May 1991

Yakima Spring River Chinook Enhancement Study

Final Report 1991

DOE/BP-39461-9

This report was funded by the Bonneville Power Administration (BPA), U.S. Department of Energy, as part of BPA's program to protect, mitigate, and enhance fish and wildlife affected by the development and operation of hydroelectric facilities on the Columbia River and its tributaries. The views of this report are the author's and do r necessarily represent the views of BPA.

This document should be cited as follows:

Fast,David; Joel Hubble, Mike Kohn, Bruce Watson, Yakima Indian Nation, Fisheries Resource Management, Thomas Vogel, Project Manager, U. S. Department of Energy, Bonneville Power Administration, Division of Fish and Wildlife, Project No. 1982-16, Contract Number DE-Al79-1983BP39461, 355 electronic pages (BPA Report DOE/BP-39461-9)

This report and other BPA Fish and Wildlife Publications are available on the Internet at:

http://www.efw.bpa.gov/cgi-bin/efw/FW/publications.cgi

For other information on electronic documents or other printed media, contact or write to:

Bonneville Power Administration
Environment, Fish and Wildlife Division
P.O. Box 3621
905 N.E. 11th Avenue
Portland, OR 97208-3621

Please include title, author, and DOE/BP number in the request.

YAKIMA RIVER SPRING CHINOOK ENHANCEMENT STUDY

Final Report
May 1991

Prepared by

David Fast
Joel Hubble
Mike Kohn
Bruce Watson

Yakima Indian Nation
Fisheries Resource Management

Prepared for

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

Project No. 82-16
Contract Number DE-Al79-83BP39461

Table of Contents

ACKNOWLEDGEMENTS 1

ABSTRACT 3

EXECUTIVESUMMARY 5

I. DESCRIPTION OF STUDY AREA 29
General Information 29
Water Resources 32
Water Supply 33
Land Use 36

II. METHODS AND MATERIALS 39

III. RESULTS AND DISCUSSION 41

A) Natural Production 41

ADULT RETURNS 41
Overview 41
Prosser Returns 41
Roza Returns 55

SPAWNING SURVEYS 60
Overview.. 60
Redd Counts 60
Carcass Data 65
Length, Fecundity and Egg Deposition 74

EMERGENCE/ EA RLY REARING 76
Overview 76
Egg-To-Fry Survival 76
Gravel Analysis 79
Post-Emergence Movements 86
Lost Creek Study 91

REARING DISTRIBUTION 96
Overview 96
Tributary Distribution 97
Mainstem Distribution 103
Snorkeling Surveys 111

OUTMIGRATION 115
Overview 115
Summer, Fall and Winter Movements 119
Spring Movements 144

LIFE STAGE SURVIVAL 195
Overview.. 195
Egg-to-Fry Survival 201
Smolt-Related Survival Estimates 208
Smolt-to-Smolt Survival 212
Egg-to-Smolt Survival 237
Smolt-to-Adult Survival 253

FACTORS LIMITING REARING POTENTIAL 262
Overview.. 262
Suboptimal Instream Flows 263
Passage Around Diversions 272
Degraded Riparian and Instream Habitat 273
Water Quality 274

B) Hatchery Operations 283

INTRODUCTION 283

OVERVIEW 290

OPTIMAL MANNER OF RELEASE 294
Smolt Survival 296
Outmigration Timing 299
Size of Experimental Fish 315
Smolt-to-Adult Survival 315

OPTIMALTIMEOFRELEASE 321
Smolt Survival 321
Outmigration Timing 326
Size of Experimental Fish 331
Smolt-to-Adult Survival 331

OPTIMAL RELEASE STOCKS 335
Smolt Survival 335
Outmigration Timing **338**
Size of Experimental Fish 344
Smolt-to-Adult Survival 344

C) Recommendations 347

LITERATURE CITED 349

APPENDICES IN A SEPARATE VOLUME

ACKNOWLEDGEMENTS

I would like to thank all of the members of the Yakima Indian Nation Fisheries Resource Management staff for their suggestions and assistance in the field. Thanks also to Joe Jay Pinkham III, William Fiander, Joe Hoptowit, Leroy Senator, Tammy Swan, and the late Matt Goudy, Jr. for maintaining the high quality of data collected in the field. Due to the duration of the project and the numerous field technicians employed over the years, it is not practical to thank each person individually.

Thanks is also offered to Dr. Paul James of Central Washington University for assistance with statistical analysis. Appreciation is also given to Beth Spanjian for her technical assistance in the editing of this manuscript.

Funding for this project was provided by the Bonneville Power Administration under Contract 82-16. The assistance and advice of Tom Vogel was invaluable.

ABSTRACT

The natural production, and potential methods of enhancing, the Yakima River spring chinook salmon *(Oncorhynchus tschawytscha)* were studied from 1982 through 1990. Researchers studied naturally produced populations to determine if runs can be sustained in the face of current harvest and environmental conditions. Survival through each life stage was evaluated to determine limitations to natural production.

In the last 20 years, the spring chinook adult returns to the Yakima River have ranged from a low of 823 fish in 1972 to 9,442 in 1986. The average run since 1981 has been 3,819 adults. Over the past 10 years the runs steadily increased from their respective brood years until 1988 when the upper Yakima River experienced three consecutive years of declining returns.

The Yakima Basin is comprised of three distinct substocks of spring chinook -- American River, Naches River and tributaries, and the upper Yakima River. Data collected from spawning surveys indicates that differences in the substocks include age and length as well as spatial and temporal differences. Carcass data indicates that American River fish are predominately 5-year-old adults; the Yakima River consists of 4-year-olds. The Naches River and tributaries is a combination of 4- and 5-year-olds.

The length fecundity relationship developed from 23 females was:

EGGS = 195.2(mid-eye to hypural length in cm) - 7,736.

A total of 14 redds were successfully redd-capped in 1985 and 86. The mean estimated egg-to-fry survival rate was 59.6% and ranged from 21.9% to 90%. Early juvenile rearing distribution generally corresponded to adult spawning range. Juveniles migrated into the lower reaches of the Yakima in the fall and winter months. Most of these fish moving past Wapatox dam on the Naches River in the fall did not migrate past Prosser until the following spring.

Spring smolt outmigration at Prosser dam has ranged from 92,934 in 1989 to 282,514 fish in 1988 (mean = 177,561). Smolt outmigration is concentrated in April (mean 63%) and May (32%). Egg-to-smelt survival has ranged from 1.3% to 10.6%. Survival has generally declined since the I983 outmigration. Regression analysis indicated that biotic density-dependent or depensitory factors (egg deposition and total smolt production) explain more annual variability than flow related parameters. The most significant flow parameters were avoidance probability at diversion dams and low flow days in juvenile early rearing areas.

Smolt-to-adult survival for wild spring chinook salmon was based on estimated outmigration of smolts at Prosser Dam from 1983 through 1987. The total number of adults

(3-year-old through 6-year-old fish) returning from these smolt outmigrations has ranged from 4,209 to 8,596 fish (mean 5,655). Smolt-to-adult survival has averaged 3.7% and has ranged from 1.7% to 6%.

The major factors that limit spring chinook rearing potential in the Yakima Subbasin were determined to be suboptimal instream flows, passage around diversions, degraded riparian and instream habitat, and reduced water quality.

Supplementation experiments using hatchery reared fish to enhance natural production were conducted. These experiments tested the manner of release (acclimation ponds vs. direct river releases), the time of release (fry in June, parr in September, and pre-smolts in November), and the brood stock used (progeny from wild by wild crosses - WxW, wild by hatchery - WxH, and hatchery by hatchery - HxH). Success was measured as post-release survival, as smolts to prosser and adults back to the Yakima.

The acclimated smolts survived at a higher rate in three of the four years (about equal in the fourth year). The smolt to adult survival for acclimated fish was higher than survival of trucked fish in all four years. The studies of release timing had mixed results to the smolt stage with the September release being higher in 1984 (10.96% vs. 3.71%) and the November releases exhibiting higher survival in 1985 (9.39% vs. 0.79%). The September releases did exhibit a survival advantage to the returning adult stage (0.08% vs. 0.05%). Too few of the June fry releases passed Prosser as smolts in the year following their release to analyze with statistical reliability. These releases had a mean survival to the adult stage of only 0.016% over the two years. The estimated survival to Prosser of the hatchery reared “wild” smolts was marginally higher than for the hybrid and hatchery brood stock produced smolts. The “wild” fish also returned as adults at a slightly higher rate than the hybrid group.

Recommendations as to the direction of future research efforts on the Yakima spring chinook are also discussed.

EXECUTIVE SUMMARY

INTRODUCTION

The population of Yakima River spring chinook salmon *(Oncorhynchus tschawytscha)* has been drastically reduced from historic levels reported to be as high as 250,000 adults (Smoker 1956). This reduction is the result of a series of problems including mainstem Columbia dams, dams within the Yakima itself, severely reduced flows due to irrigation diversions, outmigrant loss in irrigation canals, increased thermal and sediment loading, and overfishing. Despite these problems, the return of spring chinook to the Yakima River has continued at levels ranging from 854 to 9,442 adults since 1958.

In October 1982, the Bonneville Power Administration contracted the Yakima Indian Nation to develop methods to increase production of spring chinook in the Yakima system. The Yakima Nation's current enhancement policy attempts to maintain the genetic integrity of the spring chinook stock native to the Yakima Basin. Relatively small numbers of hatchery fish have been released into the basin in past years.

The goal of this study was to develop data that will be used to present management alternatives for Yakima River spring chinook. The study has five major objectives. The first objective is to determine the distribution, abundance and survival of wild Yakima River spring chinook. Researchers studied naturally produced populations to determine if these runs can be sustained in the face of present harvest and environmental conditions. Survival through each life stage was evaluated in an attempt to determine limitations to natural production in the basin. Researchers conducted survival-to-emergence studies to determine survival through the incubation stage. They also analyzed the relationship between survival to emergence and gravel substrate quality.

Seining at selected sites, snorkeling and electroshocking surveys have been conducted to evaluate distribution and abundance of juvenile fish. Smolt outmigrations are monitored at the Wapatox juvenile fish trap on the Naches River and at the Roza and Prosser juvenile fish traps on the mainstem Yakima River. Adult returns are determined by monitoring the Yakima tribal dip-net fishery, counting adults at prosser and Roza fish ladders, and through spawning ground surveys. Physical parameters, such as water temperatures and stream flow, are monitored throughout the basin.

The second major objective of this study is to determine the relative effectiveness of different methods of hatchery supplementation. This objective is divided into three subobjectives:

A) Determination of optimal release time.

Smolt releases are the norm, but fingerlings were released in June, September, and November of 1984 and 1985. Downstream survival of these smolts was evaluated and adult returns were monitored.

B) Determination of optimal manner of release.

In the past, fish have either been transported from a hatchery and released into the Yakima River, or raised in rearing ponds. These methods, as well as the use of acclimation ponds, were evaluated.

C) Determination of optimal release stocks.

Smolts were released in 1986 and 1987 as hatchery x hatchery, hatchery x wild, and wild x wild crosses to determine the effect of genetic makeup on the success of various releases. Success was measured as the number of adults returning.

Adverse interactions between hatchery releases and wild stocks were minimized by scatter-planting hatchery fish so densities in the river remained low enough to minimize competition for food and space.

The last three major objectives of the study are to locate and define areas in the watershed that may be used for the rearing of spring chinook; to define strategies for enhancing natural production of spring chinook in the Yakima River; and to determine the physical and biological limitations on production within the system.

This project has been a multi-year undertaking that evaluated different management and enhancement strategies. Annual reports were presented for 1983 (Wasserman and Hubble 1983), 1984 (Wasserman et al. 1985), 1985 (Fast et. al 1986), 1986 (Fast et al. 1987), 1987 (Fast et al. 1988), 1988 (Fast et al. 1989) and 1989 (Fast et al. 1990).

NATURAL PRODUCTION

Adult Returns

In the last 20 years, the spring chinook returns to the Yakima River have ranged from a low of 854 fish in 1972 to 9,442 in 1986. The average run since 1981 has been 3,819 adults. The first adult returns to benefit from the additional winter flows for egg incubation

and the subsequent "flip-flop" water management plan returned as 4-year-olds in 1984 and 1986 respectively:

Year	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Return	1334	1549	1324	2676	4527	9442	4364	4356	4917	3698

The median date of adult passage is May 16 and June 1 at Prosser (RM 47) and Roza dams (RM 128), respectively. The middle 50% of the migration passes Prosser from May 9 to May 23, a total of 14 days. The middle 50% passes Roza from May 23 to June 17, a total of 25 days. Length frequency histograms developed from Prosser indicate that 5-year-olds return earlier than 3- or 4-year-olds. It appears likely that the American and Naches stocks (predominately 5-year-olds), which spawn earlier than Yakima stocks (4-year-olds), also migrate earlier.

Spawning Surveys

The Yakima Basin is comprised of three distinct substocks of spring chinook -- American River, Naches River and tributaries (excluding the American River), and the Yakima River (including Cle Elum River). Electrophoresis was used to differentiate the substocks (Busak, WDF, pers. commun., 1990). Data collected from spawning surveys indicates differences in the substocks include age and length as well as spatial and temporal differences.

Redd counts in the upper Yakima River have averaged 716 in the last decade and have ranged from 294 to 1,793 redds. Counts in the Naches Subbasin averaged 441 in the last decade and ranged from 54 to 1,3 13 redds. Carcass data indicates that American River spring chinook are predominately 5-year-old adults; the Yakima River consists of 4-year-olds. The Naches River and tributaries is a combination of 4- and 5-year-olds.

The length fecundity relationship was developed from eggs taken from 23 females at Roza Dam. The best fit **($r^2 = .898$)** for this linear regression was:

EGGS = 195.2(mid-eye to hypural length in cm) - 7,736

Emergence/Early Rearing

A total of 14 redds were successfully redd-capped in 1985 and 1986. The mean estimated egg-to-fry survival rate was 59.6%, while egg-to-fry survival in individual redds ranged from 21.9% to 90%. Estimated mean temperature units required for first emergence was 1,600 (April 11); for 50% emergence, 1,779 (April 26); and for 100% emergence, 2,259 (May 15).

No meaningful correlation was found between the quality of spawning gravel and egg-to-fry survival rate. The primary factor contributing to this is probably the necessity of taking the gravel samples as much as three meters away from the egg Rocket. This was necessary because of excessive water depths immediately adjacent to the redd. The mean percent fines (<0.85 mm) was 11.39% in 1984, 11.93% in 1985 and 15.9% in 1986. These values in relation to the mean egg-to-fry survival rate are within values reported by other researchers. Bjomn (1983) found that survival with 10% fines <0.85 mm ranged from 20% to 80%, depending on the percent fines < 9.5 mm.

Downstream movement of spring chinook fry immediately after emergence was observed in the American River and upper Yakima River. In the American River, 36 fry were captured in 1983 and 785 fry in 1984. Median passage occurred April 17, and movements continued from March 20 to June 4 in 1984. Seventeen fry were captured in the upper Yakima River in 1983 (trapping ceased April 21), and 237 fry were captured in the upper Yakima in 1984. Median passage occurred April 16, and movements continued from March 8 to June 13 in 1984.

A total of 1,518 newly emerged fry were counted into Lost Creek ponds, an series of three small ponds excavated from a braid of the upper Naches River (RM 38.7). Fry traps were positioned near the inlet and outlet of these ponds. Between April 29 and June 2, 965 (63.6% of the total) fry were counted out of the inlet trap and released into the ponds. From April 29 through August, only 74 fry were counted out of the outlet trap. It is believed that most immigrant fry overwintered in the ponds as a total of 720 smolts were counted out of the downstream trap the following spring. It should be noted that almost all (98%) of the smolts had left the pond by March 18.

Rearing Distribution

The distribution of juveniles in the tributaries to the Yakima River were generally confined within the first river mile. A couple of exceptions were the Teanaway River where juveniles were found in the North Fork (RM 1.5), Middle Fork (RM 0.5 to RM 2.5) and West Fork (confluence to RM 4.2). Densities ranged from 0.14 to 0.51 fish/m*. Juveniles were also found in the Wilson Creek system; juveniles were found farthest upstream in Naneum Creek at RM 1.8. Other tributaries where juveniles were found beyond one river mile were Swauk, Dry and Manastash creeks. Spring chinook spawning has been

documented in the Teanaway River and Manastash Creek, and is suspected in the Wilson Creek system.

Researchers suspect that little juvenile rearing occurs in the Cle Elum River because of the high late spring and summer flows that exist once water is released from the Cle Elum Reservoir for irrigation. Above Lake Easton, an occasional juvenile has been found in Cabin Creek.

Below Roza Dam, the number of tributaries declines; juveniles were not found in any of them during the summer months. However, during the winter, juveniles were found in Wenas, Wide Hollow and Ahtanum creeks, and Wanity Slough.

In the Naches system, juvenile rearing in the American River corresponds with the adult spawning range. Juveniles were found primarily from Union Creek (RM 11.5) to Hell's Crossing (RM 5.8). Juveniles were found at the lone sample site in the Bumping River at RM 0.9. However, it is likely juveniles rear as far upstream as Goose Prairie (RM 14.3), the upper end of adult spawning. In the Little Naches River, juveniles were distributed in correspondence with adult spawning; juveniles extended upstream to RM 6.1, though in limited numbers. With the completion (in 1988) of Salmon Falls fish ladder at RM 5, it is likely that juvenile rearing above the falls will steadily increase over time, as adult spawning continues to increase above this point.

Juveniles were collected as far upstream as RM 4.8 (the highest sample site) in Rattlesnake Creek. Again this is within current spawning distribution.

Spring distribution of juveniles in the Yakima mainstem was greatest at Selah (RM 118) with 40.4% of the total, and at Cle Elum (RM 181) with 33.4% of the total. These coincide with two main spawning areas upstream.

Summer distribution of juveniles in the Yakima mainstem was almost exclusively above Roza Dam (RM 135). The absence of fish below this point is a function of poor rearing conditions (primarily temperature). The greatest percent of the summer totals was found in the Yakima Canyon (67.4%) and at Ellensburg (RM 169), with 19.5% of the total. The shift downstream to these two areas indicates juveniles are moving downstream from their natal areas throughout the summer.

With the cooling of the lower river in the fall, juveniles begin to migrate into this portion of the Yakima River. This coincides with the initiation of the fall outmigration in the Naches and upper Yakima rivers. The highest percent of total fish was at Toppenish (RM 95) with 60.1% and at Selah with 15.6%, reflecting this migration pattern.

Winter distribution in the mainstem Yakima shows continued increase of juveniles moving into the lower river. Within the lower river, Selah and Prosser had the highest percent of total fish captured with 13.1% each.

Outmigration

Summer, Fall and Winter Movements

At Wapatox, the movement of juvenile chinook in the summer (July and August) represents only a small fraction of the total outmigration seen each year. Passage estimates range from a low of 878 fish in 1986 to 1,794 fish in 1987. Mean fork length for all years combined was 80 mm in July and 83 mm in August.

By far the greatest period of outmigration at Wapatox occurs in the fall. Wapatox monitoring ceases when the river begins to ice up and threatens the screens. Accordingly, fall/winter monitoring at Wapatox ceases on different dates every year, and comparisons of the relative magnitude of fall movements between years becomes difficult. For brood years with comparable monitoring periods, fall migrants represented from 47% (1988 brood year) to 89.7% (1984 brood year) of the total brood year production. On an absolute basis, the estimated number of fall migrants has ranged from 8,988 fish in 1989 to 60,186 fish in 1986. Most Naches system fall migrants do not migrate to the lower Yakima during the fall and winter. Of 20,000 fall migrants branded and released at Wapatox in the fall of 1986, only 38.7% of the fish that survived to Prosser actually passed Prosser in the winter of 1986-87; the bulk of the survivors (61.3%) passed Prosser in the spring (March 1 through June 30). Similarly, 17.2% of the Naches fall migrants branded and released at Wapatox during the fall of 1988 passed Prosser during the winter of 1988-89, while 82.8% passed Prosser the following spring. Chapman and Bjomn (1969) concluded from studies in the Salmon River drainage that decreasing stream temperatures in the fall trigger a search for suitable winter habitat which, if unsuccessful locally, results in a downstream migration. Something similar may be occurring in the Naches system, and perhaps also in the upper Yakima. There is, however, also some evidence that winter migrations may, to some degree, be driven by a genetic predisposition for winter movements.

Mean fork length of winter migrants at Wapatox over all years was 85 mm in September, 96 mm in October, and 95 mm in both November and December.

The smolt trap at Roza has never been operated in the summer, and has been operated for only one winter -- from December 12, 1989 through April 17, 1990. Although the Roza facility has not yet been calibrated (the relationship between diversion and entrainment has not yet been determined) and total passage cannot yet be estimated, it appears from inspection of raw catches alone that the seasonal distribution of movements at Roza is similar to Wapatox; many more fish pass in the fall and winter than in the spring. The raw catches of spring chinook juveniles (primarily pre-smolts) in December, January, February, March and April were 582, 1,486, 2,558, 469 and 73 fish, respectively. The mean fork lengths observed over these months were 106 mm, 107 mm, 105 mm, 107 mm and 115 mm, respectively. Like winter migrants observed at Wapatox, most Roza winter migrants do not

move into the lower Yakima during the winter; only 24.6% of the Prosser observations of fish branded and released at Roza during the winter of 1989-90 occurred before March 1. This observation and the similar observation at Wapatox indicates a major overwintering area must exist in the middle Yakima, somewhere above Prosser Dam. There is some evidence indicating that this area is concentrated in a reach bordered by Marion Drain and Satus Creek.

Considerable numbers of chinook fry (mean length 36 mm) were observed at Roza, some as early as February. As the nearest spring chinook redd to Roza in 1989 was 12 miles upstream, this suggests fry are moving considerable distances downstream immediately after emergence.

The seasonal distribution of juvenile movements at Prosser is considerably different from Wapatox and Roza. Here, the passage of spring smolts (from March 1 through June 30) is always much larger than the passage of winter migrants (the passage of juvenile salmonids in the summer is essentially zero). Over four years of year-round operation (1986-1990), winter migrants have made up only 19.9% to 23% of "total brood year production" (winter migrants + spring smolts). The constancy of the relative contribution of winter migrants is striking in view of the fact brood year egg deposition has ranged from 5.56 million to 15.07 million. This constancy has led to speculation that winter movements may, at least in part, be genetically controlled -- that – 20% of the Yakima population inherits the predisposition to migrate during the winter. This hypothesis is supported by the fact that 280,000 spring smolts passed Prosser in 1988, while the total brood year production in 1989 was only 116,000 fish, of which 23,000 were winter migrants. If winter migration were completely the result of an inadequate quantity of winter habitat, there should have been no winter migrants in 1989; the passage of 280,000 spring smolts the year before demonstrated that the quantity of winter habitat was more than adequate.

Winter migrants are not seen at Prosser until late November, and passage usually reaches a peak in December. Over all years, 63% of the passage of winter migrants has occurred in November and December.

It is believed that the winter migrants observed at Prosser originate from both the upper Yakima and the Naches system. This belief is based on the fact that, month by month, branded Naches system winter migrants are always significantly smaller than unbranded fish. (Because of colder water temperatures and lower overall productivity, the Naches system produces spring chinook that are smaller than upper Yakima fish at all life stages. The larger, unbranded fish were therefore assumed to originate from the upper Yakima.) Moreover, in the winter of 1986-87, the proportion of branded Naches system fish observed at Prosser was much smaller than the proportion marked and released at Wapatox.

Although winter migrants at Prosser probably originate from all parts of the basin, the movements of (branded) Naches system fish and presumptive (unbranded) upper Yakima fish is remarkably synchronous. This synchrony may reflect a common mid-Yakima

overwintering site for winter migrants throughout the basin. In a basinwide electroshocking survey of the Yakima in the winter of 1986-87, the greatest catch per unit effort of both branded and unbranded juveniles occurred in the middle Yakima, between the outlet of Marion Drain and the mouth of Satus Creek. The major spring chinook overwintering area in the basin may be concentrated in this reach.

Spring Movements

As mentioned, the passage of spring smolts at Wapatox is always less than the passage of winter migrants. Spring smolt outmigrations have ranged from 6,671 fish in 1986 to 41,511 in 1985. Outmigrations at Wapatox are, however, difficult to estimate because the low elevation of the trap causes the trap to flood, rendering the trap inoperable a considerable portion of every year. Operations are further complicated by the fact that the trap cannot be operated until the screens in the Wapatox canal are installed, which usually occurs about April 1. The fact that smolts are captured in large numbers the first day of operation leads to the conclusion that smolt outmigration on the Naches typically begins considerably earlier than April 1. The observed portion of the outmigration at Wapatox is heavily concentrated in April, although some smolts are observed as late as June. Over all years, the mean fork lengths of smolts observed in April, May and June are **95** mm, 100 mm and 109 mm, respectively.

The Roza facility has been operated through the entire spring only once, from April 1, 1989 through August 31, 1989. Again, the Roza trap has not been calibrated, so passage cannot be estimated. Nevertheless, it is interesting to note that the raw catches of young-of-the-year were 12 times as numerous as smolts (5,581 vs. 446 fish). This observation may suggest that most upper Yakima chinook have moved below Roza some time prior to smolting. The mean fork length of all smolts observed at Roza in 1989 was 115 mm.

As is the case at Wapatox, the smolt outmigration at Prosser is concentrated in April. From 1983 through 1990, a mean of 63% of all smolt passage occurred in April, although the proportion has ranged from 4 1.7% in 1984 to 90% in 1990. Mean May passage is 32 %, and has ranged from 7.8% in 1990 to 52.4% in 1984. Very little passage occurs in March and June, which has accounted for a mean of only 1.8% and 3.3%, respectively. The date of median passage has ranged from April 16 in 1990 to May 4 in 1984; the overall median passage date is April 25.

Early April represents a kind of threshold for outmigration at Prosser. One might speculate that some seasonal cue -- perhaps photoperiod, water temperature or their combination -- characteristic of early April triggers a behavioral “predisposition to migrate” in the majority of the population. In any case, after the first few days of April, abrupt increases in discharge begin to trigger disproportionately large increases in outmigration. Note that “flow pulses” have no discernable effect in March, when most of the population may be presumed to consist of pre-smolts; nor in June, when most of the population has already emigrated. The migratory response is especially large when the pulse follows a

prolonged period of declining flows. Note that abrupt increases of flow stimulate movement; stable and declining flows depress movement, even when the absolute measure of discharge during a period of decline is still quite large. While outmigration is stalled because of declining flows, smolts are subject to extended periods of vulnerability to predators, especially if they have "holed up" in the perilous reach between Sunnyside and Prosser. An analysis of the correlation between passage and flow shows that stimulatory pulses increase discharge a minimum of 20% (over "base flow") in a period of two days or less. Larger pulses occurring after prolonged periods of declining flows can trigger spectacular responses, as occurred in 1988, when over 330,000 hatchery coho and 69,000 spring chinook passed Prosser in a single day.

The length of spring chinook smolts at Prosser generally decreases through the season. Over all years, mean fork lengths in March, April, May and June were 138 mm, 130 mm, 125 mm and 129 mm, respectively. As all spring chinook smolts are age-1 +, this trend presumably indicates that larger fish smolt earlier. Condition factor remains essentially constant through the outmigration.

Over all years, total spring outmigration has ranged from 282,514 fish in 1988 to 92,934 in 1989 (mean = 177,561). This considerable range of production and rearing density is associated with significant impacts on mean size and condition factor between years. Egg-to-smolt survival is positively correlated with both mean length and mean condition factor, and estimated egg deposition is negatively correlated with mean length and mean condition factor. Interestingly, these statistically significant relationships hold only *for* the month *of April;* there is little statistical evidence of a density-dependent impact on growth in May. This observation has prompted speculation that the outmigration of one of the three known substocks of Yakima spring chinook (American River, Naches system and upper Yakima) precedes or follows the other two, and that the stock status (the "seeding level") of this "asynchronous" substock is substantially different from the other two.

An examination of the relationship between the rapidity of outmigration (of wild smolts) and spring flows in a number of reaches along the migratory pathway was essentially fruitless. No relationship was found between median migration date and any flow-related parameter along the migratory route above Prosser. A very weak relationship was, however, found between mean spring water velocity below Sunnyside Dam and "middle 80% passage time" -- the period separating cumulative passage of 10 % and 90% of the run. The 80% passage time reflects the temporal compression of the outmigration, and may be presumed to have survival value when the population must run a gauntlet of resident predators (as may be the case in the Yakima). The correlation between Sunnyside water velocity and 80% passage time was negative -- faster water decreased passage time -- but not significant. This relationship became significant at the .05 level if data for 1987 and 1989 was omitted. If such a relationship were ultimately to be validated, the implications for managing Yakima spring chinook would be significant; passage times of less than a month would, in most years, require the release of some water from storage reservoirs.

Life Stage Survival

Point estimates of egg-to-fry survival were obtained by "capping" redds in the upper Yakima in 1985 and 1986. Nylon mesh nets, which funneled into a removable livebox at the cod end, were dug into the gravel entirely around redds. Newly emergent fry were removed from the livebox on a daily basis. Egg deposition for individual redds was estimated by substituting the mid-eye to hypural (MEHP) length from the spent female (which was snagged from the redd by hook and line) into a length-fecundity relationship for wild Yakima spring chinook. The mean egg-to-fry survival rate for redds capped in 1985 was 62.5%; the mean in 1986 was 56.4%. The mean over both years, 59.696, was assumed characteristic of the basin.

Basinwide fry production was estimated as the product of total estimated egg deposition and the assumed egg-to-fry survival rate (59.6%). Total egg deposition was estimated as the sum of the product of the number of redds deposited in each spawning area and the mean egg complement of the redds in each area. Mean egg complements by area were estimated by substituting the mean MEHP length of female carcasses collected on the spawning grounds into the length-fecundity relationship. Total fry production from 1983 through 1990 ranged from 995,428 fish in 1983 to 8,983,692 in 1986.

Smolt-Related Survival Estimates

Statistical confidence intervals could not be described for estimates of smolt passage or survival at Prosser Dam. This is because satisfactory confidence intervals could not be described for the logistic diversion/entrainment relationship employed at Prosser (passage is estimated by dividing raw catches corrected for subsampling by the estimated entrainment fraction). Readers should refer to Appendix D for a detailed discussion of this issue.

