaries, 1986-1996.



Appendix 13. Mean condition factor (K) of summer steelhead in the modified feeding schedule treatment and control groups at Dworshak National Fish Hatchery, Idaho, based on 100-fish inventories and tank inventories at Marrowstone Marine Station, Washington (HFI) and 20-fish physiological samples (PS).