As a result of the inability to specify statistical precision of smolt passage and survival estimates, readers should regard reported survival figures as indices of survival only. Accordingly, a great deal of emphasis should not be placed on absolute estimates. However, because the same (possibly biased) estimator was used on all groups monitored, *relative* passage and survival estimates across groups should be reasonably accurate.

Indices of survival to McNary Dam are also reported. These estimates were calculated as the ratio of the cumulative Passage Index (as reported by the Fish Passage Center) to the release number. These "McNary survival rates" should be interpreted in exactly the same way as Prosser "survival rates," as possibly biased indices that should, nevertheless, reflect relative survival among groups reasonably well.

Overwinter Survival

Overwinter survival has been estimated for "winter migrants" -- pre-smolts that emigrate from their natal areas the fall and winter preceding the spring of smoltification -- but never for the fraction of the population that remains in natal areas until spring. Survival of Naches system winter migrants (to Prosser Dam) has ranged from 22.2% (winter of 1986-87) to 49% (winter of 198990). The survival of winter migrants branded at Roza in the winter of 198990 was 44.9%. As mentioned in the previous section, the majority of both Naches system (Wapatox) and upper Yakima (Roza) winter migrants that survive to Prosser actually pass Prosser in the spring.

Smolt-to-Smelt Survival

There is evidence to suggest that virtually all of the mortality incurred by wild, actively outmigrating smolts occurs between Sunnyside and Prosser dams. The evidence supporting this contention is provided by four releases of branded wild spring chinook smolts made in April of 1988. Releases occurred at four sites, above Roza Dam, above Sunnyside Dam, below Sunnyside Dam and below Wapatox Dam. All fish for the Yakima releases were collected at Roza Dam (upper Yakima stock); all fish for the Naches release were collected at Wapatox Dam (Naches system stock). Each release consisted of four, distinctively branded sub-lots. The survival to Prosser of the four sub-lots released above Roza, above Sunnyside and below Sunnyside was 56%, 61% and 54%, respectively, while the mean survival of the sub-lots released at Wapatox was 40 % . If sub-lots are treated as replicates and an ANOVA is performed, none of the survival estimates are significantly different. Because survival was equivalent for all Yakima releases, it was concluded that essentially all of the mortality was incurred below Sunnyside Dam. Although the Wapatox release was not significantly different, the 15% to 20% difference in survival was regarded as "real," as representative of Naches smolts. This interpretation was justified by the smaller size and greater predatory vulnerability of Naches smolts, and by the fact past Wapatox releases have resulted in substantially lower survival rates than were observed for upper Yakima fish in 1988. The mean survival to McNary of all upper Yakima sub-lots was 40%, while the mean survival to McNary for all Naches system sub-lots was only 12%.

Survival of Wild Fish from Prosser to McNary

McNary passage indices of branded wild spring chinook used to estimate entrainment at Prosser were examined in an attempt to index survival from Prosser to McNary. Survival was indexed by dividing the McNary passage index by the number of fish released at Prosser. The mean survival estimates for wild smolts released in 1984, 1985, 1986 and 1988 were 53%, 50%, 42% and 71 %, respectively, although individual estimates ranged from 10% to 100%.

Surprisingly, no relationship between flows below Prosser and migration rate (to McNary) was observed. Even more surprising was the lack of a relationship between

migration rate and survival. Failure to demonstrate these intuitive relationships was interpreted as a probable artifact of small samples sixes and imprecise estimators.

Survival of Hatchery Fish to Prosser and McNary

The migration and survival rates of hatchery-reared smolts from upriver release points to Prosser and McNary dams *were* related to flow. Specifically, migration rate and survival were positively correlated with water velocity in two reaches -- the Yakima River bordering the city of Yakima, and the Yakima River below Sunnyside Dam. The correlation between migration rate and water velocity was significant for both reaches, as was the correlation between water velocity below Sunnyside and survival to both Prosser and McNary.

The importance of the relationship between flows below Sunnyside and smolt survival is that mean flows must be much greater than is commonly observed if survival is to be substantially improved by flow augmentation alone. For example, flows below Sunnyside would have to average -4,300 cfs through April and May to achieve a McNary survival rate of 50%, while a survival rate of 75 % entails mean flows of – 7,200 cfs. Mean flows below Sunnyside from 1982 through 1987 for April and May have been 2,295 cfs and 3,000 cfs, respectively.

Potential Causes of Poor In-basin Survival

Six potential causes of poor survival were identified. They are:

1) Entrainment or trauma associated with entrainment/bypass at irrigation diversions.

2) Physical stranding in braided areas and side channels.

3) Disease.

4) Poor water quality.

5) Residualization.

6) Predation exacerbated by low flows below irrigation diversions.

Available data indicates that all possibilities but the last (flow-mediated predation) are unlikely to play a major role in the Yakima River.

A plausible argument can be made that *all* in-basin smolt losses are attributable to predation by northern squawfish If squawfish feed at the rate of one smolt every three days for an outmigration of 68 days (April 1 through June 7), a population of only -9,000 squawfish would be required to cause losses as large as those estimated in the Yakima.

Consumption rates of one smolt per day require a population of only – 3,000 squawfish. The densities of squawfish that would be required between Sunnyside and Prosser to give a total population of 3,000 to 9,000 fish are not unusual, and have been documented in a number of northwestern rivers and reservoirs.

Three areas besides the reach between Sunnyside and Prosser have been identified as potential "hot spots" for squawfish predation. They are the forebay and bypass outfall area of Roza Dam; the forebay and bypass outfall area of Wapato Dam; and the Naches River between Wapatox Dam and the Wapatox Powerplant outfall.

Egg-t&molt Survival

Expressed as spring smolts (outmigrants observed between March 1 and June 30), egg-to-smolt survival has ranged from 1.1% (1989 outmigration) to 8.8% (1983 outmigration). If winter migrants are classed as smolts, the range is 1.3% to 10.6%. Survival has generally declined since the 1983 outmigration, reaching a low point in 1989, and rebounding to 3.6% in 1990.

Yakima Indian Nation biologists performed a number of regressions to attempt to elucidate the cause(s) of the observed decline in egg-to-smolt survival. The analysis included two biotic variables (egg deposition and total smolt production) and 24 abiotic variables that consisted of hydraulic parameters for specific reaches at specific times. Among the hydraulic variables were such items as:

1) The number of days flows were low enough in the Easton reach of the Yakima to risk stranding fry in side channels and braids during the early post-emergent period (April through July).

2) The mean width, depth and cross-sectional area through the winter (October through February) in a number of reaches where overwintering might occur.

3) The probability of avoiding entrainment in major irrigation diversions.

4) The mean velocity, depth, width and cross-sectional area of the reach below Sunnyside Dam during outmigration.

The only significant one-variable correlations were between egg-to-smolt survival and: egg deposition; the number of days Easton flows threatened fry stranding; the mean width, depth and cross-sectional area of the Yakima Canyon during the winter before outmigration; and the mean overwinter cross-sectional area in the lower Naches the winter before outmigration. None of the irrigation dam "avoidance probabilities" were significant, nor were any of the hydraulic parameters describing conditions below Sunnyside Dam during outmigration.

In stepwise regressions covering brood years 1981 through 1988 that used all "independent variables, " biotic as well as abiotic, the first variable entered was egg deposition and the second was total smolt production. The coefficient of the egg deposition term was negative, suggesting density-dependent mortality; the coefficient of the smolt production term was positive, suggesting depensatory smolt mortality. The third variable entered was avoidance probability at Wapato Dam and the fourth was the combined avoidance probability at Roza, Wapato and Sunnyside dams. It should, however, be noted that the two-variable regression, which included no hydraulic variables, had an $\mathbf{R^2}$ of .93. Addition of the two hydraulic variables increased $\mathbf{R^2}$ only 6% to .99.

A second stepwise regression was performed omitting any variable relating to egg deposition to highlight important variables related to flow. For the years covered by the study (brood years 1981 through 1988), the first variable entered was the number of days flows were critically low in the Easton reach during the early post-emergent period. Subsequent variables either related to avoidance probabilities at irrigation diversions, or to widths and depths in suspected overwintering areas. The $\mathbf{R^2}$ for the best four-variable regression excluding egg deposition was .98 for the data relating only to the years of the study.

The preceding regression analysis led Yakima biologists to draw five major conclusions:

1) Biotic density-dependent or depensatory factors (egg deposition and total smolt production) appear to explain more annual variability in egg-to-smolt survival than do the particular flow-related variables examined.

2) Nevertheless, good fits can be obtained with flow-related variables alone at the three- and four-variable level.

3) The most significant flow-related variables are avoidance probability at Wapatox and Wapato dams, and the frequency of critically low flows in the Easton reach during the early post-emergent period.

4) The decline in egg-to-smolt survival from the 1981 brood through the 1987 brood was primarily attributable to increasing egg deposition, increasing frequencies of low flow days at Easton during the post-emergent period, and decreasing avoidance probabilities at several irrigation dams.

5) Perhaps most significantly, even if egg deposition and total smolt production are the best predictors of egg-to-smolt survival ***under the current conditions,*** it does not follow that flows are unimportant nor, indeed, that they are not the primary factor limiting production. To see the truth of this assertion, one need only consider the Yakima Canyon, which is probably the single most important habitat for summer rearing in the basin. Instream flows in the Yakima Canyon

through the irrigation season (roughly late June or July through mid October) are so high that weighted usable area for juvenile spring chinook rearing is only about 20 percent of optimal. Thus, because they are regulated and are very similar from year to year (at least during the irrigation season), flows may be limiting although not particularly useful as predictors.

Smolt-to-Adult Survival

Estimates of smolt-to-adult survival **(S_{sa})** for wild spring chinook salmon in the Yakima system were based on the estimated outmigration of smolts at Prosser Dam from 1983 through 1987. Adult returns corresponding to each year's smolt outmigration were calculated as the sum of the jacks (3-year-old fish) returning one year after the outmigration, and the 4-, 5-, and 6-year-old adults returning two, three and four years after the outmigration. Jack return was determined directly from counts at viewing windows on fish ladders at Prosser Dam. The contribution of 4-, 5- and 6-year-old adults entailed an age-class analysis based on scales collected from carcasses on the spawning grounds.

Three distinct substocks of spring chinook (American River, Naches River and upper Yakima River) occur in the Yakima Subbasin (Busack 1990). The age-class composition of each substock was determined separately. The proportion of total returns attributed to each substock in a given year was estimated by the proportion of all redds counted in the basin deposited in each of the three, distinct spawning areas. The age-class composition of each substock was then applied to the appropriate proportion of the total adult return (exclusive of jacks) to the Yakima Subbasin. Total adult return was estimated by the sum of Prosser Dam counts and the tribal ceremonial and subsistence harvest below Prosser.

Smolt-to-adult survival estimates begin with the 1983 outmigration and end with the outmigration of 1987. Smolt outmigrations were also estimated in 1988, 1989 and 1990, but adult returns for those outmigrations are not yet complete.

The total number of adults (3-year-old through 6-year-old fish) returning from the smolt outmigrations of 1983 through 1987 has ranged from 4,209 to 8,596 fish. The average adult return for these five years was 5,655 fish. Thus, smolt-to-adult survival has averaged 3.7%, and has ranged from 1.7% to 6%. It should be noted that these figures are influenced by the location of the smolt trap and the extent of smolt mortality incurred before smolts were counted at Prosser. Experimental releases of marked wild smolts indicate that this pre-counting mortality may be on the order of 50%. Thus, smolt-to-adult survival based on the number of smolts *at the beginning of the outmigration* might be about half of the preceding figures.

Because of a lack of identifying marks (such as coded-wire tags), the factors affecting smolt-to-adult survival of wild spring chinook in the mainstem Columbia, the estuary, and on the high seas are very difficult to identify. It is believed that passage at mainstem dams, especially in drought years, has had a very negative impact on smolt survival. Some studies

(Park 1985) have also indicated that the smolt transportation program on the mainstem Snake and Columbia have had at best a marginal impact on survival of spring chinook smolts. Ocean survival depends on many factors (such as food supply, water temperature and fishing effort, especially from the new high-seas drift net fishery) that are uncontrollable and very difficult to assess for individual stocks. Adult returns are diminished by mortalities associated with ladders on mainstem dams as well as by Columbia River fisheries. These fisheries include lower Columbia commercial gillnetters, state test fisheries, sport fishing and tribal ceremonial and subsistence fishing. As discussed in the section on adult returns of hatchery-reared fish, the average Columbia River harvest rate of hatchery-reared Yakima spring chinook has been about 25 percent. It is at least possible that wild fish are subject to comparable harvest rates.

Factors Limiting Rearing Potential

The major factors that limit spring chinook rearing potential in the Yakima Subbasin were determined to be suboptimal instream flows, passage around diversions, degraded riparian and instream habitat, and water quality.

Suboptimal Instream Flows

Suboptimal instream flows are the direct result of the available water supply in the Yakima Subbasin being overallocated. This problem of water rights holders claiming more water than is available in low water years is currently being adjudicated in the Washington State Court System.

There are currently no legally binding minimum instream flows for the Yakima. Current instream flows are determined by the difference between total available water (natural runoff plus irrigation storage reservoir releases) minus irrigation and-all other demands for water. Instream flows are rarely optimal anywhere in the subbasin, and may be catastrophically low for fish production in drought years. Large volumes of water are released during irrigation season, resulting in mainstem flows that are much greater than optimal. Water releases are cut back dramatically after the irrigation ends and virtually overnight the resulting mainstem flows become suboptimal or even critically low for fish.

Passage Around Diversions

Most of the major mainstem irrigation diversion canals in the Yakima Subbasin have been outfitted with state-of-the-art bypass screening systems between 1985 and 1990 under the Phase I Screening Project. These efforts have improved smolt outmigration by reducing direct mortalities, reducing the delay in travel time, and reducing long-term mortality due to injury and descaling.

Approximately 67 small to medium sized diversions, however, are not screened or have inadequate, obsolete or deteriorating screens. These Phase II diversions are located in spring chinook production areas and collectively constitute a major hazard for dispersing fry and outmigrating smolts. The Phase II screening projects are currently being developed by the Fish Passage Technical Work Group and will be constructed by 1995. The successful construction and operation of the Phase I and II diversion screening projects will greatly reduce the mortality associated with passage around diversions in the subbasin.

Degraded Riparian and Instream Habitat

The riparian and instream habitat of the Yakima Subbasin has been degraded due to poor forest practices in the headwater areas, which has increased stream temperatures, accelerated sedimentation, accentuated sudden changes in flow, and caused earlier runoff and lower late summer natural flows. Habitat has also been degraded due to agriculture, which is responsible for overgrazing many riparian areas and channelizing many sections of the mainstem and especially the tributaries of the subbasin, and streamside development, which has removed riparian habitat and buttressed streamside areas to prevent loss of property and buildings.

Water Quality

Water, both quantity and quality, presents limitations to the natural production of spring chinook in the Yakima Subbasin. Water quantity was discussed in the suboptimal instream flow section. Water quality ranges from good to excellent in the upper reaches down to fair to poor in the lower Yakima Valley. The Yakima receives pollutants from both irrigated agricultural lands and from municipalities and industrial wastes as it flows to the Columbia. The Yakima River below Union Gap is generally unfit for salmonid survival during the summer months when irrigation return flows can comprise over 80% of the total stream flow. Water temperatures that often exceed 70°F and occasionally reach 80°F are responsible for the lack of salmonid production in the lower river. Suspended sediments from irrigation return drains also present problems in the lower basin. Under current water management, there is little chance to improve the water quality in the Yakima Subbasin.

HATCHERY OPERATIONS

Introduction

An important objective of this project was to evaluate several methods of supplementation that could potentially be used to help rebuild the spring chinook salmon runs of the Yakima Basin and elsewhere in the Columbia system. In this study, supplementation is defined as the use of hatchery-reared fish to increase the magnitude of natural production. The critical uncertainties that were tested included the manner of release, the time of release, and the brood stock used.

To evaluate the manner of release, Yakima biologists tested fish released volitionally from acclimation ponds against fish that were trucked and released directly into the river. The time of release was evaluated by releasing test groups of fish as fry in June, parr in September, and pre-smolts in November. The effect of parentage was tested by comparing survival of progeny produced by three different mating scenarios -- wild Yakima River males with Yakima females (WxW), wild Yakima males with Leavenworth Hatchery females (WxH), and Leavenworth Hatchery males and females (HxH).

Success was evaluated only in terms of post-release survival. The response variables that were measured included both survival of smolts from their release site to the juvenile evaluation facility at Chandler Canal, and also as adults returning to the Columbia and Yakima rivers. Smolt-to-adult survival was estimated in terms of the number of smolts released at upriver release points, and the number of fish estimated to have survived to Prosser. This distinction was made in an attempt to define the sources of mortality geographically.

In 1984, ‘85, and ‘86 the returning adults were collected in various fisheries, from carcasses collected on spawning surveys, and at various screens and dams to allow recovery of the coded- wire tags used as treatments marks. From 1987 through 1990 the majority of the returning experimental adults were collected at Roza fish ladder adult trap. This was done both to maximize the number of coded-wire tags recovered, and also to minimize the genetic risks associated with the spawning of non-native hatchery adults with wild/natural fish. Thus, since little if any spawning of hatchery reared salmon occurred, the reproductive success of the adults produced by these three mating scenarios was not determined in this study.

Smolt-to-Smolt Survival: Acclimated vs. Trucked Fish

In three years (1983, 1984 and 1986) of the four in which trucked and acclimated fish can be compared, the survival of acclimated fish to Prosser exceeded that of trucked fish. (No comparison is possible in 1987 because falling river levels trapped many acclimation fish in the acclimation pond). In 1985, survival to Prosser was approximately equal between

groups. Estimated survival to **McNary** was greater for acclimated fish in all four comparable years. For all releases but 1987, the mean survival to Prosser for acclimated fish was 48.496, ranging from 17.8% (1986) to 89.1% (1983), while the mean survival of trucked fish was 24.696, ranging from 8.2% (1986) to 40.4% (1984). Over these same years, the mean survival of acclimated fish at McNary was 39.796, with a range of 8.8% (1986) to 89% (1983). The mean survival of trucked fish at McNary was 22%, with a range of 4.8% (1986) to 44.6% (1983). Interestingly, the survival of both acclimated and trucked groups from Prosser to McNary was greater than survival from release point to Prosser.

In all years but 1987, the migration rate of acclimated fish was also greater than trucked fish. This was true at both Prosser Dam and McNary Dam.

There was no indication that differential size at release impacted relative survival of acclimated and trucked smolts. It was, however, observed that all hatchery-reared fish, regardless of group, were significantly larger when observed at Prosser than they were at release. This observation was assumed to result from a combination of growth and size-dependent differential mortality.

Smolt-to-Smolt Survival: Optimal Time of Release

The maximum survival to Prosser for fall-released pre-smolts was 11%, and the maximum survival to McNary was 5.5%. There was, however, no indication of the specific release time (in the fall) for optimal survival; September releases were better than November releases in 1984 (Prosser survival September ‘84 = 10.96%, November ‘84 = 3.71%), while the reverse was true in 1985 (Prosser survival November ‘85 = 9.39%, September ‘85 = 0.79%). It should be noted that the survival rates to Prosser and McNary are almost certainly underestimated because neither facility was operated in the winters of 1984-85 and 1985-86, and there is evidence that an undetermined number of fall-released pre-smolts emigrated during this period. It should also be noted that survival from Prosser to McNary (for the portion of the population that emigrated during the spring monitoring period) was again greater than survival from release point to Prosser.

The fry released in the upper Yakima in early June of 1984 and 1985 did not behave as expected. Instead of taking up residence and emigrating as smolts the following spring, most of the fish that could be accounted for simply left the system immediately, passing Prosser within two months of release. About 11% of the 1984 fry and 2.5% of the 1985 fry passed Prosser the summer they were released. No 1984 fry were observed at Chandler in the spring of 1985, and only 28 of the 9,102 branded fry released in 1985 were estimated to have passed Prosser in the spring of 1986. Note, however, that no winter monitoring was possible during the winters of 1984-85 and 1985-86. Thus, as is true of the fall pre-smolts, total passage at Prosser for the June fry is probably underestimated to some extent.

The most significant aspect of the observed patterns of outmigration is that, both in 1985 and 1986, the passage of both groups of fall pre-smolts was well ahead of wild smolts. It is therefore possible that fall-released hatchery pre-smolts migrate farther downriver during the winter then does the average wild pre-smolt.

As was the case for acclimated and trucked smolts, there was no indication that differential size at release impacted survival.

Smolt-to-Smolt Survival: Optimal Release Stocks

The stocks investigated included hatchery-reared native fish (the "wild" group), hatchery-reared Leavenworth x Yakima crosses (the "hybrid" group) and hatchery-reared Leavenworth fish (the "hatchery" group). Releases of all of these groups were made in 1986 and 1987; in each year, all groups were acclimated together in Mary's Pond on the upper Yakima River. It should be noted that the 1987 groups incorporated "quasi-replicates," as each treatment included four distinctly branded subgroups.

Estimated survival to Prosser was (marginally) greatest for the wild group in both 1986 and 1987. In 1986, the survival to Prosser of the wild, hybrid and treatment groups were 20.2 %, 18.7% and 17.8 %, respectively. The mean survival to Prosser of the combined subgroups of wild, hybrid and hatchery fish in 1987 was 10.6%, 2.8% and 3.7%, respectively. (Recall that the lower overall survival rates of the 1987 groups are an artifact attributable to an unknown number of test fish being stranded in the acclimation pond when river flows fell.) The superior survival to Prosser of wild fish was marginal in 1986, and in fact, all groups were regarded as equivalent. The difference in 1987 was more substantial. If the subgroups are regarded as replicates, the survival of wild fish in 1987 was significantly greater than the other groups, although the hybrid and hatchery groups are indistinguishable.

Estimated survival to McNary was slightly less than half the survival to Prosser in 1986 for all groups. However, the order of survival was reversed relative to Prosser, with hatchery fish doing best, hybrid fish next best and wild fish worst. The absolute differences were quite small, ranging from 6.9% (wild) to 8.8% (hatchery), and the survival of all groups to McNary should probably be regarded as equivalent. In 1987, on the other hand, the "apparent survival" of wild fish to McNary was again significantly greater than the other groups. Note that the higher recovery rates of wild fish in 1987 may not reflect better inriver survival so much as the inclination and ability to swim through a small channel in the process of drying up.

Again, for all groups and over both years, the apparent survival from Prosser to McNary was greater than the survival from release point to Prosser.

The study provided little evidence that hatchery-reared smolts that are genetically identical to natural Yakima fish will enjoy higher in-basin survival rates than non-native

hatchery-reared fish. Wild recovery rates were clearly superior to hybrid and hatchery rates only in 1987, and even then it was not clear whether higher recover rates reflected higher survival of outmigrating smolts in the Yakima River.

Adult Return Rates: Acclimated vs. Trucked Fish

Smolt-to-adult survival for acclimated fish was higher than survival of trucked fish in all four experimental releases. The mean survival of acclimated smolts from the site of release to returning adult at Prosser was 45% higher for acclimated smolts. The relative superiority of acclimated smolts falls to 23% when survival is expressed in terms of "smolts at Prosser." The diminution of the relative superiority of acclimated smolts when survival is expressed as smolts surviving to Prosser undoubtedly reflects the higher survival rate of acclimated smolts in the period immediately following release. It is, however, significant that acclimated smolts still return at higher rates than trucked fish even when based on Prosser survivors; therefore, the benefits of acclimation apparently persist after the brief period immediately following release. On the basis of this study, it would appear that about 50% of the survival benefits attributable to acclimation are expressed immediately after release.

Adult Return Rates: Optimal Release Time

Expressed in terms of fish at release, the mean adult return rate of June-released fry was only 0.016%. This low rate was greatly impacted by the extremely low (0.003%) return rate of the fry released in June of 1984. Return rates of this magnitude would obviously contribute little to overall production in the Yakima. It should, however, be noted that a previous, larger-scale study on the Lemhi River in Idaho suggested that fry released in May and June *probably* did result in a substantial increase in the production of what we have called winter migrants and, to a much lesser degree, spring smolts (Bjomn 1978). Studies of this sort indicate that the issue has not yet been settled, and a considerable amount of research involving fry releases is currently planned in Idaho.

The mean return rate per fish released for September parr was 0.08%, and the comparable figure for November pre-smolts was 0.05%. While parr and pre-smolt releases were clearly superior to fry releases, the rates we have observed in the Yakima do not justify their utilization as a means of augmenting production. Again, the Yakima study may not be applicable to other systems. Researchers in Idaho believe the technique has potential in a number of systems, and plans are under way for a number of major research projects.

Adult Return Rates: Optimal Release Stocks

The limited results of two years' releases of acclimated wild, hybrid and hatchery smolts indicated that the mean return rates per fish released were 0.06% for the two "wild" groups and 0.055& for the two hybrid groups. Due to accidental mixing of tagged fish in the hatchery, only one group of hatchery fish can be evaluated. The return rate of this group, released in 1986, was 0.04%. Thus, the effect of ancestry alone had little effect on the post-release survival of hatchery-reared fish.

Although compromised in a number of ways, the results of this study are interesting because they suggest that hatchery-reared wild stock does not perform better than either non-native hatchery stock or hatchery-wild hybrids. Therefore, genetic considerations alone may not result in substantial improvements in the post-release survival of hatchery-reared fish. The emphasis in hatchery operations, especially those employed in supplementation, must be shifted from maximizing the number of smolts released and redirected to the development of new procedures designed to increase survival in the natural environment. Undoubtedly, genetic considerations are crucial to the reproductive success and long-term fitness of hatchery-reared fish *that have survived to return as adult spawners.* However, new procedures incorporating physiological and, especially, behavioral considerations, in addition to genetic considerations, may be necessary for real improvement in post-release survival.

Again, the current study investigated neither the reproductive success nor the long-term fitness of hatchery-reared salmon that spawn in the wild. Emphatically, such research is needed in the future.

RECOMMENDATIONS

The results of the eight years of research on spring chinook salmon in the Yakima Subbasin indicated that the following critical uncertainties exist and should be addressed with further research efforts in the future.

1) Determination of the locations, causes, and magnitude of smolts lost during their inriver migrations through the subbasin.

   Researchers repeatedly observed smolt losses of 50% to 80% from upriver release points to Prosser Dam. Preliminary studies have indicated that serious losses occur below Wapatox, Sunnyside and Prosser dams, and these areas should be investigated. Investigations should not, however, be limited to these reaches, but should include the entire mainstem Yakima and Naches rivers.

A smolt survival study should not be limited to predation. Non-predatory losses could include residualization, disease, water quality (temperature, dissolved oxygen, toxins), entrainment in Phase-II diversions and physical stranding.

2) Quantification of the relationship between instream flow and smolt production.

This relationship must be defined for spring flows in reaches above major rearing areas, for winter flows and water surface elevations in suspected overwintering areas, and for summer flows in major rearing areas.

3) Development and/or refinement of habitat-based carrying capacity estimators.

All available estimators entail fairly bold assumptions, including the estimate based on weighted usable area (IFIM). These assumptions must be checked and revised as necessary.

4) Determination of the physical and\or behavioral differences between hatchery and wild smolts that could account for the magnitude of difference in their survival rates from smolt to adult.

Modification of hatchery practices could result if it is found that differences in survival can be attributed to physical or behavior changes produced by hatchery rearing.

5) Determination of whether reproductive success or long-term fitness of the locally adapted Yakima Subbasin spring chinook stocks would be affected from supplementation using local brood stocks.

Preliminary results indicated that local brood stock does not automatically produce a hatchery-reared smolt that has superior survival from smolt to adult over hatchery brood stock. However, the reproductive success or long-term fitness of the local stocks may suffer if hatchery brood stock is used in future supplementation efforts.

6) Determination of the relationship between duration of in-basin outmigration and subsequent adult returns.

7) Determination of the "outmigrant-to-adult" return rate for spring chinook passing Prosser in the late fall and winter.

As about one-fourth of brood year outmigration has been observed in the winter, this is an issue of some importance. It would also be useful to know whether the magnitude of winter movement is related to egg deposition and/or rearing density in suspected overwintering areas.

I. DESCRIPTION OF STUDY AREA

General Information

The Yakima Subbasin is located in south-central Washington. It drains an area of 6,155 square miles and contains about 1,900 river miles of perennial streams. The subbasin is centered around the city of Yakima and includes most of Yakima and Kittitas counties as well as small portions of Benton and Klickitat counties. The Yakima Indian Reservation is located in the southwest comer of the subbasin just south of the city of Yakima. The Yakima River originates near the crest of the Cascade Range above Keechelus Lake at an elevation of 6,900 feet and flows 214 miles southeastward to its confluence with the Columbia (RM 335.2; see Fig. 1). Major tributaries include the Kachess, Cle Elum and Teanaway rivers in the northern part of the subbasin, and the Naches River in the west. Major tributaries to the middle portion of the Yakima include Ahtanum, Toppenish and Satus creeks. Toppenish and Satus creeks lie wholly within the Yakima Indian Reservation; Ahtanum Creek forms the northern border of the reservation. The Naches has four major tributaries, the Bumping, American, Tieton and Little Naches rivers.

Six major reservoirs are located in the subbasin. The Yakima River flows out of Keechelus Lake (157,800 acre-feet), the Kachess River from Kachess Lake (239,000 acre-feet), the Cle Elum River from Cle Elum Lake (436,900 acre-feet), the Tieton from Rimrock Lake (198,000 acre-feet), and the Bumping from Bumping Lake (33,700 acre-feet). All reservoirs except Rimrock Lake were natural lakes before impoundment.

Six major diversion dams are on the mainstem Yakima, and several smaller dams are on the Naches. From uppermost to lowermost, the Yakima dams are Easton (RM 202.5), Roza (RM 127.9), Wapato (RM 106.6), Sunnyside (RM 103.8), Prosser (RM 47.1) and Horn Rapids (RM 18.0). The major dams on the Naches are Wapatox (RM 17.1) and Naches Cowiche (RM 3.6). A screening structure is associated with each of these diversion dams.

Sunnyside and Wapato dams usually divert at least half of the total river flow into irrigation diversions during the irrigation season, and may divert much more than half during dry periods. Prosser diversion removes approximately 1,400 cfs for irrigation and power production throughout most of the year. Due to the large irrigation diversions at Sunnyside and Prosser, flows drop dramatically in the lower river from May to October, and sometimes as early as April when runoff is low. Approximately 50% of the flows withdrawn at diversion sites re-enter the river downstream after being used for irrigation or hydropower.

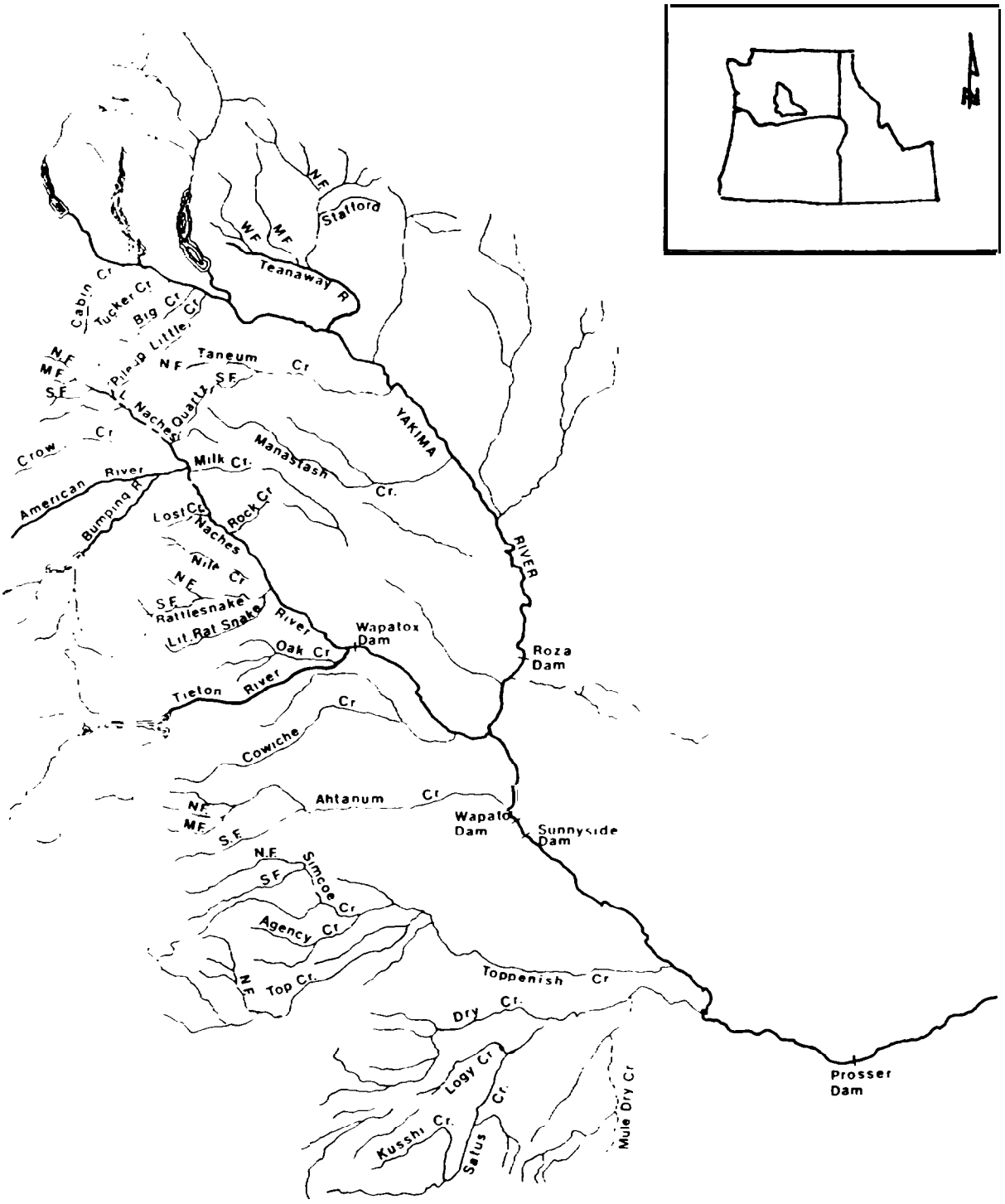


Figure 1. The Yakima River Basin in south-central Washington.

Prior to 1980, flows remained high on the spawning grounds in September and October for irrigation purposes. Many fish that spawned at this time deposited their eggs in shallow water near the bank. When flows were decreased at the end of the irrigation season, these redds were often dewatered. Following court action in 1981, the irrigation flows were decreased in the Yakima branch during the first week of September so that this problem would not continue. To offset the reduction of flows from the upper Yakima in September, flow is increased in the Naches River mainly from Rimrock Reservoir releases. This increased flow enters the Naches River below the areas where most spring chinook spawning occurs, and is therefore not believed to impact spawning success except in the Tieton River.

Topography in the subbasin is characterized by a series of long ridges extending eastward from the Cascades and encircling flat valley areas. Elevations in the subbasin range from about 7,000 feet in the Cascades to about 350 feet at the confluence of the Yakima and Columbia rivers.

Seven soil associations exist in the Yakima Subbasin. Four of these associations, (Weirman-Zillah, Renslow-Ritzville, Naches-Woldale and Warden-Shano), comprising about 18 percent of the subbasin's area, are located in gently sloping areas and are subject to intensive irrigated agriculture. These soil types are tine textured and easily eroded (Anonymous, USDA 1974).

Vegetation in the subbasin is a complex blend of forest, range and cropland. Over one-third of the land in the Yakima Subbasin is forested. Rangeland lies between cultivated areas, located in the fertile lower valleys, and the higher-elevation forests. Cropland accounts for about 16% of the total subbasin area, and 77% of existing cropland is irrigated.

The climate of the Yakima Subbasin ranges from cool and moist in the mountains to warm and dry in the valleys. Annual precipitation near the Cascade crest ranges from 80 inches to 140 inches, whereas the lower elevations in the eastern part of the subbasin receive 10 inches or less. Summer temperatures average 55°F in the mountains, and 82°F in the valleys. Average maximum winter temperatures range from 25°F to 40°F, while average minimum winter temperatures range from 15°F to 25°F. Minimum temperatures of -20°F to -25°F have been recorded in most areas.

Irrigated agriculture is the economic base of the Yakima Subbasin. In 1982, about 400,000 irrigated acres produced an estimated gross crop value of $500 million. Major crops include apples, cherries, peaches, pears, grapes, mint, grain, corn, hops and alfalfa. Livestock production and forestry are also important contributors to the economic base. The major industries in the subbasin are related primarily to the processing of agricultural and forest products.

Riparian conditions are extremely varied, ranging from severely degraded to nearly pristine. Good riparian habitat generally is found along forested, headwater reaches, whereas

degraded riparian habitat is concentrated in the valleys, frequently associated with agricultural activity, especially grazing.

Water Resources

Water is central to the productivity of the agricultural economy and the fisheries of the Yakima Subbasin. While the water resources of the subbasin are subject to problems of both quantity and quality, quantitative concerns are more important. Water quality in the Yakima Subbasin is good to excellent in the upper reaches, but only fair to poor in the lower valley. As the Yakima River passes through the Kittitas Valley (headwaters to Roza Dam), it receives pollutants from irrigated pasturelands and municipalities. Although almost all water quality indices suffer a progressive deterioration through this section, overall water quality would still be considered good as the river passes Roza Dam.

Through its middle reaches (Roza to Sunnyside Dam), the Yakima River receives treated wastes from Yakima, Selah, Union Gap, and Terrace Heights as well as irrigation returns from the Ahtanum Creek and the Moxee area. Normally, however, water quality is only slightly degraded because pollutants are diluted with large volumes of high quality water from the Naches River. Water quality can therefore still be considered good as far as Union Gap.

Water quality degrades rapidly in the lower subbasin (Sunnyside Dam to Columbia River). Most of the summer flow is diverted at Wapato and Sunnyside dams, and large volumes of warm, turbid irrigation water with a high content of nutrients, suspended sediments and fecal bacteria are added a short distance downstream. While irrigation return flows comprise about 5% of the yearly Yakima River flows in the reach from Sunnyside Dam to Wilson Creek, below Sunnyside Dam this percent increases to more than 30% on an annual basis, and to more than 80% in the summer months (Anonymous 1974). The summertime concentrations of (nitrate + nitrite) orthophosphate, chlorophyll A, specific conductance and turbidity all reflect the virtual transformation of the Yakima River below Granger (RM 83) to a seasonal irrigation return; in all cases, concentrations rise to levels approaching those observed in irrigation drains (Mongillo and Falconer 1980). However, those levels are not acutely toxic to fish.

Water temperatures and substrate quality present problems in the lower Yakima. Mean July temperatures at Kiona range from 70°F to 78°F, with maximum July temperatures occasionally reaching 80°F. Although a survey of particle size distribution of substrate materials in the lower river has never been conducted, the deposition of fine materials is undoubtedly a problem, especially between Union Gap and Kiona. Eleven major irrigation drains enter the Yakima River in this reach, discharging between 122,000 and 127,000 tons of suspended sediments yearly (USGS Open-File Report 78-946). It is possible that much of this material settles out before reaching Kiona as summertime turbidity begins rising at Union

Gap, peaks in the vicinity of Granger, and falls at Kiona to levels not substantially greater than those observed at Union Gap (Mongillo and Falconer 1980).

Pesticide contamination is also a potential problem to fish in the lower Yakima. In 1985 the Washington Department of Ecology's water quality investigations section conducted an evaluation of the hazards to human health and aquatic life presented by toxic chemicals (DDT and metabolites, 15 additional organochlorine pesticides, PCBs and mercury) in water, sediments and fish tissues. Major organochlorine compounds detected in fish were DDT, DDE, dieldrin and PCB-1260. Fish in the lower river had higher concentrations than fish in the upper river, and resident fish had higher concentrations than juvenile anadromous salmonids. Concentrations of all substances were, however, well below FDA "action levels." The concentrations of all substances in fish tissues were not high enough to suggest the possibility of impaired reproduction. DDT, DDE, DDD, dieldrin and endosulfan, evidently of historic origin, were detected in water samples taken from irrigation drains (Sulphur Creek, Birchfield Drain, Granger Drain, and Snipes/Spring Creek) and in one instance from the Yakima River at Kiona. All were present in concentrations below those known to be acutely toxic to aquatic life.

Water Supply

Water supplies in the Yakima Subbasin are severely overtaxed by the competing demands of irrigation and instream flows for fish production. Moreover, except for a minimum flow below Prosser Dam and a court-ordered minimum flow for egg incubation in the Yakima from Easton Dam to the Teanaway and in the Cle Elum River, there are no binding minimum instream flows for fish (the Washington Department of Energy is prevented by state law from requiring existing water rights to meet new instream flow requirements). Subject only to the above exceptions, current instream flows represent the difference between available water (storage plus runoff) and irrigation and other demands. As available water and demand are rather precariously balanced, instream flows are rarely optimal anywhere in the subbasin, and may be catastrophically low for fish production in drought years.

In an average year, the total available water supply in the subbasin is barely adequate for irrigation and never adequate for optimal fish production. To satisfy irrigation needs, a great volume of water is released during the irrigation season, resulting in flows in many reaches of the mainstem Yakima that are much greater than optimal. The lack of water in the subbasin for fish production is felt in the main river primarily after the irrigation season ends, when releases are cut back dramatically to refill the reservoirs, and flows in most mainstem reaches become suboptimal or even critically low for fish. Note, however, that instream flows can become critically low even during the irrigation Season, especially in reaches below diversion dams. Moreover, instream flows in many tributaries (the Teanaway River and Taneum, Manastash, Big, Wenas and Ahtanum creeks) are impacted by irrigation withdrawals more severely than the main Yakima, and the lower

reaches of these streams are virtually or actually dewatered by late spring or early summer. In dry years, water supply is wholly inadequate everywhere in the subbasin. Based on the historical record, rationing of irrigation water will be necessary in nine of 52 years (17.3 percent), and instream flows will be extremely low or nonexistent throughout the subbasin.

Water supply in the subbasin is provided by natural runoff, irrigation return flows and storage (groundwater use is negligible). Although the mean total subbasin runoff (3.4 million acre-feet) is 1.5 times the irrigation demand (2.3 million acre-feet), problems still arise because only 1.07 million acre-feet can currently be stored, and because much of the runoff occurs quickly, in May and June (Yakima River Basin Water Enhancement Project Phase II Status Report 1985). The irrigation season extends from March through mid-October, and natural runoff is normally adequate to meet demands through June. By the first week of July, however, stored waters are usually required to meet delivery demands. Since storage capacity and normal irrigation demand from July 1 through the end of the season are almost identical, releases must be carefully timed, especially if precipitation is less than normal. Moreover, it is desirable that there be some "carryover" of stored water from one season to the next, as the reservoir system may not refill following two consecutive dry years.

The Yakima River Basin Water Enhancement Project Phase II Status Report made a series of predictions based on a 52-year period of record (19261977) regarding the adequacy of irrigation supplies and anadromous fish production assuming the present demand and operating policies were maintained. As previously mentioned, some degree of rationing of irrigation water would be necessary in nine of 52 years, with less than 70% of "current diversions" (defined as the mean over the non-drought years from 1973 to 1982) being delivered in three years, and a lesser degree of rationing in six others. In the most water-deficient year, a repetition of the 1941 supply conditions, "proratable irrigators" would receive less than 40% of current supply. From a fisheries perspective, most reaches of the Yakima experience critically low, excessively high or radically fluctuating flows depending on the season. An IFIM-based (instream flow incremental method) analysis (Stemple 1985) indicated total anadromous spawning runs under current conditions would reach equilibrium at 17,600 adults under current conditions. Mean run size to the Yakima Subbasin for all anadromous fish in the decade of the 1980s has ranged from slightly more than one half to about one quarter of this figure.

A summary of specific adverse impacts on the subbasin's fisheries attributable to a problematic water supply would include:

1) Passage problems associated with diversions. Problem diversions include both those that physically impede spawning adults and unscreened diversions that entrain juveniles. Currently, these are found primarily in tributaries.

2) Passage and rearing habitat restrictions resulting from low flows. Problems occur both in tributaries and the mainstem. Most of the tributaries in the subbasin suffer from severe low flow problems in the summer and early fall, and most are attributable to irrigation diversions in their lower reaches (an important exception is the low flow problems in the Satus system, which are attributable to the combination of a low water table, permeable soils and low precipitation). Mainstem reaches also suffer periodic episodes of critically low flow, the most significant of which occur in the Yakima from Keechelus Dam to Easton Dam, in the Yakima from Easton Dam to the Cle Elum River, in the Yakima from Sunnyside Dam to the Chandler power plant outlet, and in the Naches from Wapatox diversion to the Yakima confluence. The Keechelu/Easton and Easton/Cle Elum situations are attributable to the absence of releases from Keechelus Reservoir during refilling and maintenance periods, and the others are attributable to diversions.

3) Adverse impacts to spawning and rearing habitat associated with rapid daily flow fluctuations below storage reservoirs and diversion dams. Areas having such problems include both tributaries and mainstem reaches, and are usually confined to areas immediately below reservoirs. The Yakima below Keechelus Dam and below Easton Dam, the Cle Elum River, the Kachess River, the Yakima from Sunnyside Dam to Prosser Dam, the Yakima River from Roza Dam to the Naches confluence, the Tieton River and the Bumping River all suffer episodes of severe flow fluctuation (more than 300% in 24 hours) several times a year (Mongillo and Falconer 1980).

4) Deposition of fine sediments on fall chinook spawning beds in the lower river. This problem is exacerbated by the low instream flows in the Yakima from Union Gap to Kiona during the irrigation season.

5) False attraction flows associated with irrigation returns and wasteways. This problem is also more severe in the lower river from Union Gap to Kiona, as low instream flows increase the attractiveness of returns.

6) Impaired upstream and downstream migration and degraded spawning and rearing habitat caused by annual river channel berming at small diversions in tributaries.

7) Degraded rearing habitat caused by prolonged, excessively high flows. Such problems occur in the Yakima from the Cle Elum River to Roza Dam during irrigation season, and in the Bumping and Tieton rivers during the “flip flop” portion of the irrigation season.

8) High temperatures in the lower river in July and August. These temperatures reduce rearing habitat quality to marginal, and when above **75°F** would constitute at least a partial thermal block to stocks with late summer spawning runs, such as summer chinook and sockeye.

9) Pesticide concentrations above levels considered safe for chronic exposure to fish in irrigation returns. This situation could conceivably contribute to the very low egg-to-smolt survival rates of fall chinook spawning above Prosser Dam, especially those spawning in and just downstream from Marion Drain and downstream of Prosser Dam.

Land Use

Patterns of land ownership within the Yakima Subbasin are complex (Table A). Within the boundaries of the drainage, 62% of all land is publicly owned and 38% is private. Since the Yakima Subbasin is only approximately coterminous with Yakima and Kittitas counties, a more detailed description of ownership patterns in the subbasin is afforded by the patterns observed within these counties.

Table A. Land ownership in Kittitas and Yakima counties (in acres).

Land Owner	Kittitas County	Yakima County
Federal		
National Forest	400,670	509,452
Department of Defense	102,430	160,701
Public Domain	15,048	29,084
Fish and Wildlife Service	---	1,764
State		
Dept. of Natural Resources	141,295	150,397
Department of Game	139,487	63,925
Dept. Parks and Recreation	7,993	211
Yakima Indian Reservation		1,300,OOO
County	210	963
Municipal	512	2,732
Private	664,591	721,420
TOTAL	1,482,880	2,731,520

More than 70% of the public land in Kittitas and Yakima Counties is federally owned, 26% is state owned and the remainder is owned by local governments. Most high elevation forests are on federal and state-owned lands. The semiarid land that makes up the Yakima Firing Center straddles Kittitas and Yakima counties, and is used for military maneuvers and livestock grazing. The Yakima Indian Reservation in southern Yakima County comprises 25% of the bi-county area. Most of this land is tribally owned, with only a small portion within the reservation being “deeded land.” City and county ownerships are on valley floors near population centers. Privately owned lands are primarily used for agriculture, housing, commerce and industry, and are generally situated in valleys and on foothill slopes,

where irrigation and transportation are accessible. Private corporate land holdings such as Burlington Northern and Boise Cascade are generally in forested areas.

The predominant types of land use in the Yakima Subbasin include irrigated agriculture (1,000 square miles), urbanization (50 square miles), timber harvesting (2,200 square miles) and grazing (2,900 square miles). Although the area affected by timber harvesting and grazing is roughly five times the area affected by agriculture and urbanization, the intensity of activity makes agriculture and urbanization of primary importance to water quality.

A change from row crops to hay in the Kittitas Valley has gradually occurred, and there has been a shift from row crops to permanent crops (such as grapes, apples and pears) in the lower valley. These changes affect the amount of water needed for irrigation, the methods of applying irrigation water, and the quality of water draining from fields and returning to the Yakima.

Mining, wilderness designation, and hydroelectric projects are minor land uses in the Yakima Subbasin. Approximately 7.3% (about 450 square miles) of the subbasin lies within four wilderness areas, the William 0. Douglas Wilderness Area (Bumping River drainage), the Alpine Lakes Wilderness Area (Waptus River drainage), the Goat Rocks Wilderness Area (North and South Fork Tieton River drainage), and the Norse Peak Wilderness Area (Little Naches drainage). Unfortunately, because all of the habitat would otherwise be excellent, all of the area within the Alpine Lakes and Goat Rocks wilderness areas lies above impassable dams and is inaccessible to anadromous fish. There is very little active mining in the subbasin except for a cluster of gold mining operations on Swauk Creek. A number of claims have, however, been filed on Cooper River (a Cle Elum River tributary), and there are large, inactive coal mining sites near Rosalyn. There are three small-scale hydroelectric projects associated with irrigation canals -- the Roza project (73,690 megawatts per year), the Chandler project (68,030 megawatts per year) and the Naches Drop project on Wapatox Canal. The primary purpose of the Roza hydroelectric project is to provide power for pumping facilities along its distribution system, while power from Chandler goes to the Bonneville Power Administration grid.

II. METHODS AND MATERIALS

The size and methodological diversity of this study is such that a separate "methods" section containing only descriptions of the methods and procedures used in all phases of the study would be counterproductive. To avoid confusion, each of the topics covered in the results and discussion section is prefaced by a summary of the methods and procedures appropriate to the topic at hand. Very complex or detailed methods are dealt with in special appendices; the topic-specific methodological introductions contain only summaries.

III. RESULTS AND DISCUSSION

A) Natural Production

ADULT RETURNS

Overview

In the last 20 years, the spring chinook returns to the Yakima River have ranged from a low of 854 adults in 1972 to 9,442 in 1986. The average run since 1981 is 3,819 adults. The first adult returns to benefit from the additional winter flows for egg incubation and the subsequent "flip-flop" water management plan returned as 4-year-olds in 1984 and 1985, respectively. The 5-year-olds benefitted in 1985 and 1986:

Year	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Return	1334	1549	1324	2676	4527	9442	4364	4356	4917	3698

The median date of adult passage is May 16 and June 1 at Prosser Dam (RM 47) and Roza Dam (RM 128), respectively. The middle 50% of the run passes Prosser from May 9 to May 23, a total of 14 days. The middle 50 % passes Roza from May 23 to June 17, a total of 25 days. Length frequency histograms developed from Prosser indicate that 5-year-olds return earlier than 3- or 4-year-olds. It appears likely that the American and Naches stocks (predominately 5-year-olds), which spawn earlier than Yakima stocks (4-year-olds), also migrate earlier.

The fish-per-redd counts at Roza Dam ranged from 1.6 to 2.4 from 1984 to 1987. A significant change occurred from 1988 to 1990, ranging from 2.7 to 3.7. The temperature and radio telemetry study from 1989 indicates that nine of 19 tagged adults fell back and spawned below Roza.

Prosser Returns

Methods

The total run of spring chinook is determined by adding the Prosser Dam ladder count to the harvest estimated below Prosser Dam. The methods of counting at Prosser included counting boards in the early 1980s, followed by visual window counts and video recordings. Some problems have occurred since video recordings have begun, such as poor lighting and power failures. Interpolations of data are factored in during these outages. In addition there

are some concerns that a small percentage of the adults may be able to jump the Prosser Dam. In 1983 and 1990 estimates were developed by expanding redd counts by 2.4 (average fish per redd) and adding harvested fish because of underestimated counts at Prosser.

For the 1988 spring chinook run at Prosser, fork lengths were estimated from the video tapes at the right bank viewing window. Fork lengths measured from the video monitor were expanded to an estimated actual fork length using a calibration factor. The calibration factor was determined by placing a board of known length between the viewing window and back-light board while the camera was recording. The board image was later measured on the video monitor when the video tape was played back. The resulting ratio between the actual length and video length is the calibration factor.

Length measurements were only taken when the fish image was more or less parallel to the film plane of the camera. Normally two or three film frames were recorded for each passing fish when the 120-minute tape was recording for a 24-hour period. Thus if one fish image was unparallel, the other images usually satisfied this criteria. A fish length taken from a passing fish less than parallel to the film plane would bias toward underestimation of the actual length.

During the early and latter portions of the fish run, all fork lengths were recorded. However, during the peak, length measurements were subsampled from every *nth* fish. This ranged from every third to every fifth passing fish, depending on the number of passing fish on a particular day.

Results

Historically the runs of spring chinook in the Yakima Basin were reported to be as high as 250,000 adults (Smoker 1956). In the last 30 years, the returns have been drastically reduced, reaching a low of 854 adults in 1972 (Table 1). In the last decade, the run averaged 3,819 spring chinook returning to the mouth of the Yakima River (Table 2). The return estimate ranged from 1,324 adults in 1983 to 9,442 in 1986. The last spring chinook return greater than the 1986 return was in 1957, which was estimated at 12,665 adult fish.

In 1984, a significant increase in adult returns was observed at Prosser Dam. By 1985 the numbers increased more than threefold from the three-year average from 1981 through 1983. This trend of increased adult returns continued through the decade with better than a sixfold increase in 1986 (Table 2). The increased returns are in part due to the new water management plan in the Yakima Basin, which provides incubation flows for eggs and alevins. The 4-year-olds in 1984 were the first to benefit from the incubation flows released in 1980. The “flip-flop” was initiated in 1981 to reduce flows previous to spawning thus forcing chinook spawners closer to the thalweg. This resulted in adequate protection of flow over redds while allowing reduced incubation flows. The 4-year-olds returning in 1985 were the first adults to benefit from the flip-flop. The 5-year-olds returning in 1985 and 1986 were the first adults to be affected by the two water management strategies.

Table 1. Estimated spring chinook runs to the Yakima River Basin, 1957-1990.

Year	Total redds' Naches	Yakima	Total	Escapement[b]	Harvest'	Total Run
1957	764	1216	1980	4752	7913	12665
1958	284	531	815	1956	4401	6357
1959	306	255	561	1346	3464	4810
1960	126	184	310	744	3668	4412
1961	166	175	341	818	5044	5862
1962	153	76	229	550	4185	4735
1963	185	--	--	--	2992	--
1964	50	81	131	314	3241	3555
1965	53	90	143	343	1763	2106
1966	95	32	127	305	4800	5105
1967	58	97	155	388	3195	3583
1968	25	61	86	206	2430	2636
1969	50	309	359	862	618	1480
1970	48	23	71	170	1512	1682
1971	--	97	--	--	1232	--
1972	55	101	156	374	480	854
1973	28	41	69	166	3221	3387
1974	30	40	70	168	1748	1916
1975	--	104	--	--	600	--
1976	35	108	143	343	--	--
1977	10	121	131	314	--	--
1978	95	308	403	967	--	--
1979	153	86	239	574	--	--
1980	113	353	466	1118	106	1224
1981	172	294	466	1118	216	1334
1982	54	576	630	1115	434	1549
1983	83	360	443	1156	84	1324
1984	220	634	854	2290	289	2676[d]
1985	427	951	1378	3662	865	4527[d]
1986	1313	1793	3106	8072	1340	9442
1987	677	1043	1720	3573	546	4364
1988	486	566	1052	3710	444	4356
1989	534	937	1471	3901	747	4917
1990	464	735	1199	2959	663	3698

'Redd counts for 1957-1961 are total redd counts from Major and Mighell (1969). For 1962-1980 the counts are index counts from Washington Department of Fisheries or Yakima Indian Nation coordinated surveys. Index counts in this time period were expanded by 1.8 and 2.5 for the upper Yakima and Naches systems, respectively . (Expansion factors were derived from the ratio of index counts to total counts for the respective systems. Total counts were from the Major and Mighell study and from the 1981-1987 surveys.) For 1981-1990 the counts are total redd counts from U.S. Fish and Wildlife Service, Yakima Indian Nation and Washington Department of Fisheries cooperative surveys. (Table 1 continued.)

Table 1 continued.

---

b Based on Roza Dam counts, the number of fish per redd has averaged 2.4 in the upper Yakima since 1982. Historical escapement for 1958 to 1981 was therefore estimated as the total redd count multiplied by 2.4. For 1983 and 1984 additional fish were removed at Roza Dam for broodstock, beyond harvest estimates. In addition to the tribal harvest, in 1986-90 experimental fish were sacrificed at Roza Dam for cwt recovery; and 1989 fish were removed at Roza Dam for U of W study.

'1957-1975 WDF tribal harvest estimates; 1980-1990 YIN tribal harvest estimates. All harvest estimates are for the Yakima River only.

*Total run estimates since 1984 are the sum of the Prosser Dam counts and the estimated harvests below Prosser Dam.

Table 2. Total return of spring chinook to the Yakima River. Prosser Dam Ladder courts plus harvest below Prosser equals total return.

Year	Prosser Dam Ladder Count	Harvest below Prosser Dam	Harvest above Prosser Dam	Total return Yakima River
1981	1285	49	167	1334
1982	1461	88	346	1549
1983	1252	72	12	1324
1984	2557	119	170	2676
1985	4206	321	544	4527
1986	8912	530	810	9442
1987	3992	372	174	4364
1988	4023	333	111	4356
1989	4357	560	187	4917
1990	3567	131	532	3698
Average	3561	258	305	3819

Normal passage time is fra mid-April to July 30.
1982 coLnt ended June 30.
1984 count began May 1.
1983 and 1990 underestimated passage due to equipment failures.
Actual counts for 1983 and 1990 are 794 and 2320 respectively.
Passage numbers developed from total redd count x 2.4 fish/redd plus harvest below Prosser Dam for 1983 and 1990.

In the last 10 years, the runs in the Yakima and Naches River subbasins have steadily increased from their respective brood years until 1988. Based on redd counts in the Yakima River Subbasin, the returns decreased slightly in 1988 and 1989 and dropped by approximately 60% in 1990 (based on redds in a four-year cycle). This is due in part to the second worst egg-to-smolt survival rate (1988 outmigration) to Prosser, as will be discussed in the life stage survival section of this report. The Naches system (five-year cycle) has not experienced the same declines.

The arrival of the first spring chinook adults to Prosser Dam each year ranges from March 25 to April 23. The median passage date for wild adults (19851989 data) was May 16 (Table 3) and has ranged from May 10 to May 23 (Figure 2). The cut-off date for spring chinook passage at Prosser Dam is July 31. Appendix Tables Al-A34 present daily passage and cumulative counts from 1982 to 1990.

Although the entire run of wild adults takes approximately 3.5 months to pass Prosser Dam, the middle 50% of the run passes on the average of 14 days. The range of passage of the middle 50% was 12 to 16 days. The earliest ranged from May 2 to May 17 in 1988 and the latest, from May 16 to June 1 in 1985. Figure 2a illustrates the cumulative passage from 1985 to 1990; Figure 2b shows peak timing and gives the average run timing for comparisons to the earliest, latest and the largest returns.

Spring chinook jacks lag behind the adult passage and have arrived at Prosser as early as April 19 and as late as May 14. The mean passage date for jacks is May 25 and ranges from May 17 to June 2. The middle 50% passed Prosser Dam on the average between May 18 and June 1. Figure 3 illustrates the timing differences from 1985 to 1990 and Figure 3b compares jacks and adult timing. Appendix Tables Al-A34 present daily passage past Prosser Dam from 1982 through 1990.

Researchers analyzed the adult fork lengths recorded from fish images on video tapes passing the Prosser right bank video system. The objective was to determine if percent composition by age, on a weekly basis, could be determined from the fork lengths taken from fish images recorded on the video tapes. Weekly (some weeks were combined to increase sample size) mid-eye to hypural plate (MEHP) length distributions are presented in Figures 4, 5a and 5b. Assigning MEHP length to age was based upon scale analysis to determine the age of measured spawner carcasses for the entire Yakima Basin in 1987. The resulting age probabilities for a given length interval was then multiplied by the percent of fish that occurred for each length interval. The results of this analysis are presented in Tables 4a and 4b.

Table 3. Weekly spring chinook adult passage at Prosser Dam for the years 1984 - 1990.

ADULTS

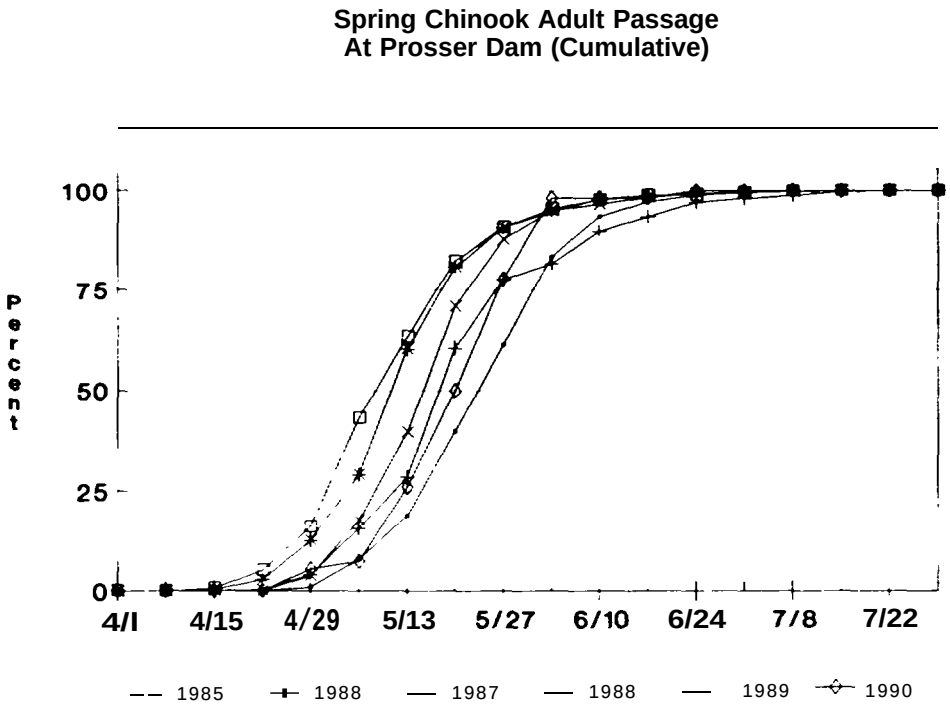
Date	1984	1985	1986	1987	1988	1989	1990		Cumulative Average (85-89)
4/01	ns	0	0	2	0	0	0		0.01
4/08	ns	0	0	0	2	0	0		0.02
4/15	ns	0	0	11	19		14		0.18
4/22	ns	0	34	90	173	03	70		1.71
4/29	77	36	318	356	401	153	220		7.51
5/06	264	266	984	602	998	570	442		22.69
5/13			1099	1137	745	901	485		42.08
5/20	889	787	2744	743	705	1283	451		66.78
5/27	390	817	1460	364	314	693	320		81.58
6/03	335	836	359	155	171	310	127		90.12
6/10	165	386	688	106	80	58	39		95.06
6/17	112	135	318	21		71	16		97.22
6/24		62	305	36	45	44	38		98.69
7/01	38	39	84	8	19	8	15		99.28
7/08	18	6	59	8	16	15	16		99.64
7/15	11	2	91	5	0	2	5		99.93
7/22	1	0	18	0		2	0		99.98
7/29	0	0	2	2	0	0	8		100.00
Total	2340	3783	8563	3646	3695	4113	3482	\a	4760

JACKS

				0	0	0	0		
4/01	ns	0	0	0	0	0	0		0.00 0.00
4/08	ns	0	0						
4/15	ns	0	0	0		0			
4/22	ns	0	0	0	1	0	0		0.00 0.06
4/29	ns	0	0	6	2	3	1		0.71
5/06	2	2	0	99	25	9	10		7.39
5/13	10	6	0	48	78	21	13		13.70
5/20	18	16	135	81	106	44	15		35.23
5/27	21	90	72	61		87			
6/03		157	32	25	71	46	11		60.73 79.54
6/10	46	91	53	11	31	11	0		90.30
6/17	30	37	20	3					
6/24	10	12	18	4	110	15	1		94.86 97.16
7/01	6	10	11	2	0	2	0		98.55
7/08	5	2	1	1	1	4	0		99.08
7/15	4	0	4	1	0	2	0		99.77
7/22	1	0	2	0	0	0 0	0 0		100.00 99.94
7/29	0	0	1						
Total	217	423	349	346	328	244	85	\b	338

\a Since the total count was underestimated with the video monitor system, estimated total passage was derived by expanding the total redd count by a factor of 2.4, plus total harvest and Roza Dam cwt fish.

\b Estimated jack passage was derived by multipling the estimated total passage by the jack to adult ratio observed at Prosser Dam.



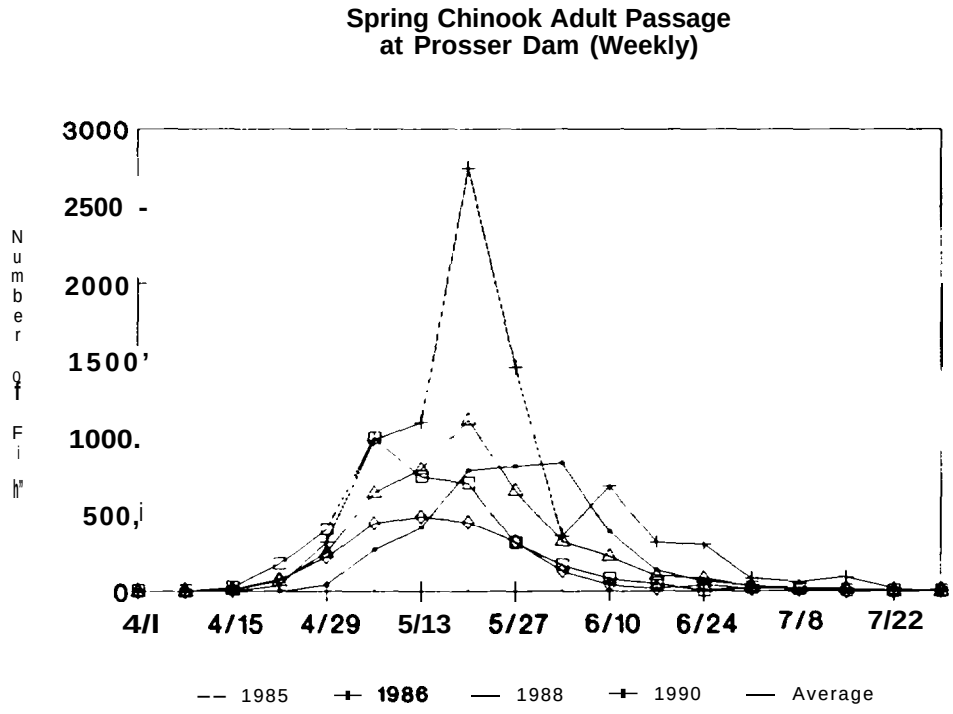
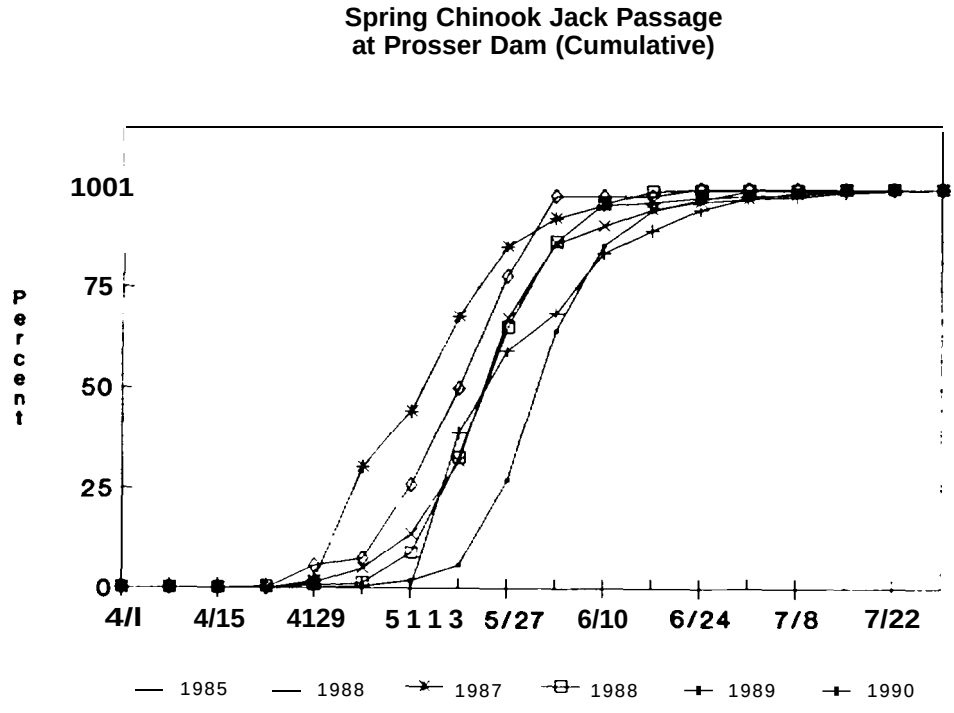


Figure 2. Spring chinook adult passage at Prosser Dam. Cumulative passage time from 1985 - 1990 (top). Passage of early, late and average runs (bottom).



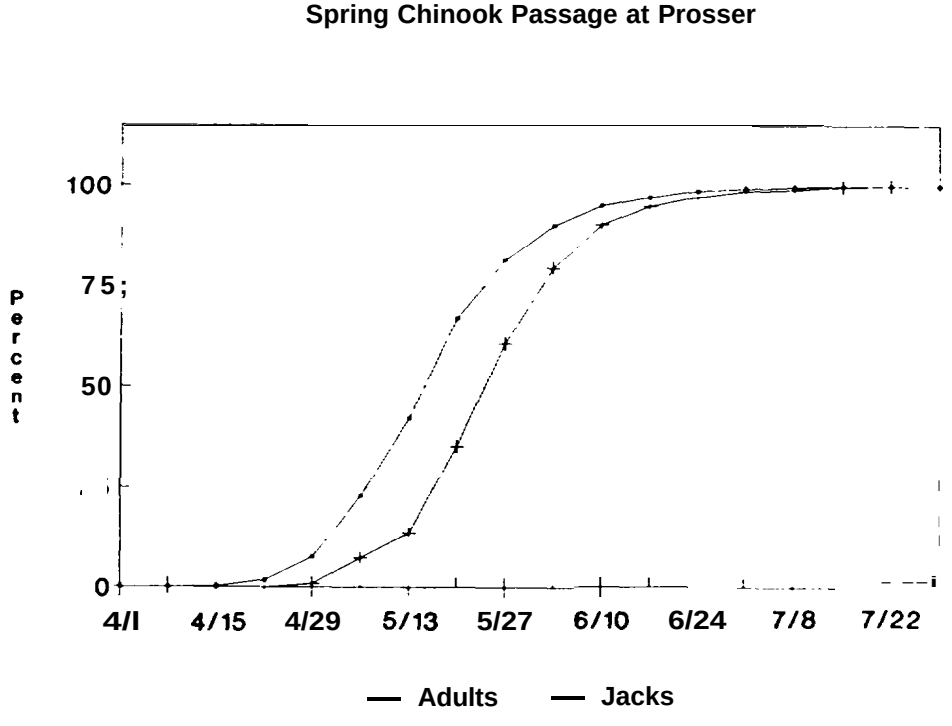


Figure 3. Spring chinook jack passage at Prosser Dam. Cumulative passage time from 1985 - 1990 (top). Timing differences of jacks and adults (bottom).

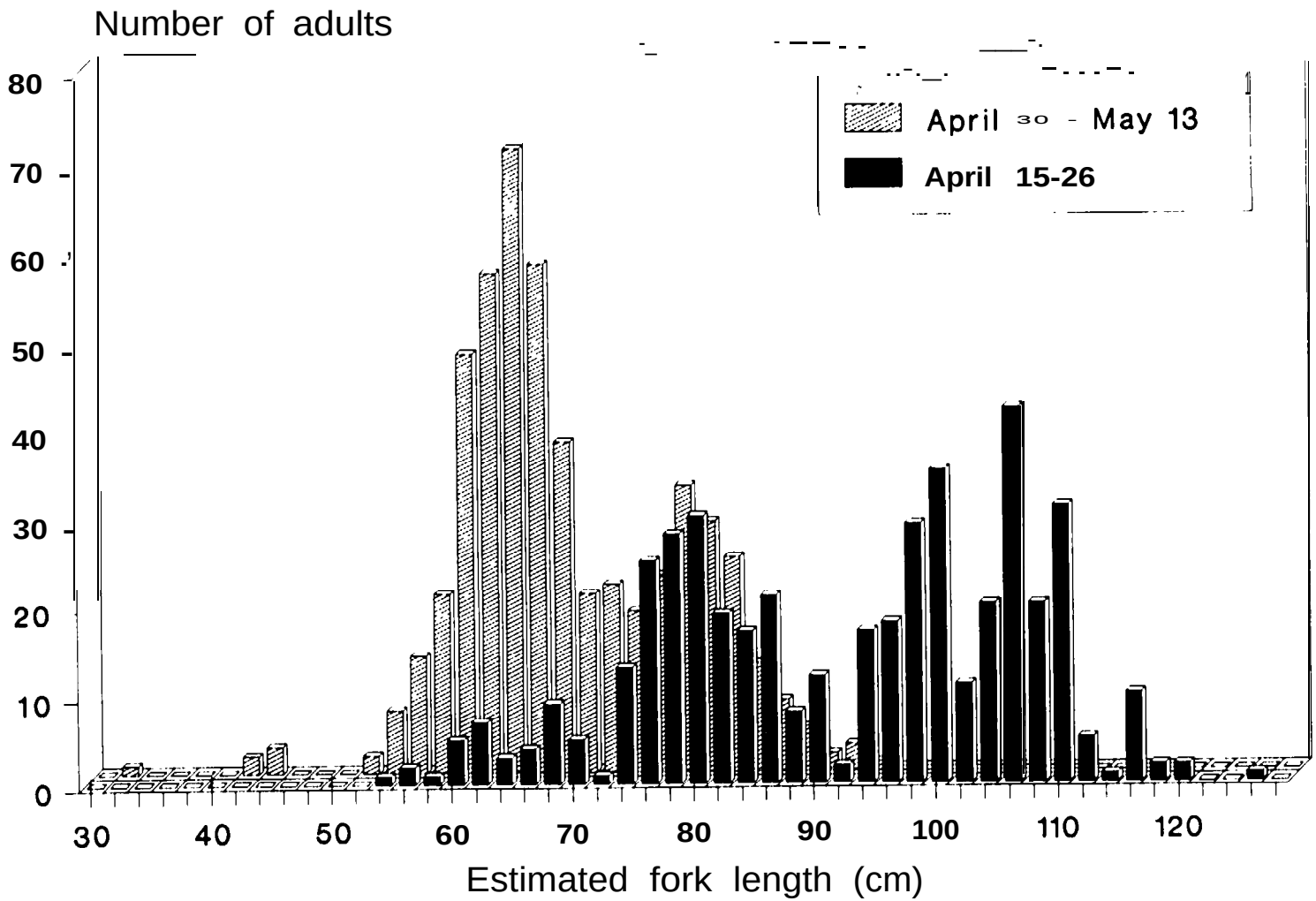


Figure 4. Estimated length distribution of adult spring at Prosser 1988 based on video tape length measurements.

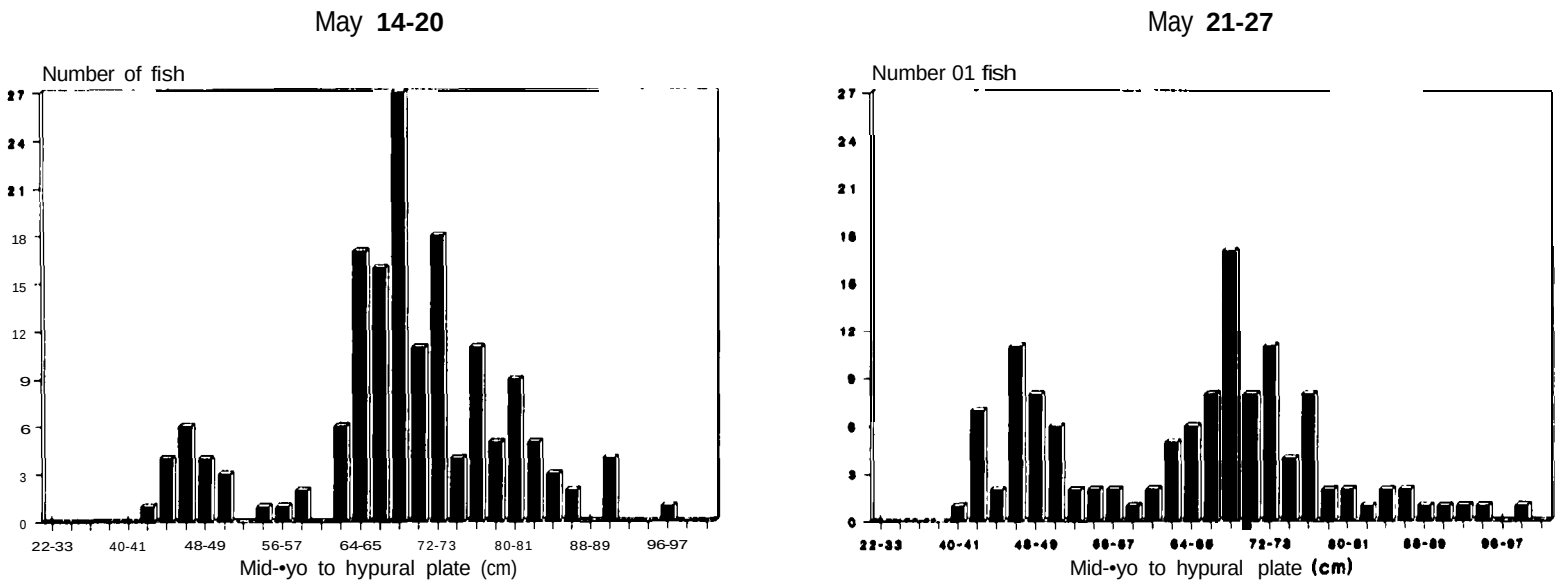


Figure 5a. Estimated length distribution of adult spring chinook at Prosser, 1988 based on video tape length measurements for May 14-20 and May 21-27.

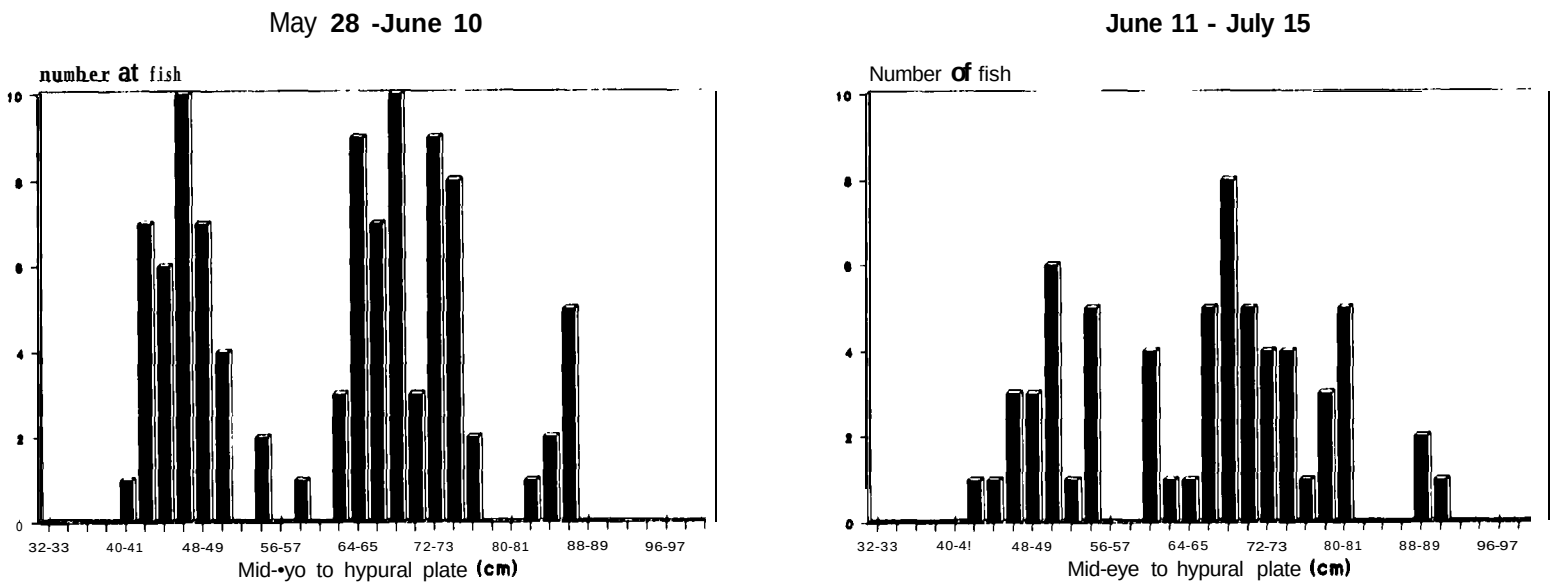


Figure 5b. Estimated length distribution of adult spring chinook at Prosser, 1988 based on video tape length measurements for May 28 through June 10 and June 11 through July 15.

Table 4.A. Weekly age composition, and MEHP length to age analysis of spring chinook adults at Prosser, 1988.

Length intervals in HEHP (cm)	Yakima basin wide 1987 MEHP length to age probabrlities for combined sexes			Week ending April 22			Week ending April 29			Week ending May 6			Week ending May 13		
				Percent ages			Percent ages			Percent ages			Percent ages		
	III	IV	V	III	IV	V	III	IV	V	III	IV	V	III	IV	V
32-33	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.6%	0.0%	0.0%
34-35	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
36-37	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
38-39	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
40-41	68.8%	31.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
42-43	75.0%	25.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
44-45	66.7%	33.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.8%	0.4%	0.0%
46-47	66.7%	33.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.8%	0.4%	0.0%
48-49	15.4%	84.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%	0.0%	0.0%	0.0%	0.1%	0.5%	0.0%
SO-51	4.2%	95.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
52-53	2.8%	97.2%	0.0%	0.0%	1.6%	0.0%	0.0%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
54-55	0.0%	100.0%	0.0%	0.0%	1.6%	0.0%	0.0%	1.2%	0.0%	0.0%	0.6%	0.0%	0.0%	0.0%	0.0%
56-57	0.0%	100.0%	0.0%	0.0%	2.4%	0.0%	0.0%	0.6%	0.0%	0.0%	1.0%	0.0%	0.0%	0.6%	0.0%
58-59	0.0%	99.0%	1.0%	0.0%	3.2%	0.0%	0.0%	2.4%	0.0%	0.0%	1.7%	0.0%	0.0%	3.6%	0.0%
60-61	0.0%	98.0%	2.0%	0.0%	4.8%	0.1%	0.0%	5.3%	0.1%	0.0%	1.3%	0.0%	0.0%	1.8%	0.0%
62-63	0.0%	97.6%	2.4%	0.0%	8.7%	0.2%	0.0%	4.7%	0.1%	0.0%	6.6%	0.2%	0.0%	4.2%	0.1%
64-65	0.0%	86.7%	13.3%	0.0%	3.5%	0.5%	0.0%	7.5%	1.2%	0.0%	8.6%	1.3%	0.0%	10.1%	1.6%
66-67	0.0%	86.7%	13.3%	0.0%	5.6%	0.9%	0.0%	7.8%	1.2%	0.0%	8.4%	1.3%	0.0%	6.9%	1.1%
68-69	0.0%	57.7%	42.3%	0.0%	0.9%	0.7%	0.0%	3.8%	2.8%	0.0%	7.2%	5.3%	0.0%	12.0%	8.8%
70-71	0.0%	28.0%	72.0%	0.0%	0.2%	0.6%	0.0%	0.8%	1.9%	0.0%	1.8%	4.8%	0.0%	1.9%	4.9%
72-73	0.0%	25.0%	75.0%	0.0%	0.0%	0.0%	0.0%	1.0%	3.1%	0.0%	1.6%	4.8%	0.0%	2.1%	6.4%
74-75	0.0%	17.8%	82.2%	0.0%	0.7%	3.3%	0.0%	0.7%	3.4%	0.0%	0.8%	3.7%	0.0%	0.8%	3.5%
76-77	0.0%	17.8%	88.2%	0.0%	0.6%	2.9%	0.0%	0.7%	3.7%	0.0%	0.9%	4.3%	0.0%	0.7%	3.2%
78-79	0.0%	0.0%	100.0%	0.0%	0.0%	5.7%	0.0%	0.0%	6.6%	0.0%	0.0%	2.3%	0.0%	0.0%	3.7%
80-81	0.0%	0.0%	100.0%	0.0%	0.0%	14.6%	0.0%	0.0%	9.6%	0.0%	0.0%	7.8%	0.0%	0.0%	3.1%
82-83	0.0%	0.0%	100.0%	0.0%	0.0%	6.5%	0.0%	0.0%	3.9%	0.0%	0.0%	5.4%	0.0%	0.0%	3.7%
84-85	0.0%	0.0%	100.0%	0.0%	0.0%	17.1%	0.0%	0.0%	10.5%	0.0%	0.0%	6.8%	0.0%	0.0%	2.5%
86-87	0.0%	0.0%	100.0%	0.0%	0.0%	2.4%	0.0%	0.0%	2.4%	0.0%	0.0%	5.4%	0.0%	0.0%	2.5%
88-89	0.0%	0.0%	100.0%	0.0%	0.0%	8.9%	0.0%	0.0%	8.1%	0.0%	0.0%	1.7%	0.0%	0.0%	0.6%
90-91	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%	0.0%	1.9%	0.0%	0.0%	4.3%
92-93	0.0%	0.0%	100.0%	0.0%	0.0%	1.6%	0.0%	0.0%	3.0%	0.0%	0.0%	0.8%	0.0%	0.0%	1.8%
94-95	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%	0.0%	0.6%	0.0%	0.0%	0.0%
96-97	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.6%	0.0%	0.0%	0.6%	0.0%	0.0%	0.6%
98-99	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%	0.0%	0.6%	0.0%	0.0%	0.0%
100-01	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%
Total Percent Ages				0.0%	34.0%	66.1%	0.1%	37.1%	63.1%	0.0%	40.5%	59.8%	2.3%	46.1%	52.4%

Table 4.8. Ueekly age composition, and HEHP Length to age analysis of spring chinook adults at Prosser, 1988.

Length intervals in MEHP (cm)	Yakima basinwide 1987 MEHP length to age probabilities for combined sexes			Week ending May 20 Percent ages			Week ending May 27 Percent ages			May 28 to June 10 Percent ages			June 11 to July 15 Percent ages		
	III	IV	V	III	IV	V	III	IV	V	III	IV	V	III	IV	V
32-33	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
34-35	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
36-37	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
38-39	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
40-41	68.8%	31.2%	0.0%	0.0%	0.0%	0.0%	0.6%	0.2%	0.0%	0.7%	0.3%	0.0%	0.0%	0.0%	0.0%
42-43	75.0%	25.0%	0.0%	0.5%	0.2%	0.0%	4.2%	1.4%	0.0%	5.4%	1.8%	0.0%	1.2%	0.4%	0.0%
44-45	66.7%	33.3%	0.0%	1.7%	0.8%	0.0%	1.1%	0.5%	0.0%	4.1%	2.1%	0.0%	1.0%	0.5%	0.0%
46-47	66.7%	33.3%	0.0%	2.5%	1.2%	0.0%	5.9%	2.9%	0.0%	6.9%	3.4%	0.0%	3.1%	1.6%	0.0%
48-49	15.4%	84.6%	0.0%	0.4%	2.1%	0.0%	1.0%	5.4%	0.0%	1.1%	6.1%	0.0%	0.7%	4.0%	0.0%
SO-51	4.2%	95.8%	0.0%	0.1%	1 .a%	0.0%	0.2%	4.6%	0.0%	0.2%	4.0%	0.0%	0.4%	9.0%	0.0%
52-53	2.8%	97.2%	0.0%	0.0%	0.0%	0.0%	0.0%	1.6%	0.0%	0.0%	0.0%	0.0%	0.0%	1.5%	0.0%
54-55	0.0%	100.0%	0.0%	0.0%	0.6%	0.0%	0.0%	1.6%	0.0%	0.0%	2.1%	0.0%	0.0%	7.8%	0.0%
56-57	0.0%	100.0%	0.0%	0.0%	0.6%	0.0%	0.0%	1.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
58-59	0.0%	99.0%	1.0%	0.0%	1.2%	0.0%	0.0%	0.8%	0.0%	0.0%	1.0%	0.0%	0.0%	0.0%	0.0%
60-61	0.0%	98.0%	2.0%	0.0%	0.0%	0.0%	0.0%	1.6%	0.0%	0.0%	0.0%	0.0%	0.0%	6.1%	0.1%
62-63	0.0%	97.6%	2.4%	0.0%	3.6%	0.1%	0.0%	3.9%	0.1%	0.0%	3.0%	0.1%	0.0%	1.5%	0.0%
64-65	0.0%	86.7%	13.3%	0.0%	9.2%	1.4%	0.0%	4.2%	0.6%	0.0%	8.0%	1.2%	0.0%	1.4%	0.2%
66-67	0.0%	86.7%	13.3%	0.0%	8.6%	1.3%	0.0%	5.5%	0.9%	0.0%	6.3%	1.0%	0.0%	6.8%	1.0%
68-69	0.0%	57.7%	42.3%	0.0%	9.7%	7.1%	0.0%	7.8%	5.8%	0.0%	5.9%	4.4%	0.0%	7.2%	5.3%
70-71	0.0%	28.0%	72.0%	0.0%	1.9%	4.9%	0.0%	1.8%	4.6%	0.0%	0.9%	2.2%	0.0%	2.2%	5.6%
72-73	0.0%	25.0%	75.0%	0.0%	2.8%	8.4%	0.0%	2.2%	6.6%	0.0%	2.3%	7.0%	0.0%	1.6%	4.7%
74-75	0.0%	17.8%	82.2%	0.0%	0.4%	2.0%	0.0%	0.6%	2.6%	0.0%	1.5%	6.8%	0.0%	1.1%	5.1%
76-77	0.0%	17.8%	88.2%	0.0%	1.2%	6.0%	0.0%	1.1%	5.6%	0.0%	0.4%	1.8%	0.0%	0.3%	1 .4%
78-79	0.0%	0.0%	100.0%	0.0%	0.0%	3.1%	0.0%	0.0%	1.6%	0.0%	0.0%	0.0%	0.0%	0.0%	4.7%
80-81	0.0%	0.0%	100.0%	0.0%	0.0%	5.6%	0.0%	0.0%	1.6%	0.0%	0.0%	0.0%	0.0%	0.0%	7.8%
82-83	0.0%	0.0%	100.0%	0.0%	0.0%	3.1%	0.0%	0.0%	0.8%	0.0%	0.0%	1 .o%	0.0%	0.0%	0.0%
84-85	0.0%	0.0%	100.0%	0.0%	0.0%	1.9%	0.0%	0.0%	1.6%	0.0%	0.0%	2.1%	0.0%	0.0%	0.0%
86-87	0.0%	0.0%	100.0%	0.0%	0.0%	1.2%	0.0%	0.0%	1.6%	0.0%	0.0%	5.2%	0.0%	0.0%	0.0%
88-89	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.8%	0.0%	0.0%	0.0%	0.0%	0.0%	3.1%
90-91	0.0%	0.0%	100.0%	0.0%	0.0%	2.5%	0.0%	0.0%	0.8%	0.0%	0.0%	0.0%	0.0%	0.0%	1.6%
92-93	0.0%	0.0%	IW.o%	0.0%	0.0%	0.0%	0.0%	0.0%	0.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
94-95	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
96-97	0.0%	0.0%	100.0%	0.0%	0.0%	0.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
98-99	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
100-01	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Total Percent Ages				5.1%	46.0%	49.3%	12.9%	49.4%	38.1%	18.4%	49.0%	32.7%	6.5%	52.9%	40.7%

S

Two observations can be drawn from these weekly length distributions. Firstly, jacks begin to comprise a portion of the run beginning the week ending May 13 (2.3%). The percent composition of jacks continued to increase from 5.1% for the week ending May 20 to 18.4% for the period May 28 to June 10. In the last period, June 11 to July 15, the percent composition of jacks declined to 6.5%.

Secondly, it appears the larger S-year-old fish comprise a larger portion of the early run. It was estimated for the week ending April 22 that 5year-olds comprised 66.1% of total passage; for the week ending April 29, it was 63.1%; for the week ending May 6, it was 59.8%; for the week ending May 13, it was 52.4%; for the week ending May 20, it was 49.3 %; and for the week ending May 27, it was 38.1% . For the periods May 28 to June 10 and June 11 to July 15, 5-year-olds estimated run composition was 32.7% and 40.7%, respectively.

Though the observed trends are apparent, it appears that estimating age composition from video lengths overestimates the percentage of 5-year-olds and underestimates the 4-year-olds. Based on the basinwide 1987 age-to-MEHP-length analysis from recovered spawning carcasses, the estimated percent composition of 4- and 5-year-olds is 71% and 26.7%) respectively. If a bias was observed, researchers expected the bias to be toward overestimation of the 4-year-olds, the reason being that a length measurement taken from a fish non-parallel to the camera would appear smaller because of the angle of the fish in relation to the camera. The greater the degree of being non-parallel, the greater the error in underestimating the true fish length. Because this is the only obvious type of bias that can occur in fish video measurements, researchers are unclear as to why the bias appears to be toward overestimating fish lengths. It is assumed that the carcass data is a non-biased sample of the population. At this time there is no reason to suspect that the larger carcasses (5-year-olds) are being selected against in the spawner surveys. This work will be continued for the 1991 spring chinook run and will provide an additional year's worth of data for comparison.

The length data collected throughout the run indicates that 5-year-olds return earlier than the 3- and 4-year-olds. It appears likely that these early returning adults are the American and Naches substocks (predominately 5-year-olds) which are larger and spawn approximately a month earlier than the Yakima substock (predominately 4-year-olds), which is much smaller.

Roza Return

Met hods

Spring chinook adults returning to the upper Yakima River were monitored with a combination trap and counting board as they passed Roza Dam. The trap-counting board had plexy glass slide gates located at the entrance and exit. The gates were open while fishing to allow attraction flow through the trap. When an adult or jack entered the trap both gates were closed. To improve visibility within the trap the interior was painted white. In

addition, the trap could be adjusted vertically to improve visibility during times of high turbidity.

The trap was operated from early May through September. In 1989 a video system was installed to monitor any early arrivals and to detect other species throughout the year. The water clarity at the trap was such that it allowed visual examination for the presence or absence of adipose fins. Adults and jacks with adipose fins were enumerated and passed while clipped fish (experimental fish) were sacrificed for the recovery of coded-wire tags.

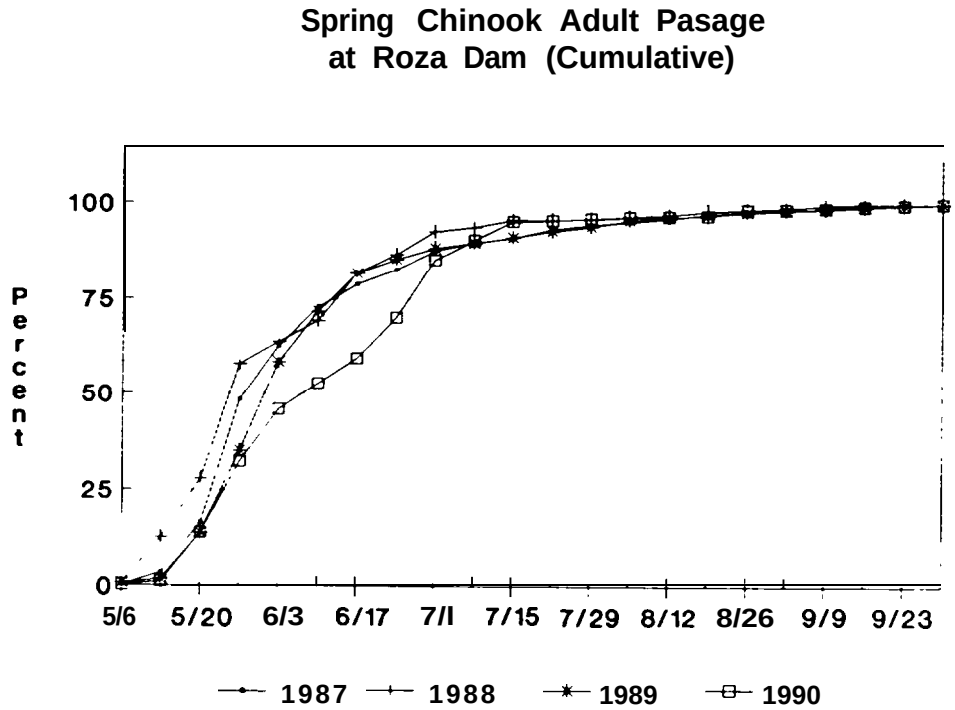
Results

The first adults normally return about the first week of May, with the earliest return recorded on April 30 in 1988. The median date for adults has averaged June 1 (data from 1987-1990) and has ranged from May 26 to June 8. On the average, 50% of the run passes Roza Dam in a 25-day period from May 23 to June 17. Figure 6 illustrates cumulative and peak timing of passage past Roza Dam.

The spring chinook jacks began passing Roza in mid-May, with the first return by May 12 in 1989. The median date of passage for jacks has averaged June 14, but has ranged from May 26 to July 13. On the average, 50% of the run passes Roza Dam in 20 days from June 4 to June 24. Figure 7 shows cumulative and peak passage past Roza Dam.

The ratio of spawning escapement to total redd deposition in the upper Yakima River has varied greatly over the course of the study. From 1984 to 1987 the "fish-per-redd ratio" ranged from 1.6 to 2.4, while the range over the years 1988 to 1990 was 2.7 to 3.7. A radiotelemetry study of adult spring chinook conducted in 1989 (Berman 1989) indicated that nine of 19 adults tagged at Roza "fell back" and spawned below the dam (four of the nine fallbacks spawned near Selah and the remaining five spawned near Yakima). In light of the low fish-per-redd ratios observed between 1984 and 1987, it is unlikely that any significant "fallback" occurred during these years. However, the combination of the Berman study and the relatively higher fish-per-redd ratios observed since 1987 suggest that some fallback may have occurred between 1987 and 1990.

It is possible that spawning below Roza Dam began the first year that adults were trapped at Roza. Bryant and Parkhurst described the spring chinook spawning area as extending only as far downstream as Ellensburg in the 1930s, and Major and Mighell reported a similar distribution in the late 1950s and early 1960s. The first quantitative records of spawning below Roza were made in 1985 when 91 redds were located. Because adult trapping resulted in regular, temporary passage interruptions (the trap was closed from dusk to dawn to facilitate observations), and because there is no record of spawning before the trap was installed, it is at least plausible that spawning below Roza was initially caused by the trap.



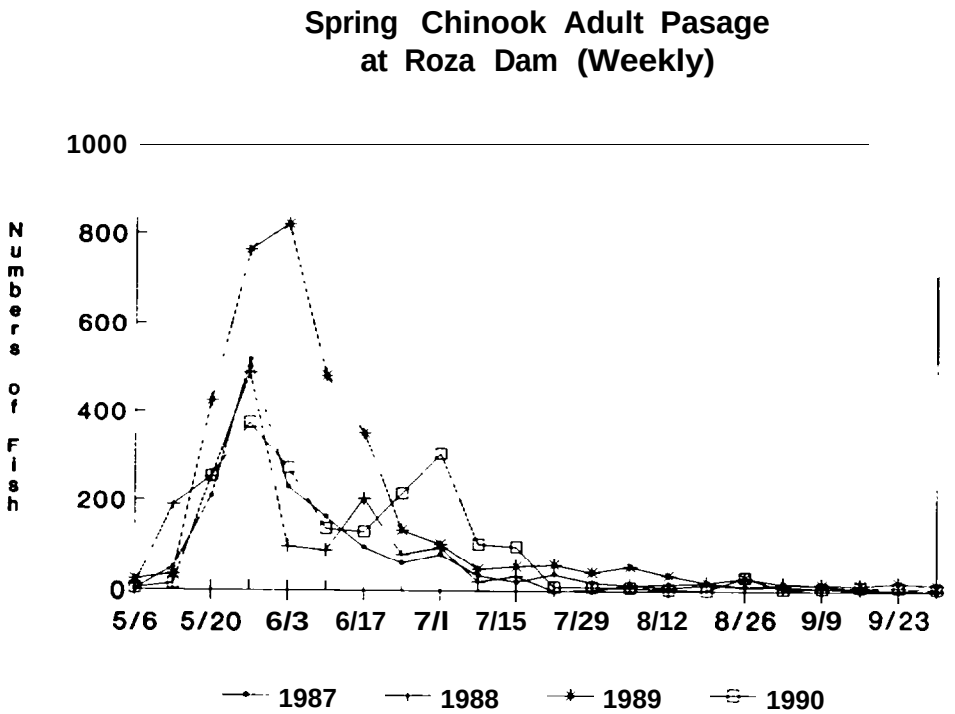
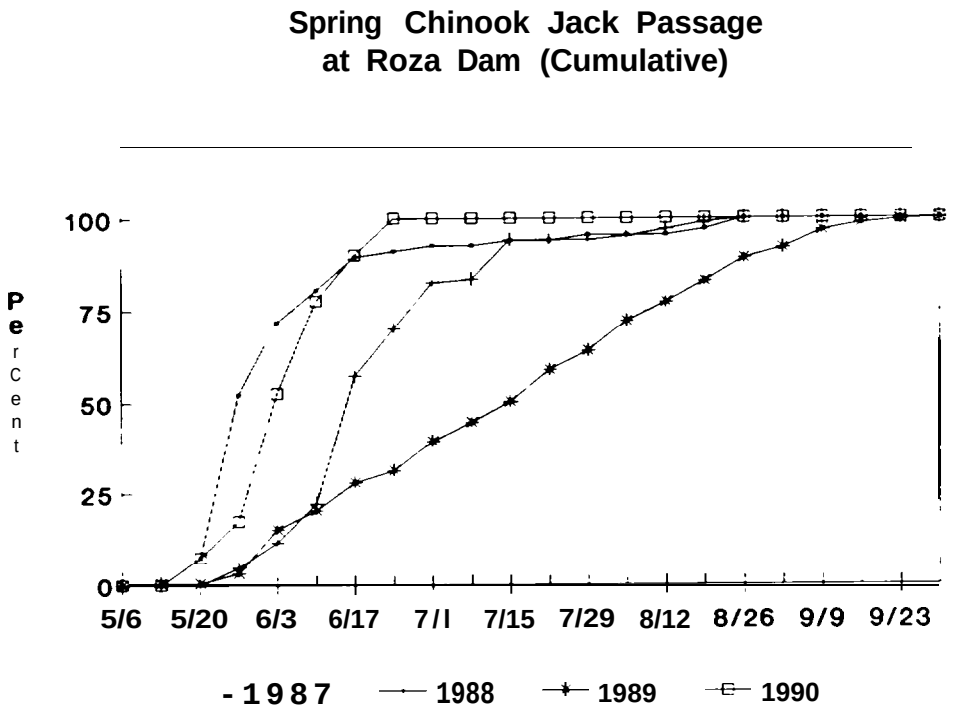


Figure 6. Spring chinook adult passage at Roza Dam. Cumulative passage time from 1987 - 1990 (top). Peak passage by week from 1987 - 1990 (bottom).



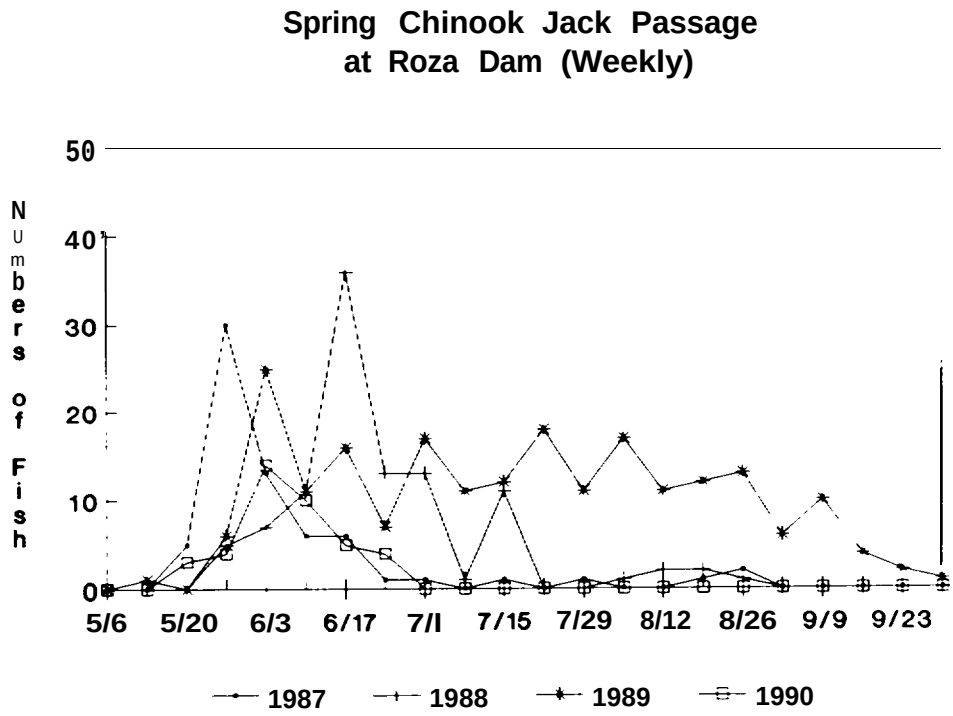


Figure 7. Spring chinook jack passage at Roza Dam. Cumulative passage time from 1987 - 1990 (top). Peak passage by week from 1987 - 1990 (bottom).

Assuming a significant amount of fallback does in fact occur, one might speculate that it is entirely a recent phenomenon ultimately attributable to passage interruptions associated with trapping. As indicated by fish-per-redd ratios, fallback may have begun in 1988 and continued through 1990. Consider only the last two years, when fallback was respectively conclusively demonstrated or quite probable. The fish that fell back in 1989 may themselves have been spawned in some of the 9 1 redds that were counted below Roza in 1985. Similarly, fallback in 1990 may have comprised (exclusively) fish that emerged from some of the 321 redds deposited below Roza in 1986. Such “Roza-spawned” fish necessarily contribute to fallback every time they migrate a bit too far upstream and “overshoot” their rather restricted natal spawning area.

SPAWNING SURVEYS

Overview

The Yakima Basin is comprised of three distinct substocks of spring chinook -- American River, Naches River and tributaries (excluding the American River) and the Yakima River (including Cle Elum River). Electrophoresis was used to differentiate the substocks (Busak, WDF, pers. commun., 1990). Data collected from spawning surveys indicates differences in the substocks include age and length as well as spatial and temporal differences.

Redd counts in the upper Yakima River have averaged 716 in the last decade and have ranged from 294 to 1,793 redds. Counts in the Naches Subbasin averaged 441 in the last decade and ranged from 54 to 1,313 redds. Carcass data indicates that American River spring chinook are predominately 5-year-old adults; the Yakima River consists of 4-year-olds. The Naches River and tributaries is a combination of 4- and 5-year-olds.

The length fecundity relationship was developed from eggs taken from 23 females at Roza Dam. The best fit (r^2= .898) for this linear regression was:

EGGS = 195.2(mid-eye to hypural length in cm) - 7,736

Redd Counts

Methods

Researchers conducted spawning ground surveys by walking or rafting, depending on which method was best suited for a particular reach. The Naches tributaries were surveyed on foot and the Naches and Yakima rivers were surveyed by raft. Two rafts were used from the Yakima-Cle Elum river confluence because of the increased width of the river. Two rafts were also used below Easton Dam because of the magnitude of spawning and to cover the long side channels.

When the spring chinook redds were located, they were flagged with surveyor's tape on the bank and numbered consecutively. Researchers also recorded the date and distance from the bank on the flag, so that redds could be relocated. This method was used to avoid recounting or missing any redds. Each week a new color of flagging material was used. The number of redds, live fish and carcasses were recorded on data sheets and were summed at the end of the reach.

Researchers checked spring chinook carcasses for sex, fork and hypural lengths, and spawning condition. Scales were collected and used for age determination. The heads were

collected from adipose-clipped fish and the tags read. The caudal fins were removed from carcasses so it would be obvious on subsequent trips that they had been sampled.

Results

Spring chinook spawning grounds in the Yakima River Basin were originally defined in the 1930s (Bryant and Parkhurst 1950). These surveys focused on presence and absence more than the timing and magnitude of spawning. Comprehensive surveys were conducted from 1957 to 1961 by the Bureau of Commercial Fisheries (Major and Mighell 1969). These surveys were conducted weekly in a systematic manner very similar to the way surveys are carried out today.

From 1962 through 1975, spawning index areas were established and surveyed during a single peak count. From 1976 to 1980, some of these areas were enlarged and a few new areas added. Since 1981, researchers conducted the surveys in a much more comprehensive manner. Multiple surveys were performed throughout the spawning period and covered all of the utilized habitat.

Spring chinook spawning in the Yakima Basin begins in late July and continues through mid-October. The temporal as well as spatial distribution within the basin can be split into three distinct groups -- American River, Naches River and tributaries (excluding the American River), and the Yakima River (including Cle Elum River). Spawning in the American River begins in late July and is complete by the end of August. Spawning in the Naches and its tributaries begins in late August and ends by late September. Spawning in the Yakima Subbasin begins in early September and continues through the middle of October. Table 5 lists peak spawning times observed over the course of the study. Rattlesnake Creek surveys were conducted after spawning was complete and are actually somewhat earlier than described in the table.

Table 5. Peak spawning times for wild Yakima spring chinook in various portions of the Yakima Subbasin.

Area	Early Peak	Late Peak
American River	Aug. 8	Aug. 15
Naches River	Sept. 8	Sept. 18
Little Naches	Sept. 1	Sept. 11
Bumping	Sept. 6	Sept. 8
Rattlesnake	< Sept. 11	< Sept. 17
Yakima River	Sept. 15	Sept. 28
Cle Elum	Sept. 16	Oct. 1

Spring chinook redd counts in the last decade have averaged 716 in the upper Yakima. The numbers have ranged from 294 to 1793 redds (Table 6). The adult returns from previous brood years (four-year cycle) have increased in the early and mid 198Os, but began to decline in 1988. In 1990 only 769 redds were located in the upper Yakima. These adults were the offspring of the 1986 brood, which dug 1,793 redds resulting in a decrease of 57%. A decrease of 11% and 2 % were observed in 1988 and 1990, respectively. This follows several years of increases ranging from 295% in 1987 to 323% in 1985.

In the last 10 years, the redd counts in the Naches Subbasin have averaged 441 and have ranged from 54 to 1,3 13 redds (Table 6). The adult returns in the Naches system have continued to increase from previous brood years (Naches, five-year cycle) throughout the mid to late 80s. This increase has slowed in the last few years because comparisons in the early 80s were to such drastically reduced numbers.

Table 6. Spring chinook redd counts in the Yakima Subbasin, 1981-1990.

SPAWNING REACH	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Upper Yakima Svstem										
Easton Dam to Game Ramp	126	204	104	302	322	352	278	186	280	254
Game Ramp to Freeway Br.	35	92	32	66	77	127	45	37	85	67
Freeway Br. to S. Cle Elum Br.	30	159	87	145	137	352	191	127	191	135
S. Cle Elum Br. to Teanaway River	39	80	77	67	118	253	205	76	118	100
Teanaway to Thorp Br.'	2	8	20	9	22	118	70	20	18	52
Thorp Br. to KOA[b]	--	--	--	11	17	110	26	14	7	16
KOA to Roza Dam[c]	5	--	25	--	11	82	13	8	0	4
Roza Dam to Selah Br.[d]	--	--	--	--	91	321	140	19	29	61
Cle Elum River	57	30	15	31	153	77	75	79	192	46
Teanaway River[e]	--	--	--	0	3	0	--	0	6	--
Hanastash Cr.[e]	--	--	--	3	0	0	--	--	4	--
Misc.	--	--	--	--	--	1[f]	--	--	7[g]	--
Naches Svstem										
American River	72	11	36	72	141	464	222	239	187	143
Bumping River	20	6	11	26	74	196	133	59	101	111
Little Naches River	16	12	9	41	44	110	41	47	53	51
Rattlesnake Cr.	0	2	4	24	11	17	29	17	6	7
Naches River'	64	23	23	57	157	526	252	124	187	152
Upper Yakima Subtotal	294	576	360	634	951	1793	1043	566	937	735
Naches Subtotal	172	54	83	220	427	1313	677	486	534	464
Basinwide Total	466	630	443	854	1,378	3,106	1,720	1,052	1,471	1,199

(Table 6 continued)

Table 6 continued.

'This reach extended only to Ellensburg Town Ditch (RM 161.3) from 1981-1984.

[b]The 1984 count applies to the reach between Ellensburg Town Ditch and KOA, below which there was no survey.

[c] The 1981 and 1983 redd counts apply to the reach between Ellensburg Town Ditch and the Wilson Creek Game Ramp. There was no survey below the Town Ditch in 1982. Surveys below the Wilson Cr. Game Ramp (RM 148.2) began in 1986.

[d]Surveys began in 1985.

'Surveys began in 1984.

'One redd found in City of Yakima reach.

[f]Two redds found in Big Creek, five above Easton Dam.

[h] The Naches River below Horseshoe Bend was surveyed for the first time in 1985, when no redds were found between the Bend and the Naches City Br. (RM 12.9). Since 1986, surveys have extended from the Bend to the Yakima confluence.

Carcass Data

The carcass sampling conducted during spawner surveys provided length, sex and scale data. This information was then used to develop length frequencies, sex ratios and age compositions. This data, in conjunction with redd counts and the length fecudity model (next section), provides the basis for yearly egg deposition estimates. This information in turn is used to study survival through the various life stages in the Yakima Basin.

Eletrophoresis work conducted by the Washington Department of Fisheries separated the Yakima Basin into three distinct sub-stocks (Busak, WDF, pers commun.,l990). The carcass data was broken up accordingly into the three substocks: the American River, The Naches River and tributaries (excluding the American River) and the Yakima River (including the Cle Elum River). The carcass data reinforces differences in the substocks in regards to length and age differences as well as temporal and spatial distributions.

From 1986 to 1990 a total of 1,625 carcasses were examined from spawners surveys. Surveyers collected 298 from the American River, 317 from the Naches and tributaries, and 1,010 from the Yakima and Cle Elum rivers. The age data derivived from scale analysis indicates that the American substock is primarily 5-year-olds and the Yakima is primarily 4-year-olds. The Naches and tributaries is a combination of 4- and 5-year-olds (Table 7).

Age separation by length (mid-eye to hypural) occurred at 48 cm to 50 cm and approximately at 67 cm to 70 cm between 3-, 4- and 5-year-olds Overlap of 4- and 5-year-olds was common, but the 4-year-olds were rarely longer than 70 cm. It appears that it is more likely for 5-year-olds to run smaller, occasionally reaching the low 60s cm. Several 6-year-olds were sampled from the American and Naches systems and ranged in length from 73 cm to 94 cm. Figures 8-15 illustrate length frequency for each major substock and the combined lengths of all stocks by sex.

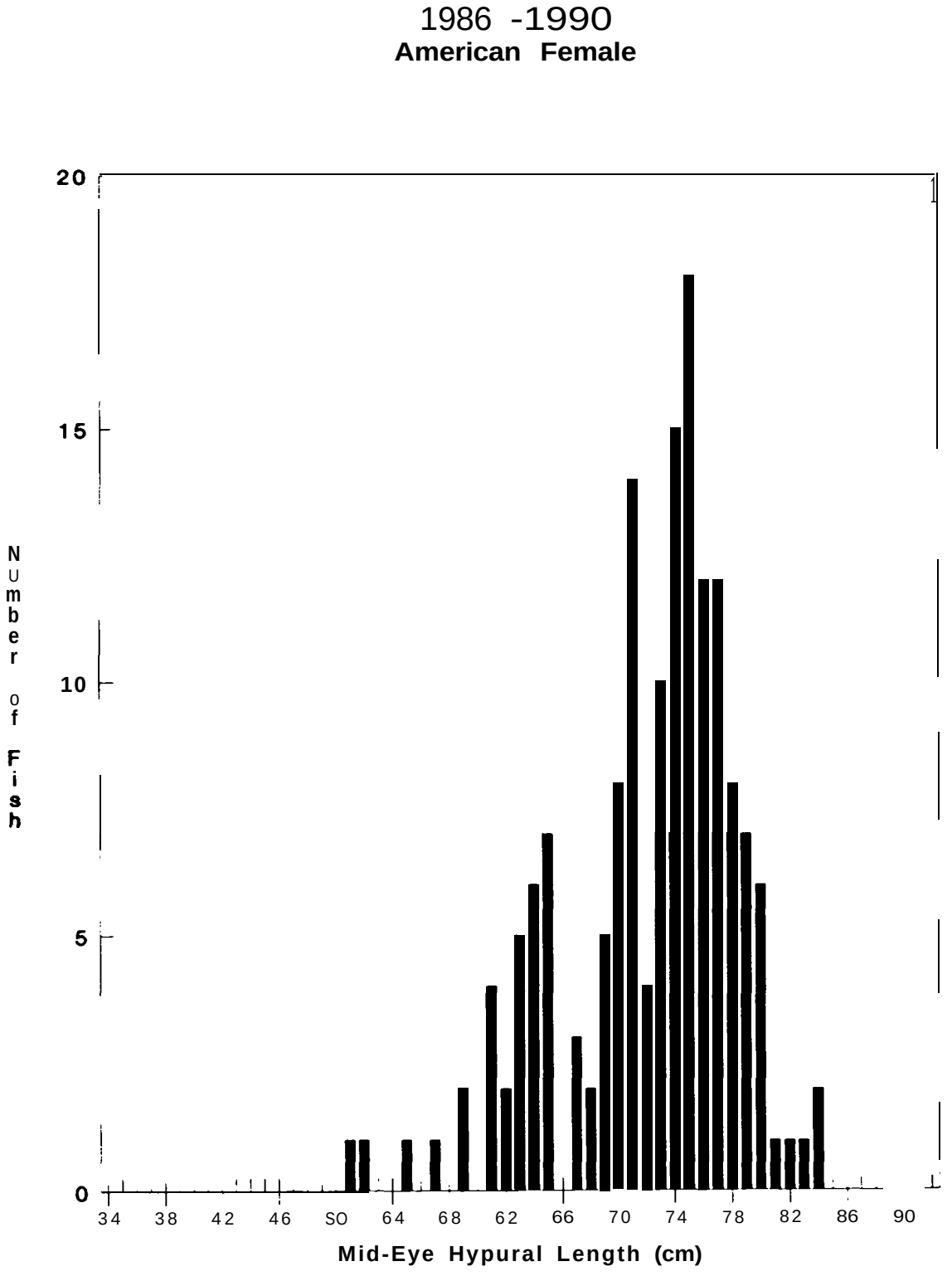


Figure 8. Hypural length distribution from spring chinook carcasses collected during spawners surveys on the American River from 1986 - 1990.

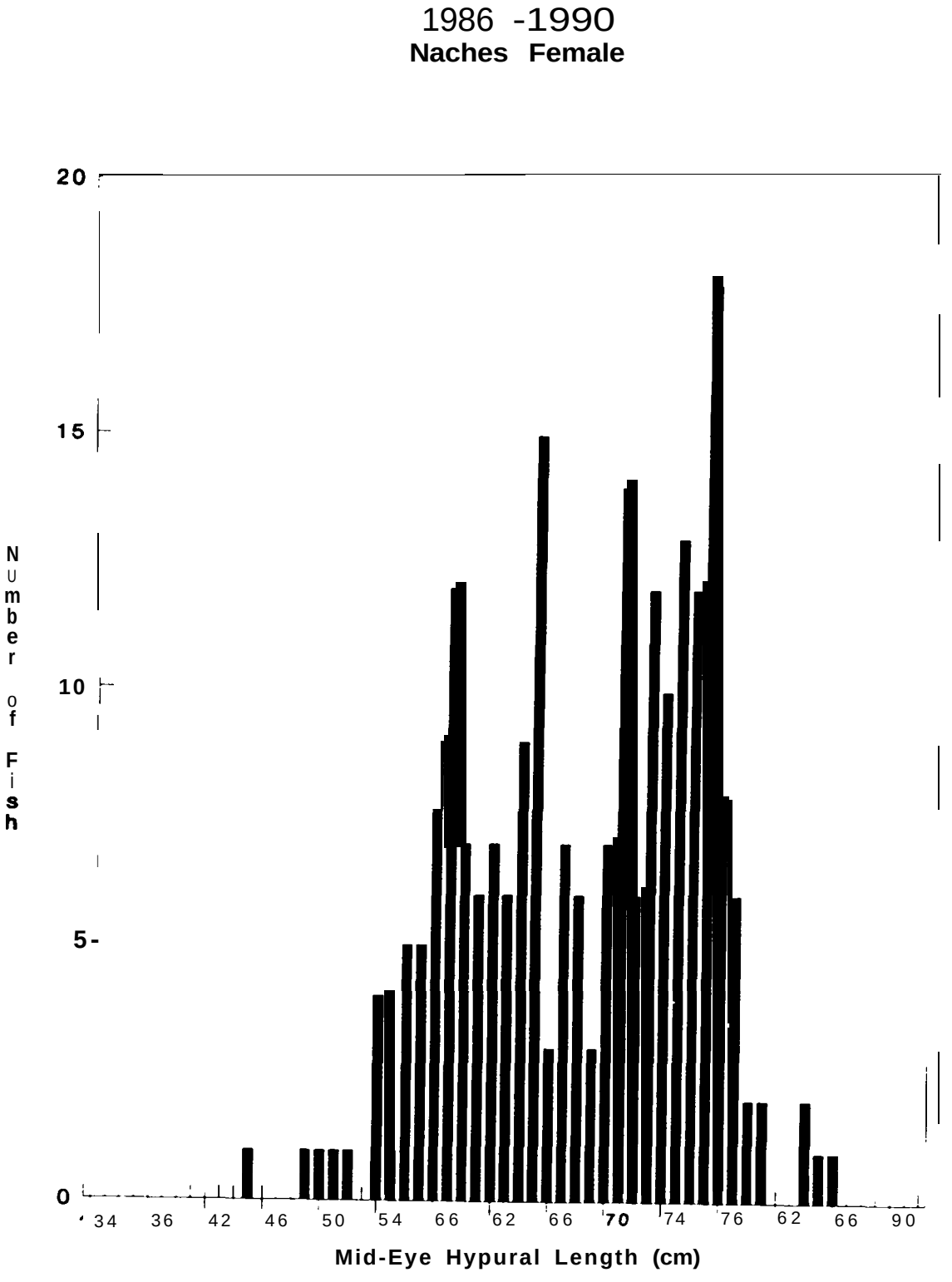


Figure 9. Hypural length distribution from spring chinook carcasses collected during spawners surveys on the Naches River and tributaries from 1986 - 1990.

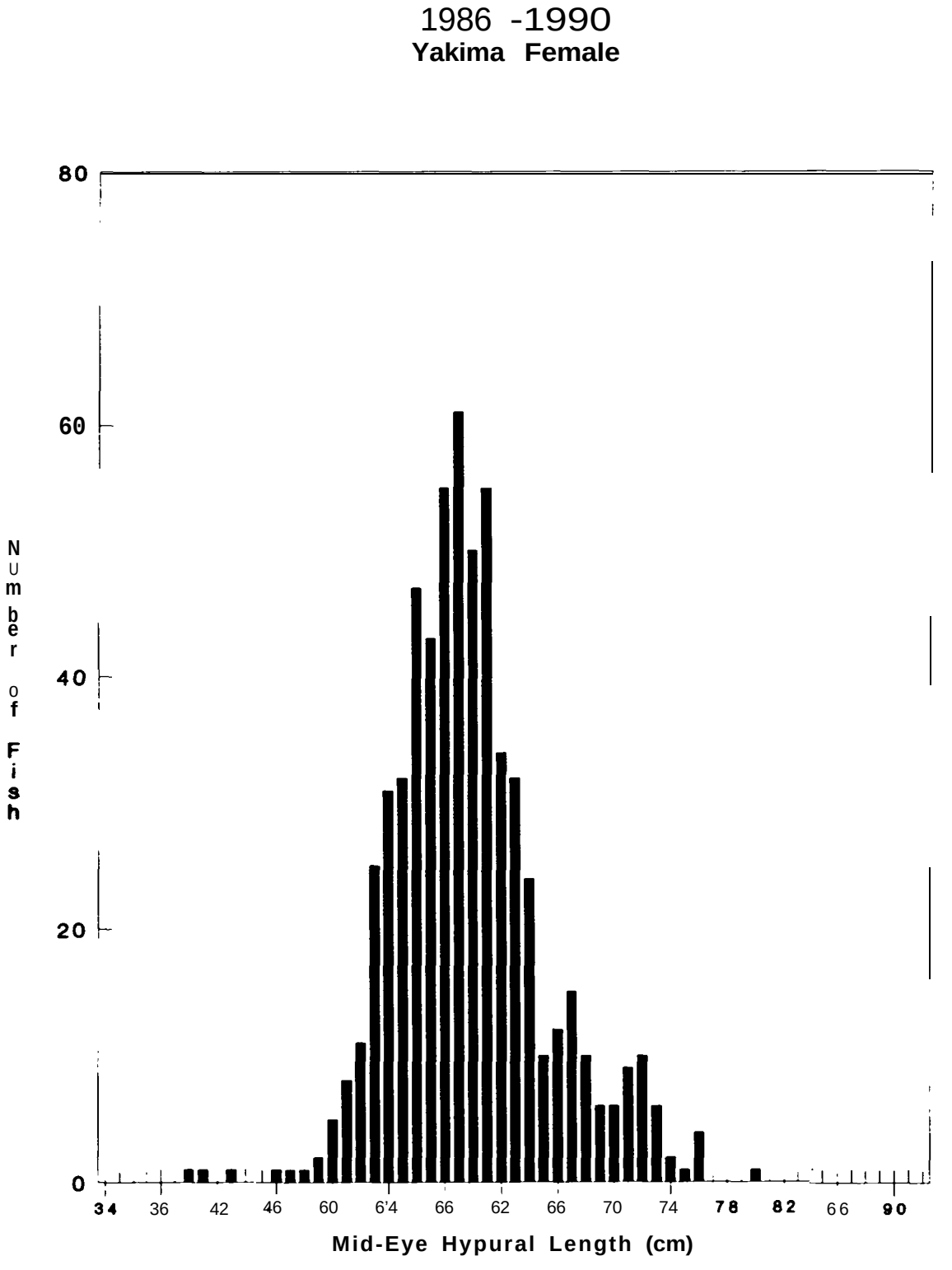


Figure 10. Hypural length distribution from spring chinook carcasses collected during spawners surveys on the Yakima River from 1986 - 1990.

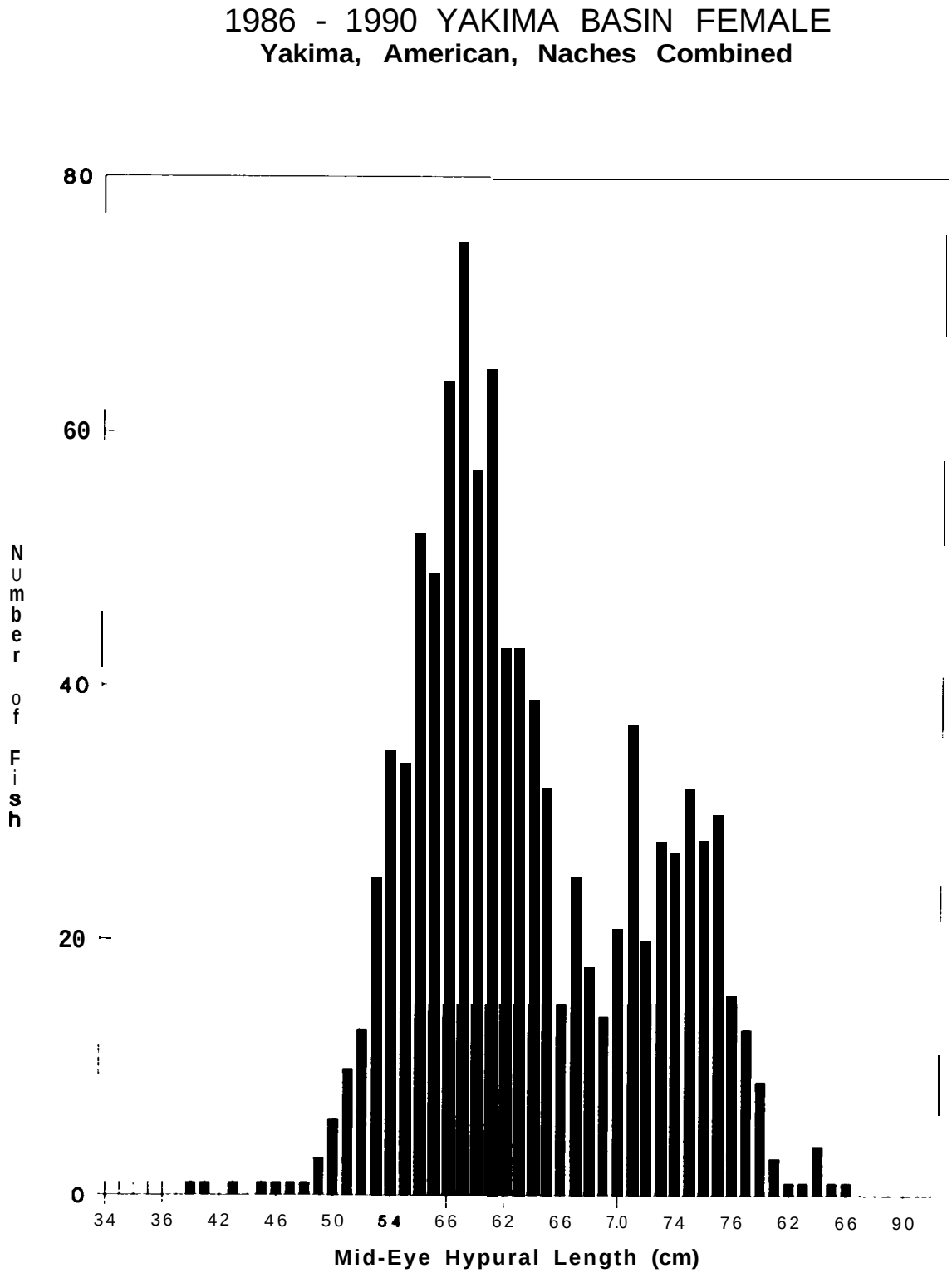


Figure 11. Hypural length distribution from spring chinook carcasses collected during spawners surveys on the Yakima River and tributaries from 1986 - 1990.

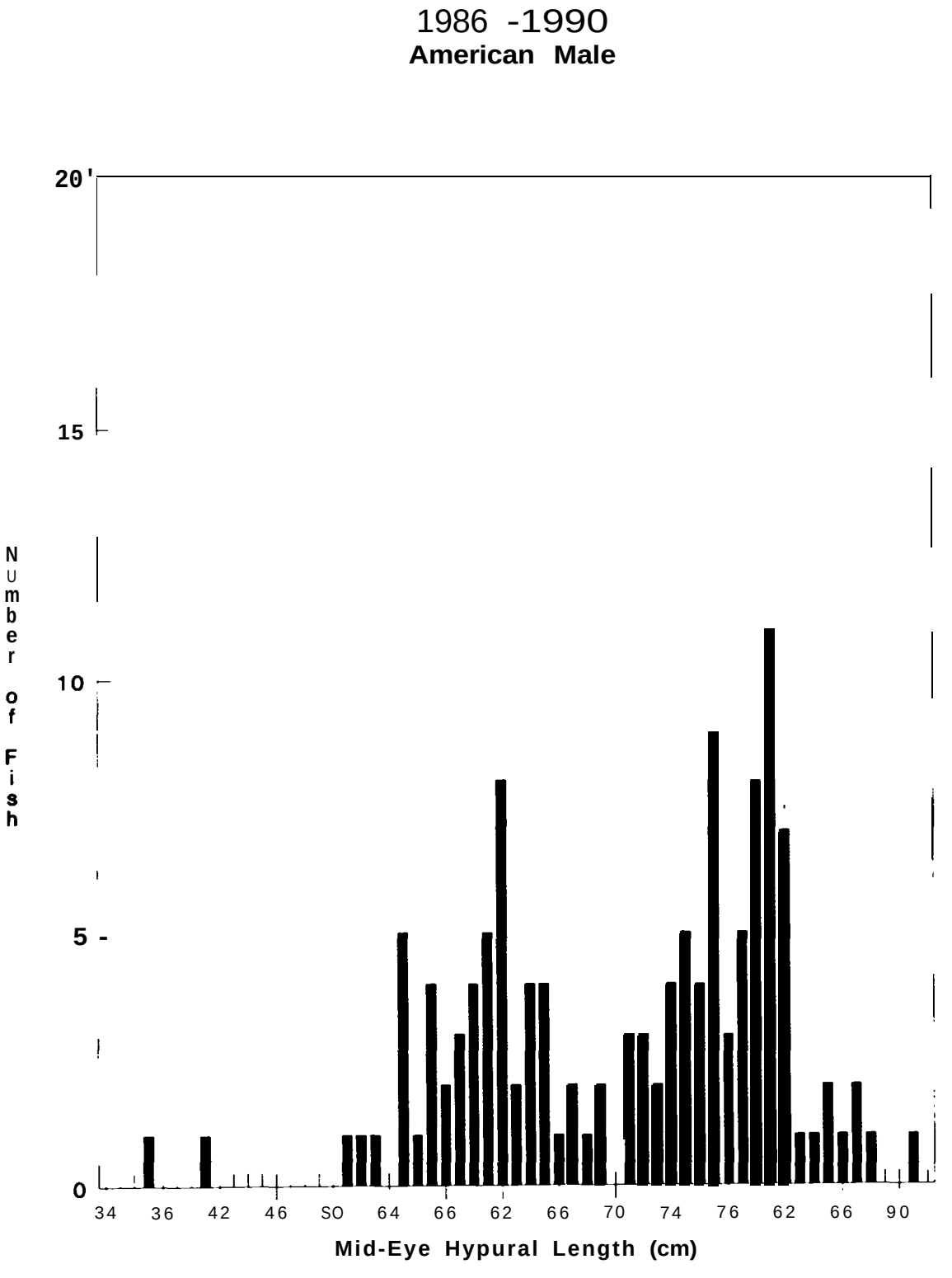


Figure 12. Hypural length distribution from spring chinook carcasses collected during spawners surveys on the American River from 1986 - 1990.

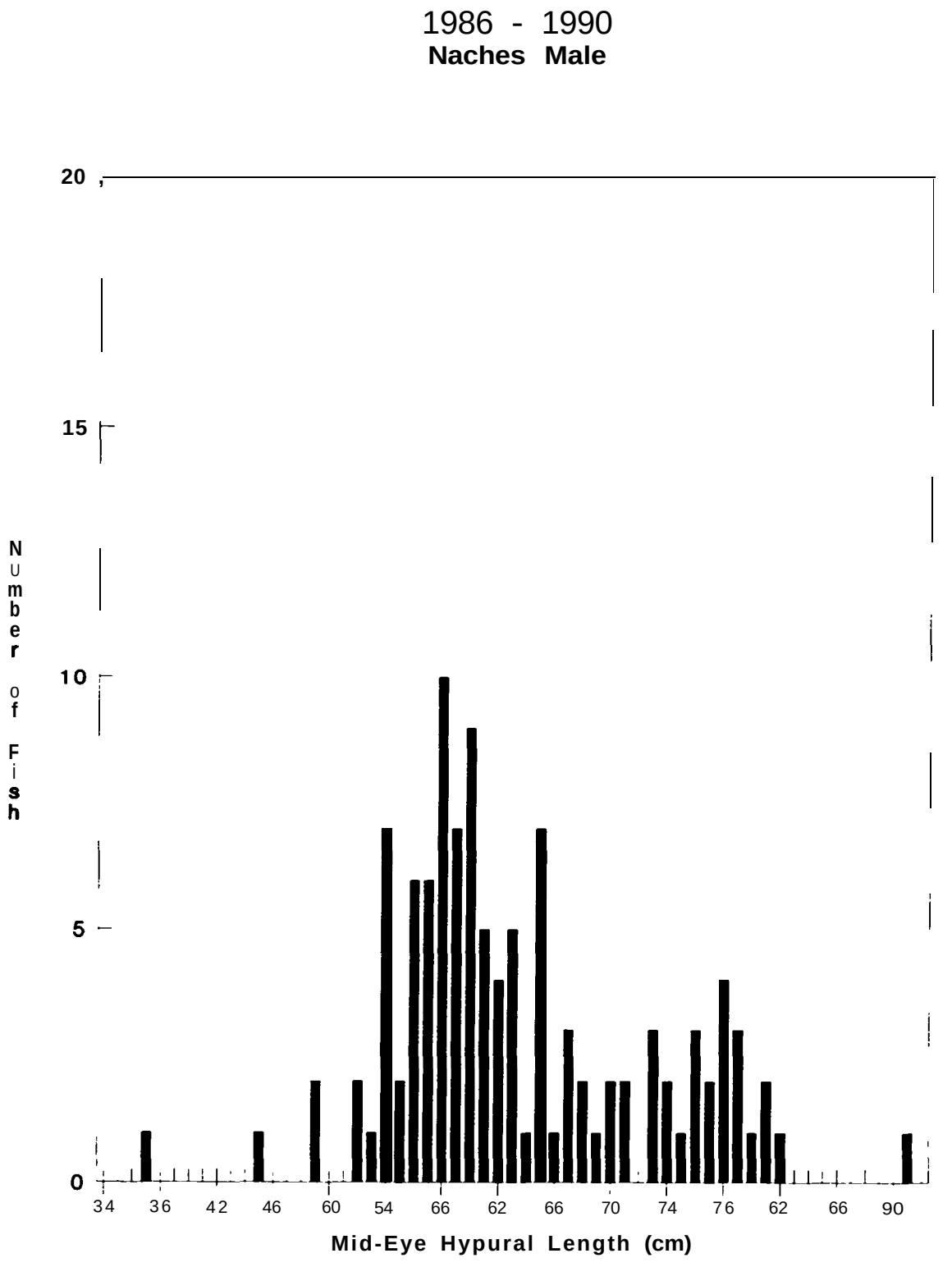


Figure 13. Hypural length distribution from spring chinook carcasses collected during spawners surveys on the Naches River and tributaries from 1986 - 1990.

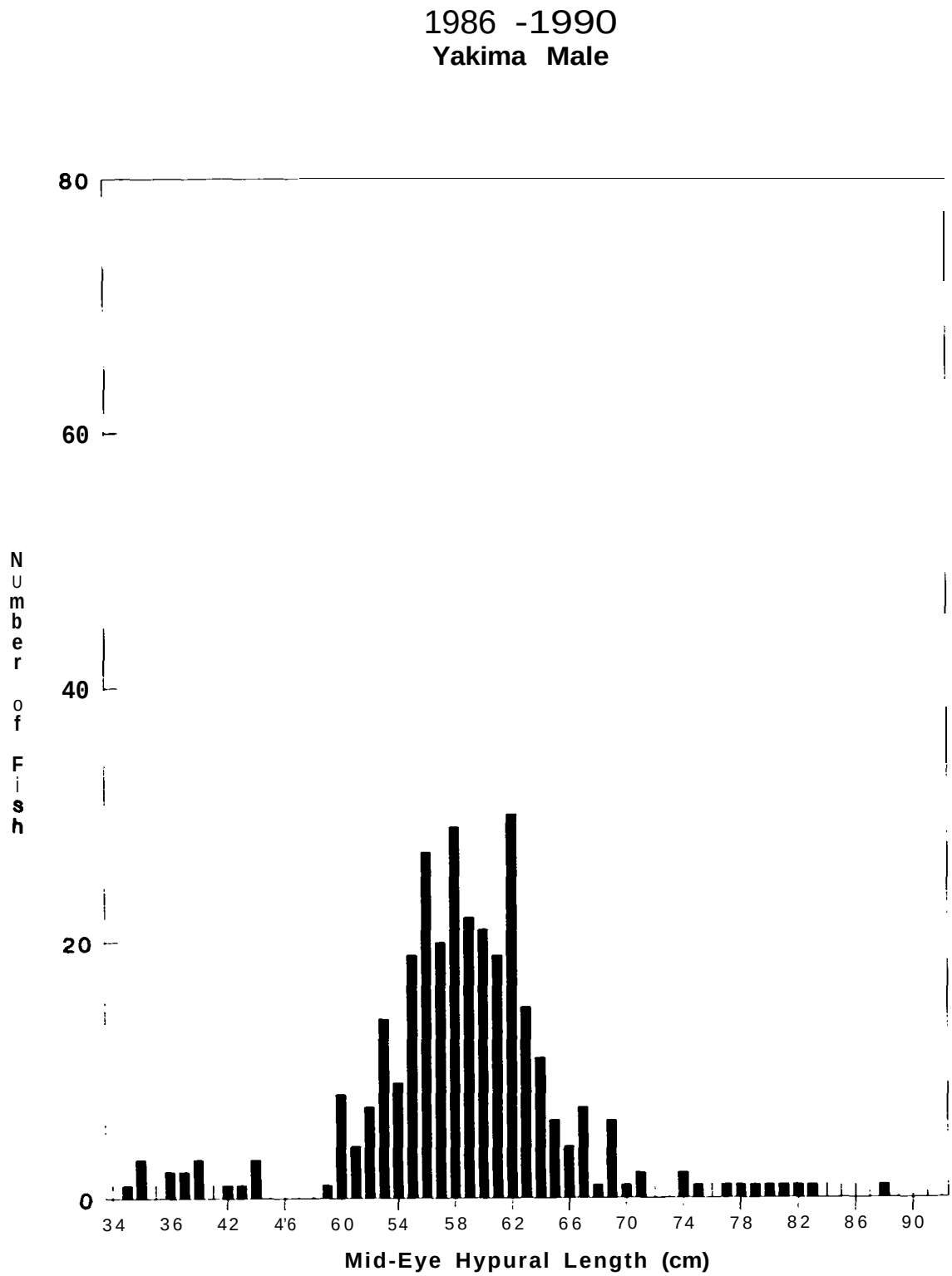


Figure 14. Hypural length distribution from spring chinook carcasses collected during spawners surveys on the Yakima River from 1986 - 1990.

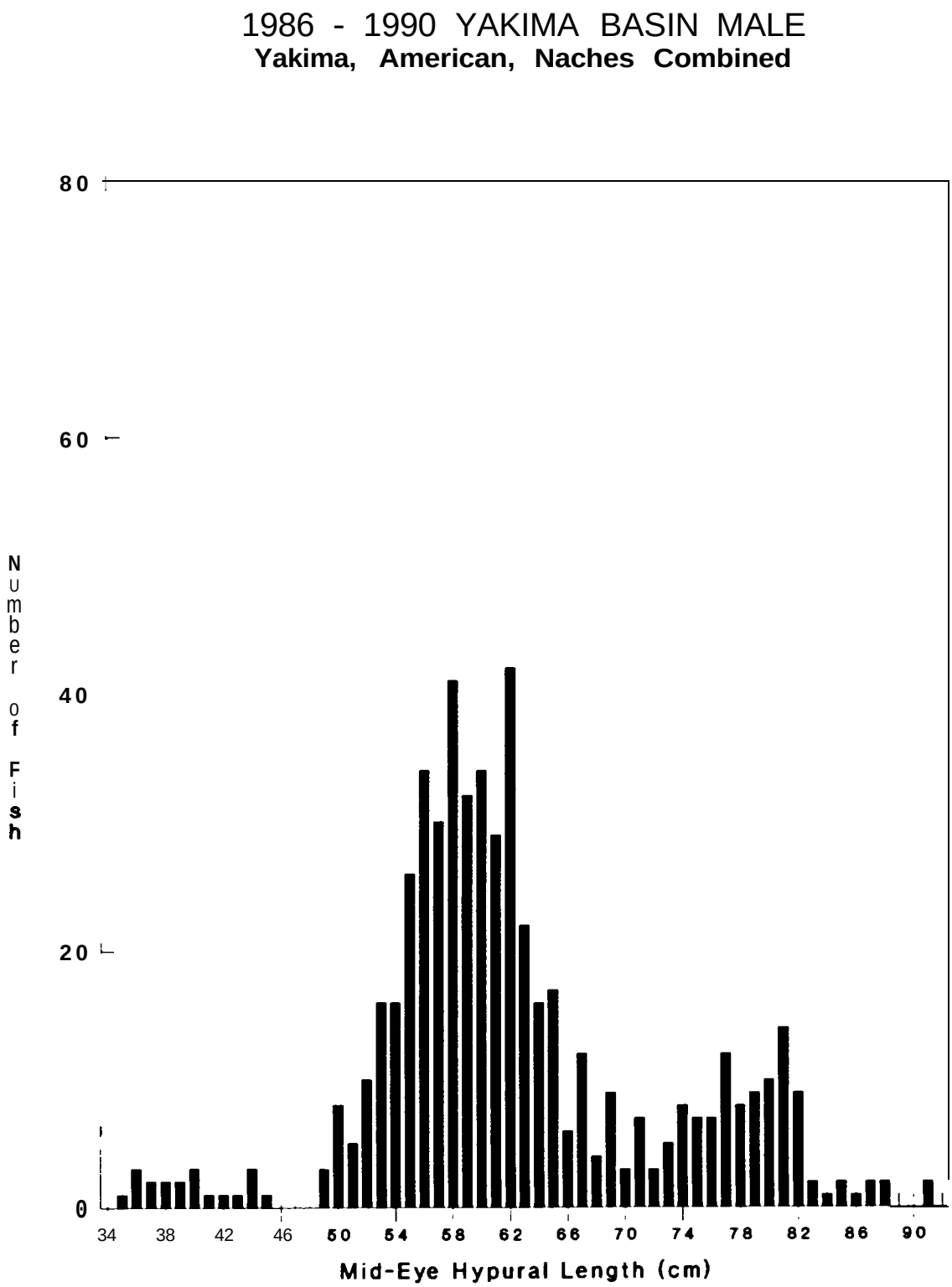


Figure 15. Hypural length distribution from spring chinook carcasses collected during spawners surveys on the Yakima River and tributaries from 1986 - 1990.

Table 7. Age composition of wild Yakima spring chinook spawners by sex and substock, 1980-1990. Age determined from analyses of scales taken from carcasses on the spawning ground.

	Substock/Spawning Area					
	American R.		Naches System		Upper Yakima	
Age	Female (% by age	Male (% by age)	Female (% by age)	Male (% by age)	Female (% by age)	Male (% by age)
3	0	1	2	4	2	7
4	20	38	46	65	90	87
5	79	60	51	29	8	6
6	1	1	1	2	0	0

Length, Fecundity and Egg Deposition

The number of eggs deposited by an individual female was estimated from a length-fecundity model based upon a sample of 23 upper Yakima spring chinook females. The best fit ($r^2 = .898$) for this linear regression line was:

EGGS = 195.2(mid-eye to hypural length in cm) - 7,736 (Figure 16).

Retained eggs were subtracted from the estimated egg deposition. The estimated number of eggs within each of the 23 females used in the length-fecundity analysis was determined by weighing four subsamples, each consisting of exactly 100 eggs. The mean weight of these four samples was then divided into the total weight of the eggs taken from each female.

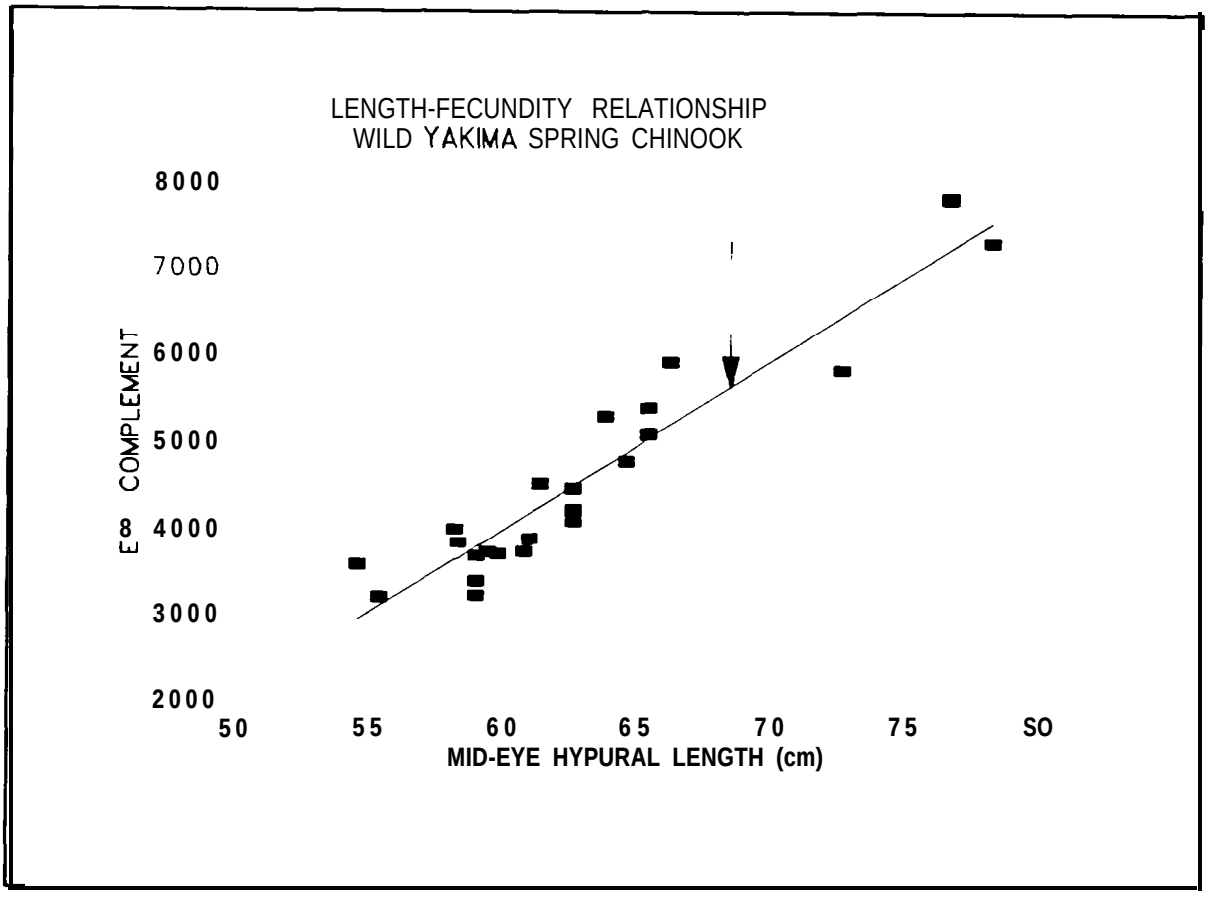


Figure 16. Relationship between mid-eye hypural length and fecundity, Yakima spring chinook.

EMERGENCE/EARLY REARING

Overview

A total of 14 redds were successfully redd-capped in 1985 and 1986. The mean estimated egg-to-fry survival rate was 59.6%, while egg-to-fry survival in individual redds ranged from 21.9% to 90%. Estimated mean temperature units (TUs) required for first emergence was 1,600 (April 11); for 50% emergence, 1,779 TUs (April 26); and for 100% emergence, 2,259 TUs (May 15).

No meaningful correlation was found between the quality of spawning gravel and egg-to-fry survival rate. The primary factor contributing to this is probably the necessity of taking the gravel samples as much as three meters away from the egg pocket. This was necessary because of excessive water depths immediately adjacent to the redd. The mean percent tines (<0.85 mm) was 11.39% in 1984, 11.93% in 1985, and 15.9% in 1986. These values, in relation to the mean egg-to-fry survival rate, are within values reported by other researchers. Tappel and Bjomn (1983) found in laboratory experiments that survival with 10% fines <0.85 mm ranged from 20% to 80%, depending on the percent fines <9.5 mm.

Researchers observed downstream movement of spring chinook fry immediately after emergence in the American River and upper Yakima River. In the American River, 36 fry were captured in 1983 and 785 fry in 1984. Median passage occurred April 17, and movements continued from March 20 to June 4 in 1984. Seventeen fry were captured in the upper Yakima River in 1983 (trapping ceased April 21), and 237 fry were captured in the upper Yakima in 1984. Median passage occurred April 16, and movements continued from March 8 to June 13 in 1984.

A total of 1,518 newly emerged fry were entrained into lost Creek ponds, an series of three small ponds excavated from a braid of the upper Naches River (RM 38.7). Fry traps were positioned near the inlet and outlet of these ponds. Between April 29 and June 2, 965 (63.6% of the total) fry were counted out of the inlet trap and released into the ponds. From April 29 through August, only 74 fry were counted out of the outlet trap. Researchers believe that most immigrant fry overwintered in the ponds, as a total of 720 smolts were counted out of the downstream trap the following spring. It should be noted that almost all (98 %) of the smolts had left the pond by March 18.

Egg-To-Fry Survival

Methods

Researchers conducted egg-to-fry survival studies in the upper Yakima River between RM 189.8 and RM 200. Spent spring chinook females were snagged from their redds, and their mid-eye to hypural length was recorded, as was the number of retained eggs. The

number of eggs deposited by an individual female was estimated by substituting mid-eye to hypural length into the length-fecundity model described above (Fig. 16). Retained eggs were subtracted from the deposition estimate.

After the female was snagged from its redd, the four comers of the redd (determined by the outermost scoured area) were marked with rebar. The following spring, approximately two weeks before initial emergence, researchers capped each redd with a 3.2 mm nylon mesh trap. The sides, top and bottom of each trap was buried to a depth of 15 cm to 20 cm. The cod end at the downstream end funneled into a small livebox.

Traps were checked daily and the number of emergent fry recorded. A thermograph was installed in the vicinity of the redd caps to monitor daily stream temperature, to estimate cumulative temperature units (TUs) for emergence.

Redd capping in 1984 was unsuccessful because of inappropriate trap design. The 1984 traps utilized a plain mesh cod-end to collect newly emergent fry. It was later determined that a high percentage of fry were being forced through the mesh as result of high water velocity and pressure. The apparent mean survival rate in 1984 was only 20.6%, and ranged from 13% to 30.6%. Modification of the cod-end to include a livebox corrected this problem in 1985 and 1986.

Results

Researchers successfully conducted emergence studies to determine the egg-to-fry survival rate in 1985 and 1986. Results are presented in Table 8. In 1985, six spring chinook redds were successfully capped and the estimated mean survival rate was 62.4 % , ranging from 29.3% up to 84.8%. In 1986, eight redds were successfully capped, and the mean egg-to-fry survival rate was estimated at 56.7%. Within individual redds, survival ranged from 2 1.9 % to 90%. The overall estimated mean egg-to-fry survival rate for both years combined was 59.6%.

The estimated mean number of TUs required for first emergence was 1,711 (April 13) in 1985 and 1,488 (April 10) in 1986. The mean for both years combined was 1,600 TUs (April 11). The estimated number of TUs required to 50% emergence was 1,937 (May 2) in 1985 and 1,621 (April 21) in 1986. For both years combined, the mean was 1,779 TUs (April 26). The estimated number of TUs required for complete emergence was 2,216 (May 19) in 1985 and 2,303 (May 11) in 1986. The mean TUs required to 100% emergence for both years combined was 2,259 TUs (May 15).

Table 8 Results of 1985 and 1986 egg-to-fry survival study in the upper Yakima Basin

Location (RM)	capture date	Female Length (mm)	Estimated fecundity	Number emergent fry	Percent survival	Date of 1st emergence	T.U's required	Date of 50% emergence	T.U's required	Date of 100% emergence	T.U's required
196.5	24-Sep-84	680	3,279	2,550	77.8	02-Apr-85	1,623	07-May-85	2,019	31-May-85	2,428
196.5	24-Sep-84	620	2,289	1,942	84.8	12-Apr-85	1,729	09-May-85	2,049	24-May-85	2,300
196.5	24-Sep-84	705	3,692	1,288	34.9	10-Apr-85	1,707	03-May-85	1,958	24-May-85	2,300
194.2	25-Sep-84	737	4,221	2,863	67.8	01-May-85	1,912	06-May-85	1,979	24-May-85	2,276
190,5	27-Sep-84	760	4,600	1,347	29.3	01-Apr-85	1,541	01-Apr-85	1,541	12-Apr-85	1,657
195.0	28-Sep-84	680	3,279	2,626	80.1	23-Apr-85	1,756	17-May-85	2,078	31-May-85	2,332
Mean	24-Sep84	697	3,560	2,103	62.4	13-Apr-85	1,711	02-May-85	1,937	19-May-85	2,216
199.2	24-Sep-85	695	3,423	3,081	90.0	24-Apr-86	1,625	29-Apr-86	1,685	04-May-86	2,283
198.4	27-Sep-85	760	4,586	1,003	21.9	04-Apr-86	1,292	18-Apr-86	1,456	16-May-86	2,398
196,5	21-Sep-85	680	3,293	2,900	88.1	17-Apr-86	1,597	28-Apr-86	1,737	18-May-86	2,582
194,2	13-Sep-85	770	4,664	1,524	32.7	08-Apr-86	1,650	21-Apr-86	1,811	11-May-86	2,623
194,2	26-Sep-85	775	4,798	1,504	31.3	06-Apr-86	1,337	23-Apr-86	1,549	31-May-86	2,126
190,5	21-Sep-85	680	3,256	2,683	82.4	11-Apr-86	1,505	21-Apr-86	1,632	11-May-86	2,444
190,5	26-Sep-85	770	4,756	1,495	31.4	25-Mar-86	1,211	26-Mar-86	1,221	11-Apr-86	1,397
189,5	19-Sep-85	750	4,435	3,356	75.7	22-Apr-86	1,688	07-May-86	1,875	16-May-86	2,571
Mean	22-Sep-85	735	4,151	2,193	56.7	10-Apr-86	1,488	21-Apr-86	1,621	11-May-86	2,303
Mean for both years	23-Sep	716	3,856	2,148	59.6	11-Apr	1,600	26-Apr	1,779	15-May	2,259

Gravel Analysis

Methods

Researchers took four gravel samples on each riffle where a redd was capped to determine if there was a correlation between egg-to-fry survival rate and quality of spawning gravel. Samples were taken in the fall shortly after completion of the spring chinook spawning season. Gravel size composition was analyzed by determining the percent of the entire gravel sample retained in each of 10 sieves (sizes 75 mm, 26.5 mm, 13.9 mm, 9.5 mm, 6.7 mm, 3.35 mm, 1.7 mm, 0.85 mm, 0.425 mm and 0.212 mm). Percent gravel retained on each sieve was expressed in terms of wet volume for geometric mean and percent tines <0.85 mm. Corrected wet volumes (dry volumes) were used to calculate the fredle index (f_1). Gravel sample collection and gravel size composition followed the methodology of Taggart (1976). The fredle index is defined as follows.

$$f_1 = d_g/S_o.$$

Where d_g = geometric mean particle size, and $S_o = (d_{75}/d_{25})^{1/2}$; and
d_{75} and d_{25} = the diameters of the particle size at the 75th and 25th percentiles of cumulative gravel sample weight.

Linear regression analysis was used to determine if a correlation existed between egg-to-fry survival rate and one the following indices of gravel quality: geometric mean particle diameter, percent fines <0.85 mm, and the fredle index (Lotspeich and Everest 1981).

Results

Gravel analysis was undertaken concurrently with egg-to-fry survival studies in 1984 through 1986 (Tables 9-l 1). No correlation between the various parameters examined and egg-to-fry survival rate was observed in any year. This lack of relationship may well have been attributable to two procedural difficulties that probably obscured whatever relationship may have existed between survival and gravel composition.

The first difficulty concerned the location of gravel sample sites in relation to the redd's location. Ideally, the sample would be taken from a spot immediately adjacent to the egg pocket. However, water depth over the redd was frequently too great to sample that closely, and samples had to be taken as much as three meters "inshore" of the redd. It is quite possible that the size distribution of gravel samples from spots this far apart was substantially different. The second problem concerned the redd cap itself. Friction between water and the mesh of the cap reduced the velocity of water moving over and through the egg pocket, causing some redd caps to act as sediment traps. In fact, some capped redds (which were excluded from analysis) became completely silted over as a result of fines settling out in the low-velocity environment inside the cap.

Table 9. Results of gravel analysis for 1984, upper Yakima River.

Sieve mid-point (mm)	Sun Country Samples 1	2	3	4	Mean	Easton Samples 1	2	3	4	Mean	Runacres No. 10 Samples 1	2	3	4	Mean
	Percent Volume (ml)														
113.5	0.0000	0.0000	0.0841	0.0000	0.0217	0.0000	0.1408	0.0939	0.0000	0.0589	0.0000	0.0000	0.0000	0.0000	0.0000
50.75	0.3719	0.2656	0.1820	0.2846	0.2780	0.3281	0.3286	0.3083	0.5043	0.3682	0.2434	0.2825	0.2545	0.2997	0.2703
19.85	0.1499	0.1511	0.1789	0.2277	0.1779	0.2207	0.1762	0.1748	0.1703	0.1848	0.1349	0.1718	0.1441	0.1319	0.1452
11.35	0.0615	0.0804	0.0631	0.0636	0.0664	0.0921	0.0505	0.0580	0.0510	0.0624	0.0746	0.0582	0.0693	0.0684	0.0677
8.1	0.0554	0.0749	0.0698	0.0639	0.0654	0.0732	0.0361	0.0523	0.0399	0.0501	0.0641	0.0525	0.0631	0.0566	0.0591
5.025	0.0930	0.1304	0.1155	0.0880	0.1053	0.0652	0.0621	0.0588	0.0534	0.0597	0.1029	0.0944	0.1209	0.1039	0.1055
2.525	0.1144	0.1449	0.1441	0.1111	0.1276	0.0742	0.0633	0.0535	0.0293	0.0545	0.1324	0.1341	0.1296	0.1594	0.1392
1.275	0.0551	0.0645	0.0572	0.0633	0.0598	0.0435	0.0392	0.0631	0.0229	0.0424	0.1147	0.1010	0.0900	0.0946	0.1002
0.638	0.0225	0.0097	0.0252	0.0242	0.0210	0.0297	0.0182	0.0450	0.0114	0.0263	0.0541	0.0490	0.0673	0.0388	0.0520
0.319	0.0180	0.0172	0.0196	0.0153	0.0176	0.0093	0.0110	0.0105	0.0091	0.0100	0.0169	0.0137	0.0214	0.0146	0.0166
0.106	0.0583	0.0614	0.0603	0.0583	0.0595	0.0640	0.0740	0.0820	0.1085	0.0826	0.0618	0.0430	0.0397	0.0322	0.0442
Geo. Mean	9.79	7.73	8.26	8.91	8.7	10.40	14.34	10.71	12.89	11.97	6.1	7.7	6.84	8.06	7.14
	Percent Finer Than < 0.85 mm														
113.500	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
50.750	1.0000	1.0000	0.9159	1.0000	0.9783	1.0000	0.8592	0.9061	1.0000	0.9411	1.0000	1.0000	1.0000	1.0000	1.0000
19.850	0.6281	0.7344	0.7339	0.7154	0.7003	0.6719	0.5306	0.5979	0.4957	0.5729	0.7566	0.7175	0.7455	0.7003	0.7297
11.350	0.4781	0.5833	0.5550	0.4876	0.5224	0.4512	0.3543	0.4231	0.3254	0.3881	0.6216	0.5458	0.6014	0.5685	0.5845
8.100	0.4167	0.5029	0.4919	0.4240	0.4560	0.3591	0.3039	0.3651	0.2744	0.3256	0.5471	0.4875	0.5321	0.5001	0.5168
5.025	0.3613	0.4281	0.4220	0.3602	0.3907	0.2859	0.2678	0.3128	0.2345	0.2755	0.4829	0.4351	0.4690	0.4435	0.4577
2.525	0.2683	0.2977	0.3065	0.2721	0.2853	0.2207	0.2057	0.2540	0.1812	0.2158	0.3800	0.3407	0.3480	0.3395	0.3522
1.275	0.1539	0.1528	0.1624	0.1611	0.1577	0.1465	0.1424	0.2005	0.1519	0.1613	0.2476	0.2066	0.2185	0.1802	0.2130
0.638	0.0988	0.0883	0.1052	0.0978	0.0980	0.1030	0.1032	0.1374	0.1290	0.1189	0.1329	0.1056	0.1284	0.0855	0.1128
0.319	0.0763	0.0786	0.0799	0.0736	0.0770	0.0732	0.0850	0.0925	0.1176	0.0926	0.0787	0.0567	0.0611	0.0467	0.0608
0.106	0.0583	0.0614	0.0603	0.0583	0.0595	0.0640	0.0740	0.0820	0.1085	0.0826	0.0618	0.0430	0.0397	0.0322	0.0442
Percent < 0.85	9.88	8.83	10.52	9.78	9.80	10.30	10.32	13.74	12.90	11.89	13.29	10.56	12.84	8.55	11.28

Continue Table 9.

Table 9 Continued. Results of gravel analysis for 1984, upper Yaklma River.

Sieve mid-point (mm)	Runacres No. 9 Samples 1	2	3	4	Mean	Elk Meadows Samples 1	2	3	4	Mean
	Percent Volume (ml)									
113.5	0.0000	0.0000	0.0000	0.1073	0.0289	0.0000	0.2000	0.2253	0.0000	0.1031
50.75	0.3188	0.3325	0.2221	0.2206	0.2682	0.2536	0.2873	0.2020	0.2875	0.2552
19.85	0.1615	0.1620	0.2298	0.1571	0.1795	0.2306	0.2082	0.1683	0.2495	0.2136
11.35	0.0650	0.0714	0.0721	0.0558	0.0659	0.0729	0.0694	0.0500	0.0776	0.0672
8.1	0.0749	0.0612	0.0595	0.0577	0.0631	0.0599	0.0567	0.0472	0.0633	0.0566
5.025	0.1204	0.1153	0.1097	0.0995	0.1107	0.0750	0.0667	0.0954	0.0910	0.0820
2.525	0.0948	0.1194	0.1188	0.1164	0.1125	0.0501	0.0476	0.1211	0.0970	0.0784
1.275	0.0604	0.0684	0.0409	0.0491	0.0536	0.0096	0.0170	0.0334	0.0301	0.0220
0.638	0.0459	0.0258	0.0368	0.0446	0.0388	0.0057	0.0094	0.0176	0.0119	0.0110
0.319	0.0155	0.0033	0.0310	0.0340	0.0222	0.0039	0.0064	0.0111	0.0161	0.0090
0.106	0.0428	0.0406	0.0793	0.0577	0.0566	0.2388	0.0315	0.0285	0.0761	0.1019
Geo. Hean	9.13	9.96	6.86	8.95	8.54	5.02	21.27	15.99	9.44	10.76
	Percent Finer Than < 0.85 mm									
113.500	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
50.750	1.0000	1.0000	1.0000	0.8927	0.9711	1.0000	0.8000	0.7747	1.0000	0.8969
19.850	0.6812	0.6675	0.7779	0.6721	0.7030	0.7464	0.5127	0.5727	0.7125	0.6417
11.350	0.5197	0.5055	0.5481	0.5150	0.5234	0.5158	0.3045	0.4045	0.4630	0.4282
8.100	0.4547	0.4341	0.4760	0.4592	0.4575	0.4429	0.2352	0.3544	0.3855	0.3610
5.025	0.3797	0.3729	0.4165	0.4014	0.3944	0.3830	0.1785	0.3072	0.3222	0.3043
2.525	0.2594	0.2576	0.3068	0.3019	0.2837	0.3080	0.1118	0.2118	0.2312	0.2223
1.275	0.1646	0.1381	0.1880	0.1855	0.1712	0.2579	0.0642	0.0907	0.1342	0.1439
0.638	0.1042	0.0697	0.1471	0.1364	0.1176	0.2483	0.0473	0.0573	0.1040	0.1220
0.319	0.0583	0.0439	0.1103	0.0918	0.0789	0.2427	0.0379	0.0397	0.0922	0.1110
0.106	0.0428	0.0406	0.0793	0.0577	0.0566	0.2388	0.0315	0.0285	0.0761	0.1019
Percent < 0.85	10.42	6.97	14.71	13.64	11.76	24.83	4.73	5.73	10.40	12.19

Table 10. Results of gravel analysis for 1985, upper Yaklma River.

Sieve mid-point (mm)	Easton Ridge 1 Samples				Easton Ridge 2 Samples					Easton Ridge 3 Samples			
	Percent Volume (ml)												
	2	3	4	Mean	1	2	3	4	Mean	1	2	4	Hean
113.5	0.0933	0.0000	0.0000	0.0287	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
50.75	0.2128	0.3331	0.3728	0.3088	0.3101	0.3307	0.3202	0.2475	0.3023	0.3694	0.4598	0.4319	0.4175
19.85	0.1612	0.0852	0.1019	0.1139	0.1356	0.1485	0.1457	0.1375	0.1419	0.1486	0.1163	0.1039	0.1238
11.35	0.0376	0.0532	0.0507	0.0476	0.0698	0.0620	0.0539	0.0613	0.0617	0.0492	0.0422	0.0370	0.0429
8.1	0.0381	0.0520	0.0461	0.0458	0.0552	0.0551	0.0654	0.0603	0.0590	0.0507	0.0414	0.0531	0.0488
5.025	0.0810	0.0616	0.0889	0.0763	0.0974	0.0910	0.0916	0.0916	0.0929	0.0831	0.0695	0.0716	0.0751
2.525	0.0909	0.0790	0.1019	0.0900	0.0784	0.0984	0.0894	0.0874	0.0884	0.0739	0.0797	0.1409	0.0985
1.275	0.1272	0.1881	0.1229	0.1485	0.1336	0.0905	0.1415	0.1838	0.1372	0.1115	0.0668	0.0577	0.0799
0.638	0.0853	0.1056	0.0566	0.0837	0.0545	0.0551	0.0803	0.1083	0.0746	0.0678	0.0575	0.0300	0.0518
0.319	0.0315	0.0160	0.0163	0.0209	0.0176	0.0221	0.0073	0.0075	0.0136	0.0131	0.0134	0.0231	0.0166
0.106	0.0412	0.0260	0.0419	0.0358	0.0477	0.0467	0.0049	0.0149	0.0285	0.0328	0.0535	0.0508	0.0451
Geo. Mean	7.45	6.65	a.31	7.40	7.53	8.28	8.76	6.30	7.66	9.31	lo.84	10.11	10.02
	Percent Finer Than < 0.85 mm												
113.500	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
50.750	0.9067	1.0000	1.0000	0.9713	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
19.850	0.6939	0.6669	0.6272	0.6625	0.6899	0.6693	0.6798	0.7525	0.6977	0.6306	0.5402	0.5681	0.5825
11.350	0.5327	0.5816	0.5253	0.5485	0.5542	0.5208	0.5341	0.6150	0.5559	0.4820	0.4240	0.4642	0.4587
8.100	0.4952	0.5284	0.4745	0.5009	0.4844	0.4588	0.4803	0.5538	0.4942	0.4328	0.3817	0.4273	0.4158
5.025	0.4571	0.4764	0.4284	0.4551	0.4292	0.4037	0.4149	0.4935	0.4352	0.3821	0.3403	0.3741	0.3670
2.525	0.3762	0.4148	0.3395	0.3788	0.3317	0.3128	0.3234	0.4019	0.3423	0.2990	0.2708	0.3025	0.2919
1.275	0.2853	0.3357	0.2376	0.2888	0.2534	0.2144	0.2340	0.3145	0.2539	0.2251	0.1911	0.1617	0.1933
0.638	0.1580	0.1477	0.1147	0.1403	0.1198	0.1239	0.0925	0.1307	0.1167	0.1137	0.1243	0.1039	0.1135
0.319	0.0727	0.0420	0.0582	0.0566	0.0653	0.0688	0.0122	0.0224	0.0421	0.0459	0.0668	0.0739	0.0617
0.106	0.0412	0.0260	0.0419	0.0358	0.0477	0.0467	0.0049	0.0149	0.0285	0.0328	0.0535	0.0508	0.0451
Percent < 0.85	15.80	14.77	11.47	14.03	11.98	12.39	9.25	13.07	11.66	11.37	12.43	10.39	11.35

contin;;b-rei;T;-Tij----"

Table IO Continued. Results of gravel analysis for 1985, upper Yakima River

Sieve mid-point (mm)	Sun Country 2 Samples 1	2	3	4	Mean	Elk Meadows Samples 1	2	4	Mean	West Nelson Samples 1	2	3	4	Mean
Percent Volume (ml)														
113.5	0.0000	0.1096	0.1168	0.0000	0.0665	0.0000	0.0597	0.0587	0.0401	0.0000	0.0000	0.0000	0.0000	0.0000
50.75	0.1105	0.2103	0.2535	0.3526	0.2314	0.2938	0.2478	0.2445	0.2614	0.2645	0.3641	0.3188	0.3117	0.3151
19.85	0.2355	0.0828	0.1050	0.0851	0.1225	0.1441	0.1134	0.1149	0.1239	0.0982	0.0752	0.1594	0.1143	0.1090
11.35	0.0843	0.0291	0.0554	0.0517	0.0535	0.0734	0.0716	0.0587	0.0674	0.0630	0.0510	0.0625	0.0623	0.0594
8.1	0.0727	0.0604	0.0614	0.0669	0.0646	0.0678	0.0567	0.0538	0.0592	0.0428	0.0510	0.0563	0.0494	0.0495
5.025	0.0814	0.0671	0.0871	0.2128	0.1058	0.0876	0.0866	0.0905	0.0883	0.0831	0.1044	0.0656	0.0883	0.0865
2.525	0.1628	0.1051	0.1168	0.1216	0.1243	0.1073	0.1522	0.1589	0.1403	0.1763	0.1772	0.1344	0.1870	0.1704
1.275	0.1512	0.1566	0.0752	0.0395	0.1065	0.0960	0.1164	0.1198	0.1111	0.1285	0.0922	0.0781	0.0883	0.0978
0.638	0.0262	0.0716	0.0317	0.0182	0.0388	0.0650	0.0358	0.0562	0.0528	0.0504	0.0316	0.0375	0.0286	0.0370
0.319	0.0233	0.0268	0.0238	0.0091	0.0215	0.0141	0.0090	0.0073	0.0100	0.0202	0.0073	0.0219	0.0156	0.0159
0.106	0.0523	0.0805	0.0733	0.0426	0.0646	0.0508	0.0507	0.0367	0.0455	0.0730	0.0461	0.0656	0.0545	0.0594
Geo. Mean	5.25	5.98	8.90	9.54	7.24	7.46	7.81	7.71	7.66	5.44	8.28	7.83	7.42	7.13
Percent Finer Than < 0.85 mm														
113.500	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
50.750	1.0000	0.8904	0.8832	1.0000	0.9335	i.0000	0.9403	0.9413	0.9599	1.0000	1.0000	1.0000	1.0000	1.0000
19.850	0.8895	0.6801	0.6297	0.6474	0.7022	0.7062	0.6925	0.6968	0.6985	0.7355	0.6359	0.6813	0.6883	0.6849
11.350	0.6541	0.5973	0.5248	0.5623	0.5797	0.5621	0.5791	0.5819	0.5747	0.6373	0.5607	0.5219	0.5740	0.5760
8.100	0.5698	0.5682	0.4693	0.5106	0.5262	0.4887	0.5075	0.5232	0.5073	0.5743	0.5097	0.4594	0.5117	0.5165
5.025	0.4971	0.5078	0.4079	0.4438	0.4615	0.4209	0.4507	0.4694	0.4481	0.5315	0.4587	0.4031	0.4623	0.4670
2.525	0.4157	0.4407	0.3208	0.2310	0.3557	0.3333	0.3642	0.3790	0.3597	0.4484	0.3544	0.3375	0.3740	0.3804
1.275	0.2529	0.3356	0.2040	0.1094	0.2314	0.2260	0.2119	0.2200	0.2195	0.2720	0.1772	0.2031	0.1870	0.2100
0.638	0.1017	0.1790	0.1287	0.0699	0.1249	0.1299	0.0955	0.1002	0.1084	0.1436	0.0850	0.1250	0.0987	0.1123
0.319	0.0756	0.1074	0.0970	0.0517	0.0862	0.0650	0.0597	0.0440	0.0556	0.0932	0.0534	0.0875	0.0701	0.0753
0.106	0.0523	0.0805	0.0733	0.0426	0.0646	0.0508	0.0507	0.0367	0.0455	0.0730	0.0461	0.0656	0.0545	0.0594
Percent < 0.85	10.17	17.90	12.87	6.99	12.49	12.99	9.55	10.02	lo.84	14.36	a.50	12.50	9.87	11.23

Table 11. Results of gravel analysis for 1586, Lppr Yakhm River.

Sieve mid-pxnt (mm)	Salmon La Sac Sanples 1	2	3	4	Mean	Sun Gxntryl Samples 1	2	3	4	Mean	Sun Contry 3 hnples 1	2	3	4	Mean	Elk Meadows Samples 1	2	3	4	Men
	Percent Volume (mL)																			
113.5	0.0C00	0.0856	0.0675	0.0000	0.0363	0.0000	0.0000	0.0000	0.1105	0.0276	0.0562	0.0890	0.0362	0.0000	0.0i'03	0.1684	0.0000	0.0794	0.0982	0.0865
50.75	0.2620	0.1497	0.2571	0.2513	0.2300	0.2737	0.2943	0.4CD3	0.1870	0.2887	0.2740	0.2881	0.2740	0.3384	0.2936	0.2189	0.3920	0.2208	0.1757	0.2518
19.85	0.1486	0.0802	0.1377	0.1658	0.1331	0.1018	0.1572	0.1147	0.1445	0.1295	0.0913	0.0937	0.CQI3	0.1212	0.0594	0.0976	0.CSKJ	0.1241	0.1214	0.1103
11.35	0.0579	0.0508	0.0571	0.0779	0.0609	0.0561	0.0669	0.0560	0.0623	0.0603	0.0577	0.038	0.0577	0.0707	0.0565	0.0505	0.0452	0.0471	0.0439	0.0467
8.1	0.0605	0.0615	0.0468	0.0603	0.0573	0.0491	0.0836	0.0533	0.0595	0.0614	0.0481	0.0609	0.0481	0.0631	0.0550	0.0471	0.0477	0.0447	0.0310	0.0426
5.095	0.1688	0.1952	0.1714	0.1055	0.1602	0.1228	0.1003	0.0827	0.1076	0.1034	0.1010	0.2295	0.1010	0.1338	0.1413	0.0943	0.1432	0.0844	0.1783	0.1250
2.525	0.1436	0.2086	0.1403	0.1834	0.1@o	0.1789	0.1070	0.1067	0.1190	0.1279	0.1394	0.0843	0.1394	0.1515	0.1287	0.1448	0.1407	0.2258	0.1835	0.1737
1.275	0.0705	0.0668	0.0390	0.0576	0.0585	0.0737	0.0535	0.0453	0.0453	0.0545	0.0577	0.0351	0.0577	0.0328	0.0458	0.0673	0.0352	0.0596	0.0310	0.0483
0.638	0.0277	0.0294	0.0234	0.0276	0.0270	0.0491	0.0268	0.0427	0.0368	0.0388	0.0313	0.0187	0.0313	0.0278	0.0273	0.0168	0.0151	0.0298	0.0181	0.0199
0.319	0.0126	0.0160	0.0130	0.0126	0.0135	0.0281	0.0134	0.0293	0.0198	0.0227	0.0264	0.0094	0.0264	0.0253	0.0219	0.0135	0.0126	0.0124	0.0129	0.0128
0.105	0.0479	0.0561	0.0468	0.0578	0.052-1	0.0667	0.0970	0.0693	0.1076	0.0352	0.0769	0.0515	0.0769	0.0354	0.0602	0.0838	0.0704	0.0720	0.1059	0.0@3
Geo Mean	7.60	6.37	9.61	7.35	7.65	6.03	7.33	8.99	7.23	7.32	8.45	10.79	8.45	9.38	9.22	9.65	9.33	7.33	6.64	a.14
	Percent Finer Than < 0.85 mm																			
113.5oo	1,oooo	1,0000	1,oooo	1,oo00	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	0.9255	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
50.750	1.0000	0.9144	0.9325	1.0000	0.9627	1.0000	1.0000	1.0000	0.8895	0.9703	0.9255	0.9110	0.9038	1.0000	0.9520	0.8316	1.0000	0.9206	0.9018	0.9192
19.850	0.7380	0.7647	0.6753	0.7487	0.7317	0.7263	0.7057	0.6000	0.7025	0.6791	0.7284	0.6230	0.6298	0.6616	0.6730	0.6128	0.6080	0.69%	0.7351	0.6646
II.350	0.5894	0.6845	0.5377	0.5629	0.5978	0.6246	0.5485	0.4853	0.5581	0.5495	0.6332	0.5293	0.5385	0.5404	0.5677	0.5152	0.5101	0.5757	0.6047	0.5535
8.100	0.5315	0.6337	0.4805	0.5050	0.5367	0.5684	0.4816	0.4293	0.4958	0.4833	0.5457	0.4895	0.483	0.4697	0.5062	0.4646	0.4648	0.5285	0.5607	0.5071
5.025	0.4710	0.5722	0.4338	0.4447	0.4794	0.5193	0.3980	0.3760	0.4363	0.4284	0.4351	0.4286	0.4327	0.4066	0.4341	0.4175	0.4171	0.4K39	0.5297	0.4646
2.525	0.3023	0.3770	0.2623	0.3392	0.3198	0.3965	0.2977	0.2933	0.3286	0.3262	0.2188	0.1991	0.3317	0.2727	0.2599	0.3232	0.2i39	0.3995	0.3514	0.3380
1.275	0.1587	0.1684	0.1221	0.1558	0.1512	0.2175	0.1906	0.1867	0.2096	0.2005	0.1611	0.1148	0.1923	0.1212	0.1502	0.1785	0.1332	0.1737	0.1680	0.1623
0.638	0.CB62	0.1016	0.01331	0.0980	0.0927	0.1439	0.1371	0.1413	0.1643	0.1471	0.1o58	0.0796	0.1346	0.0884	0.1041	0.1111	0.0980	0.1141	0.1370	0.1152
0.319	0.0605	0.0722	0.0597	0.0704	0.0656	0.0347	0.1104	0.0987	0.1275	0.1082	0.0841	0.0609	0.1034	0.0606	0.0788	o.o943	0.0829	0.0844	0.1189	0.0949
0.106	0.0479	0.0561	0.0468	0.0578	0.0521	0.0667	0.0970	0.0693	0.1076	0.0854	0.0625	0.0515	0.0769	0.0354	0.0579	0.0808	0.0704	0.0720	0.1059	0.0822
Percent < 0.85	8.82	10.16	8.31	9.80	9.27	14.39	13.71	14.13	16.43	14.71	10.58	7.96	13.46	8.84	10.41	11.11	9.80	11.41	13.69	11.51

Continued-TX~~C

Table 11 Continued. Results of gravel analysis for 1986, upper Yakima River

Sieve mid-point (mm)	Elk Meadows 2 Samples 1	2	3	4	mean	LDS Site Samples 1	2	3	4	Mean	Side Channel Samples 1	2	3	4	Mean
	Percent Volume (ml)														
113.5	0.0000	0.0000	0.0000	0.0000	0.0000	0.0994	0.0652	0.1561	0.0000	0.0802	0.0000	0.0000	0.0000	0.0000	0.0000
50.75	0.2556	0.2771	0.2953	0.2568	0.2712	0.3867	0.2440	0 1878	0.2866	0.2763	0.1364	0.2095	0.1985	0.2259	0.1926
19.85	0.1216	0.1461	0.1530	0.1649	0.1464	0.0635	0.1014	0.0701	0.0948	0.0825	0.1313	0.1307	0.1267	0.1499	0.1346
11.35	0.0546	0.0403	0.1056	0.0595	0.0650	0.0497	0.0676	0.0498	0.0582	0.0563	0.0535	0.0602	0.0681	0.0678	0.0624
8.1	0.0521	0.0554	0.0409	0.0703	0.0547	0.0691	0.0580	0.0543	0.0884	0.0674	0.0553	0.0747	0.0756	0.0862	0.0730
5.025	0.0769	0.0756	0.0366	0.1297	0.0797	0.0856	0.1232	0.1290	0.1552	0.1232	0.1434	0.1950	0.1456	0.1622	0.1615
2.525	0.1588	0.1285	0.0603	0.1378	0.1214	0.1215	0.1667	0.1765	0.1358	0.1501	0.0812	0.1037	0.1947	0.1047	0.1211
1.275	0.0844	0.0957	0.1315	0.0838	0.0988	0.0497	0.0628	0.0724	0.0754	0.0651	0.0432	0.0664	0.0529	0.0534	0.0540
0.638	0.0372	0.0378	0.0841	0.0243	0.0458	0.0166	0.0266	0.0249	0.0237	0.0229	0.0518	0.0539	0.0416	0.0308	0.0445
0.319	0.0149	0.0126	0.0151	0.0108	0.0133	0.0083	0.0097	0.0136	0.0086	0.0100	0.0276	0.0290	0.0284	0.0185	0.0259
0.106	0.1439	0.1310	0.0776	0.0622	0.1037	0.0497	0.0749	0.0656	0.0733	0.0659	0.2763	0.0768	0.0681	0.1006	0.1304
Geo. Mean	4.68	5.35	6.53	7.29	5.88	13.18	7.63	8.46	6.99	a.78	2.26	5.55	5.51	6.00	4.51
	Percent Finer Than < 0.85 mm														
113.500	1.0000	1.0000	1.0000	1.0000	1.0000	1.1436	1.0676	0.8190	1.0000	1.0000	0.8325	1.0975	1.0945	1.0000	1.0000
50.750	1.0000	1.0000	1.0000	1.0000	1.0000	1.0691	0.9010	0.7376	1.0000	0.9215	0.8325	1.0975	1.0945	1.0000	1.0000
19.850	0.7444	0.7229	0.7047	0.7432	0.7277	0.7901	0.7005	0.4208	0.7134	0.6498	0.6580	0.8797	0.9452	0.7741	0.8098
11.350	0.6228	0.5768	0.5517	0.5784	0.5814	0.6740	0.6256	0.3688	0.6185	0.5666	0.5492	0.7407	0.8015	0.6242	0.6755
8.100	0.5682	0.5365	0.4461	0.5189	0.5147	0.5967	0.5725	0.3281	0.5603	0.5101	0.4991	0.6660	0.7429	0.5565	0.6134
5.025	0.5161	0.4811	0.4052	0.4486	0.4608	0.5304	0.5145	0.2715	0.4720	0.4423	0.4370	0.5830	0.6824	0.4702	0.5412
2.525	0.4392	0.4055	0.3685	0.3189	0.3837	0.3895	0.3768	0.2014	0.3168	0.3169	0.2746	0.4232	0.5255	0.3080	0.3808
1.275	0.2804	0.2771	0.3082	0.1811	0.2650	0.1989	0.1884	0.1018	0.1810	0.1659	0.1883	0.2095	0.4367	0.2033	0.2600
0.638	0.1960	0.1814	0.1767	0.0973	0.1646	0.1271	0.1111	0.0611	0.1056	0.0999	0.1330	0.1515	0.3894	0.1499	0.2065
0.319	0.1588	0.1436	0.0927	0.0730	0.1169	0.0967	0.0845	0.0475	0.0819	0.0767	0.0881	0.1058	0.3327	0.1191	0.1618
0.106	0.1439	0.1310	0.0776	0.0622	0.1034	0.0856	0.0700	0 0407	0.0733	0.0666	0.0639	0.0747	0.3025	0.1006	0.1358
Percent < 0.85	19.60	18.14	17.67	9.73	16.46	12.71	11.11	6.11	10.56	9.99	13.30	15.14	38.94	14.99	20.65

Percent fines <0.85 mm in the 18 pairs of survival estimates and gravel quality indices ranged from 9.27% to 38.94% (gravel replicate #3 of the 1986 side channel sample contained an unusually high proportion of fines, which biased the mean for the sample upward). The mean percent fines for all successfully capped redds over all years was 13.07% -- 11.39% in 1984, 11.93% in 1985, and 15.9% in 1986 (note that the mean for 1986 would be 12.06% if the previously mentioned anomalous subsample were excluded). The observed overall mean egg-to-fry survival rate was 59.6% (1984 data was not included; see methods discussion). A survival rate of 59.6% for redds containing a mean of – 13% fines is consistent with values reported by other researchers. Cederholm et al. (1981) reported 30% survival at about 10% fines (< 0.85 mm) for natural coho redds in the Clear-water system, Washington. Koski (1966) reported a higher survival rate of approximately 70% with about 10% fines (<O-85 mm) for natural coho redds in the Alsea River, Oregon. Tappel and Bjomn (1983) found chinook egg-to-fry survival rates varied considerably in laboratory gravel samples, depending on the percent fines c9.5 mm. For example, survival at 10% fines (< 0.85 mm) ranged from 20-80% as the percent "fines" < 9.5 mm varied from 60% to 25%. Thus, from Tappel and Bjomn's work, it would appear that the precise pattern of particle size distribution has nearly as large an impact on survival as the absolute proportion of the classic " < 0.85 mm" fine particle.

For the same redds, the geometric mean ranged from 4.51 mm to 11.96 mm. The overall mean was 9.42 mm in 1984, 7.85 mm in 1985, and 7.36 mm in 1986. Over all years, mean egg-to-fry survival was 59.6% and the mean geometric mean was 8.09 mm. These figures are comparable to values reported by Tappel and Bjomn (1983). Shirazi and Seim (1979) reported survival values of approximately 90% for eggs incubated in gravel with a geometric mean particle diameter of 15 mm.

The mean fredle index in 1985 and 1986 was 3.13 and 2.49, respectively. The mean of 2.78 for both years compared with a mean survival of 59.6% is within reported values by other researchers. Tappel and Bjomn (1983) investigated chinook egg-to-fry survival in various gravel mixtures in laboratory conditions. They observed a 60% survival rate for gravel mixtures with a fredle index of about 3.8. Lotspeich and Everest (1981) investigated steelhead (0ncorhynchus mykiss) survival ("swim up" fry to emerging fry) in laboratory gravel mixtures and found a survival rate of about 58% when the fredle index was 3.8 .

Post-Emergence Movements

Met hods

The fry traps were designed to entrain newly emerged fry moving downstream from the bank to mid-stream. Traps were configured in a V-formation, constructed from a series of hardware cloth (0.25-inch mesh) panels butted to each other. Panels were 0.91 m x 2.44 m, with steel t-posts driven into the substrate, upon to which they were attached. Sandbags were placed along both the front and back to prevent scouring. A 10.2-cm PVC pipe extended downstream from the trap apex into a livebox.

Traps were checked daily and fry were anesthetized with MS-222 and enumerated. After the fork length was recorded and freeze brand applied, fry were allowed to recover and then released.

Results

Researchers installed a fry trap on the American River at Hell's Crossing (RM 5.9) on March 8, 1983 and February 10, 1984 to monitor the downstream movement of newly emergent fry. Results are presented in Table 12. The total number of fry captured in 1983 was only 39 fish, most likely a reflection of the poor spawning escapement for the 1982 brood year (11 redds). Researchers captured the first fry on March 28 and captured fry through May 20, when the trap became inoperable because of high flows. The period of highest catch was April 28 to May 2 with 16 fry. Based on an entrainment of approximately one-third of the entire stream width, the estimated total fry outmigration was 108 fish. Their mean fork length was 36 mm. Fry captured later in the season were slightly larger, probably reflecting growth. Fork lengths of newly emerged fry captured in the redd caps in the upper Yakima River ranged from 30 mm to 35 mm.

Researchers captured a total of 785 fry in 1984. The trap was monitored from February 7 through June 4; the first fry was captured March 20. Fry were captured through June 4, when trapping ceased due to high flows. Median date of downstream migration was April 17 (Fig. 17). and period of highest outmigration occurred from March 19 to March 23 with 130 fry (16.6% of the total fry counted). The total estimated passage was 11,894 fish, or 8.9% of the estimated number of emergent fry produced in the American River.

Trap efficiency was determined from a mean entrainment rate of 6.6%, based on six experimental efficiency releases. Estimated number of fry produced is based on a mean fecundity of 6,198 eggs per female, multiplied by 36 redds, multiplied by the mean egg-to-fry survival rate of 59.6%. Mean fork length over the entire trapping period was 36 mm.

Researchers monitored the downstream migration of newly emergent fry in the upper Yakima River near Ellensburg (RM 155) beginning March 25 in 1983. Unfortunately, high stream flows precluded trapping beyond April 2 1. As a result, only 25 fry were captured (Table 12). The date of first capture was March 28; mean length of these 25 fry was 34 mm.

In 1984, researchers relocated the trap upstream to RM 189 and began monitoring February 10. The date of first capture was March 8 and fry were collected up until June 13. A total of 237 fry were captured and the median date of outmigration was April 16 (Fig. 18). The decline in catch observed beginning in early May may not truly reflect fry emigration, as trap avoidance became much easier as fry increased in size. Median fork length over the entire capture period was 35 mm.

Table 12. Yakima River and American River daily spring chinook fry captures, 1983 and 1984.

Yakima R.			American R.		
	# Fish Captured			# Fish Captured	
Date	1983 \a	1984 \h	Date	1983	1984
2/10-14	--	0	2/07-11	--	0
2/15-19	--	0	2/12-16	--	1
2/20-24	--	0	2/17-21	--	0
2/25-3/01	--	0	2/22-26	--	0
3/02-06	--	0	2/27-3/03	--	0
3/07-11		19	3/04-08	0 \a	0
3/12-16		3	3/09-13	0	0
3/17-21	--	2	3/14-18	0	0
3/22-26 \b	0	14 \i	3/19-23	0	130
3/27-31 \c	9	12	3/24-28	1	90
4/01-OS	0	24	3/29-4/02	0	73
4/06-10	0	17	4/03-07	4	32
4/11-15 \d	8	18	4/08-12	5	12
4/16-20 \e	8	46	4/13-17	0	44
4/21-25		34	4/18-22	5	57
4/26-30	--	11 \j	4/23-27	0	50
5/01 -05	--	34	4/28-5/02	16	71
5/06-10		0	5 /03-07	7	80
5/11-15		0	5/08-12	0	71
5/16-20 \f	0	0	5/13-17	0	58
5/21-25 \g	--	0	S/18-22	1 \n	5
5/26-30 \g		0 \k	5/23-27	--	5
5/31-6/04 \g	--	1 \l	5/28-6/01	--	2 \o
6/05-09 \g	--	1	6/02-O5	--	4 \P
6/10-14 \g	--	1			
Totals	25	237		39	785

\a Trap located at Ellensburg (RM 152)
\b Start date was March 25.
\c Trap fish-tight 4 days.
\d Trap fish-tight 4 days.
\e Trap fish-tight 3 days.
\f Trap fish-tight 2 days.
\g High flow precluded trap operation beyond April 20.
\h Trap located above Cle Elum River confluence (RN 189).
\i Trap fish-tight 1 day.
\j Trap fish-tight 4 days.
\k Trap fish-tight 4 days.
\l Trap fish-tight 2 days.
\m Trap start date March 8.
\n Trap ceased operation May 20 due to high river flow.
\o Trap fish-tight 2 days.
\p Trap fish-tight 3 days.

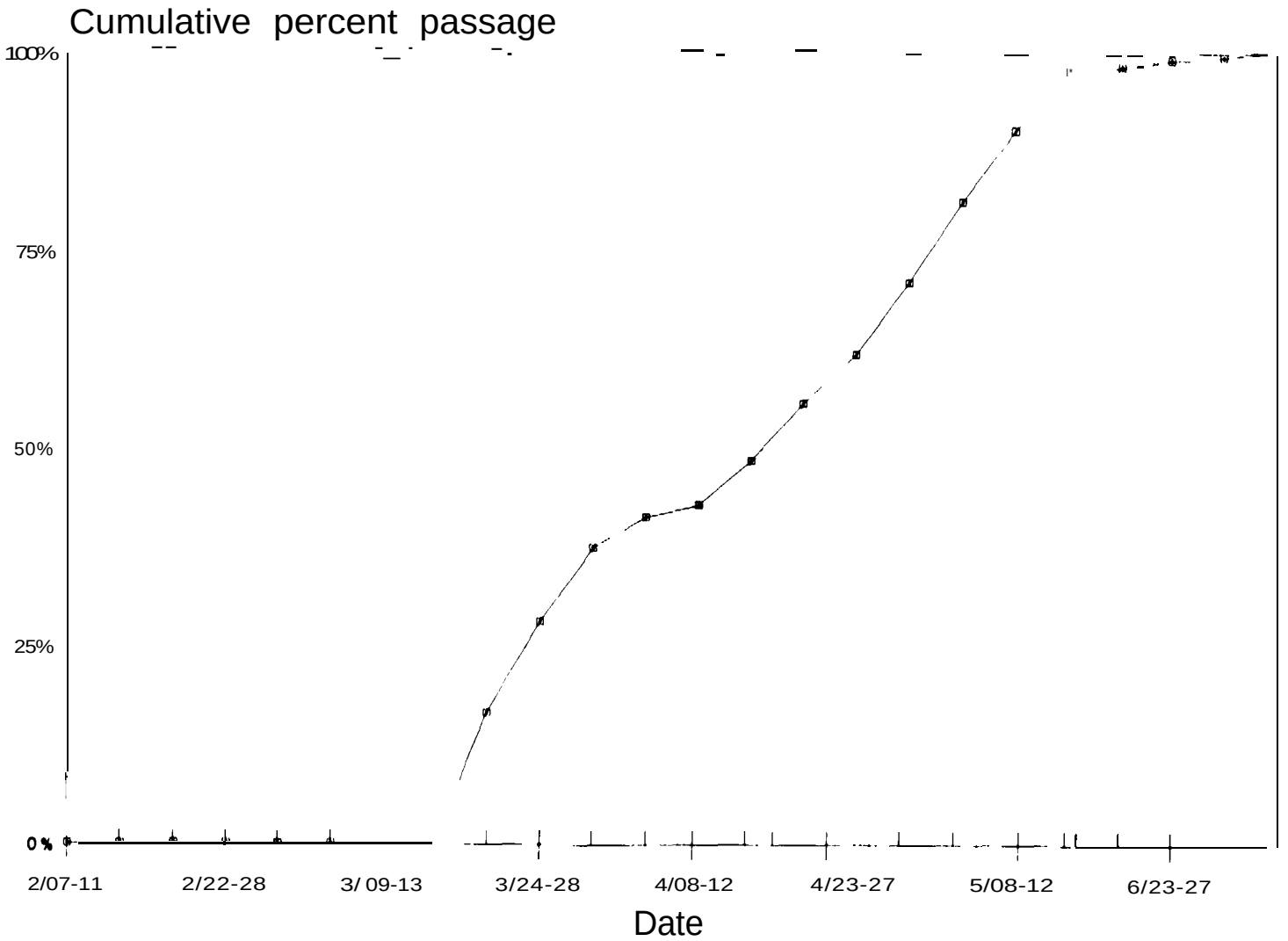


Figure 17. Cumulative percent passage of spring chinook fry in the American River, 1984.

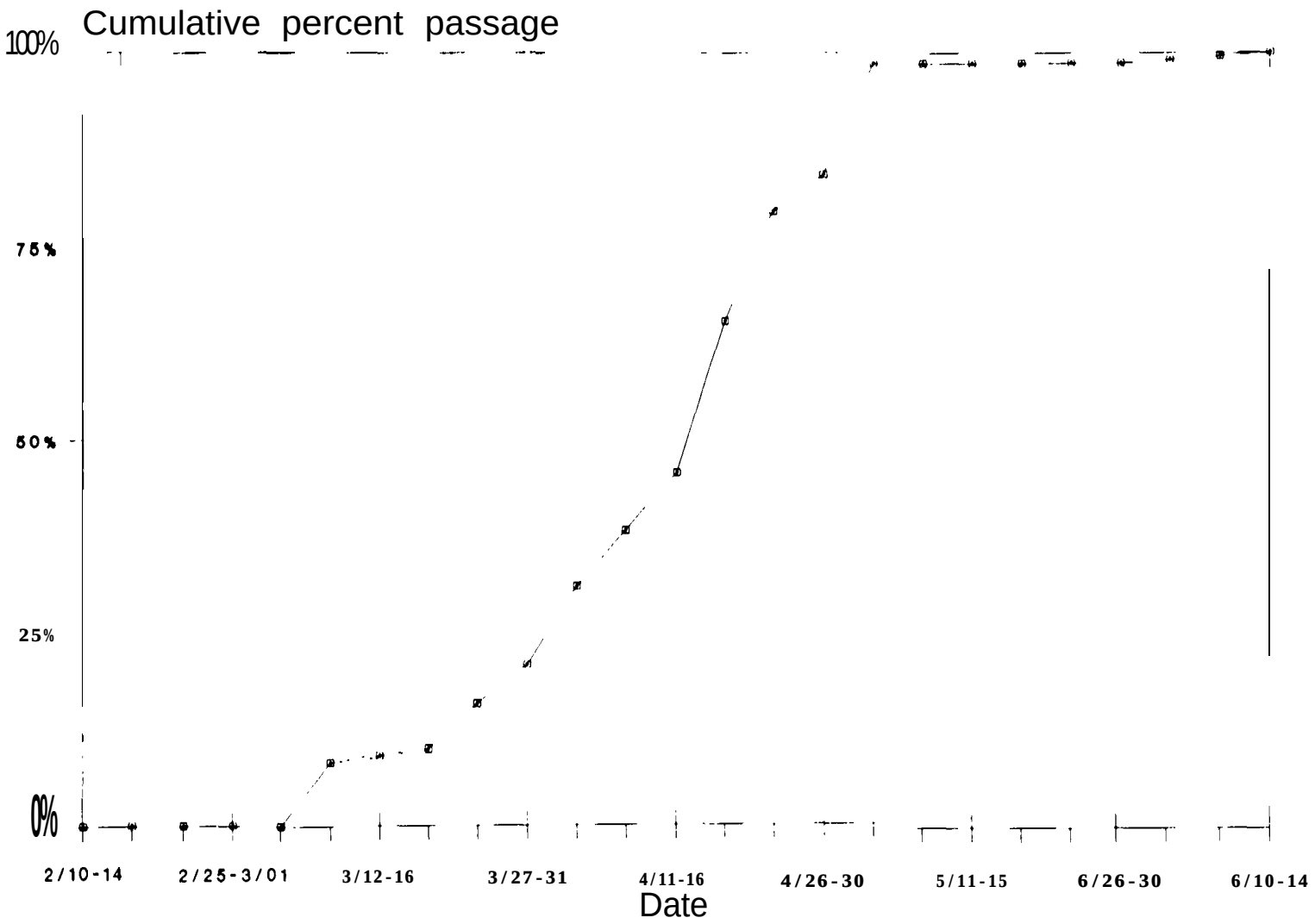


Figure 18. Cumulative percent passage of spring chinook fry in the Yakima River, 1984.

The observed period of fry capture in 1984 was consistent with observed redd capping results that same year. Date of first emergence ranged from March 9 through April 14 and median emergence date ranged from April 9 to May 13 (Table 8).

From the 1984 data, it is apparent that peak emergence in both the American River and upper Yakima River occurs at similar times. Median downstream migration occurred April 17 in the American River (Fig. 17) and April 15 in the upper Yakima River (Fig. 18). However, the mean date for spawning in the upper Yakima River (above Twin Bridges) was September 23 in 1983. This compares with August 17 as the mean date of spawning in the American River in 1983. The fact that the mean spawning date was 36 days earlier in the American River is consistent with the colder water temperatures that occur here, compared with those temperatures in the upper Yakima River. Thus to accumulate the necessary temperature units required to emerge from the gravel at the proper time, American River spring chinook must initiate spawning much earlier than those spawning in the upper Yakima River.

Lost Creek Study

Methods

Lost Creek ponds are located off the Naches River at RM 38.7. Water flows off the river via a headbox and into the upper pond (40 m x 30 m), then into the lower pond (100 m x 20 m) and then back into the river. Pond depths average 0.5 m to 1.5 m.

The inflow trap consisted of four hardware cloth (6.3 mm mesh) panels butted to each other in a V-configuration. Panels were 0.91 m x 2.44 m, with steel t-posts driven into the substrate, upon to which they were attached. Sandbags were placed along both the front and back to prevent scouring. A 10.2-cm PVC pipe extended downstream from the trap apex into a livebox. The outflow trap consisted of a livebox placed under the spillway at the lower pond's outlet.

Fry captured in the inflow trap were measured (fork length), freezed branded with a double dot brand, and held overnight prior to release. The same brand code was applied in March and April, and again in July and August. Different brand codes were used in May and June. Researchers enumerated fry recaptured in the outlet trap daily, and recorded their fork length and brand code.

Results

Interest for studying juvenile spring chinook rearing in Lost Creek ponds was generated from observations made in 1985 while using these ponds to hold adult spring chinook for brood stock. During the course of that summer (1985) it became apparent that many juvenile spring chinook were using the ponds for rearing purposes. In 1986,

researchers installed two traps in March, an inflow trap and an outflow trap, and monitored juvenile spring chinook immigration and emigration from these ponds through August.

A summary of weekly immigration through the inflow trap is presented in Table 13. Researchers captured a total of 1,518 spring chinook fry. The actual number of fry immigrating into the ponds may be greater because enumeration of immigrating fry was not possible during periods of high river discharge, which caused the trap not to be "fish-tight." The period of highest fry immigration occurred from April 29 through June 2, representing 63.6% of the total immigration enumerated. Two factors most likely accounted for this. Firstly, peak fry emergence is occurring at this time, so there is an abundance of newly emergent fry in the river. Secondly, mean daily discharge during this period was high (1,634 cfs), causing many of these newly emergent fry (which are poor swimmers) to be displaced downstream and become entrained into the diversion ditch.

A summary of brand releases at the inflow trap and brand recoveries at the outflow trap is presented in Table 14. The total number of fry branded and released was 1,352 fish; the total number recovered was 74 fish.

The recapture rate for all brand groups combined was 5.5%. Percent recapture rates were 3.5% for the June fish (right anterior), 4.4% for the March-April fish (right anterior), 6% for the May fish (right posterior) and 8.6% (9.9% if only considering July, since no fish were captured in August) for the July-August fish. The low recapture rates suggest that the majority of spring chinook fry resided through the summer in the ponds. One cannot preclude that low recapture rates were the result of a high mortality rate in the ponds. Efforts to evaluate the population size of each group through the summer proved unsuccessful. However, researchers believe that the mortality rate in the ponds was low. This is based on visual observations of abundant numbers of fry in the pond through the summer, in addition to the fact that no piscivorous fish (such as squawfish) other than a few resident rainbow trout were ever observed in the ponds. Also dense mats of elodea existed throughout the ponds providing excellent cover.

Mean monthly fork length of immigrating fry from March through June ranged from 36 mm up to 39 mm, indicating these fry were newly emerged. Mean monthly growth rates were determined for the May group. The mean fork length at capture in May was 37 mm; mean monthly fork length at recapture was 38 mm in May, 48 mm in June and 51 mm in July. Thus the monthly mean plus growth increment in May was 1 mm, in June 10 mm, and in July 3 mm.

Table 13. Weekly catch of spring chinook at Lost Creek ponds inlet trap, 1986 and weekly catch of spring smolts in the outlet trap, 1987.

Date	Chinook Fry	Chinook Smolt
2/28-3/03		32
3/04-IO	29	517
3/11-I7	48	156
3/18-24	15	6
3/25-31	34	0
4/01 -07	22	1
4/08-14	88	0
4/15-21	33	0
4/22-28	79	0
4/29-5 JO5	118	3
5/06-I2	253	3
5/13-I9	257	0
5 /20-26	195	0
5/27-6/2 \a	143	2
6/03-09 \b	14	0
6/10-16	40	0
6/17-23	5	0
6/24-30	6	0
7/01-07	47	--
7/08-14	25	--
7/15-21	7	--
7/22-28 \c	--	--
7/29-8/4 \d	19	--
8/05-1 1	7	--
8/12-18	8	--
8/19-25	10	--
8/26-9	16	--
Totals	1,518	720

\a Inlet trap not fish-tight 7 days due to high water.
\b Inlet trap not fish-tight 2 days due to high water.
\c No inflow to pond all 7 days.
\d No inflow to pond for I day.

Table 14. Summary of spring chinook fry brand releases and brand recoveries at Lost Creek ponds, 1986.

Month	Brand Code	No. Released	Brands Recaptured			
			LA..	RA..	LP..	RP..
March	LA.	180	3	--	--	--
April	LA.	233	7	--	--	--
May	RA.	734	3	16	--	--
June	LP.	173	2	20	2	--
July	RP.	91	0	8	4	9
August	RP.	13	0	0	0	0
Brand Recover Totals			15	44	6	9
Percent Brand Recovery			4.4	6	3.5	9.9

Although it was not possible to continue monitoring these traps through the following spring to evaluate the number of smolts produced from the initial number of immigrating fry, researchers enumerated smolts (from the previous brood year) emigrating from the ponds between February 28 and June 30. A total of 720 smolts (1984 brood year) were enumerated, indicating that a significant number of juvenile spring chinook overwinter in these ponds. Nearly all smolts (97.9%) had emigrated from the ponds by March 18. This is approximately three weeks prior to when peak spring chinook smolt outmigration is observed at Wapatox Dam (RM 17). The mean fork length was 94 mm, similar to the mean fork length at Wapatox for April (93 mm) and May (95 mm) in 1986. Larger smolts outmigrated first. Mean smolt fork length from February 28 through March 7 was 101 mm, and declined to 84 mm for the balance of the season.

In summary, it appears that spring chinook fry enter the ponds shortly after emergence and rear there continuously until the following spring, when they smolt. It appears that fry are not specifically seeking out these particular areas, but are simply being entrained into them during the spring before their swimming ability increases. Once in these off-channel areas, rearing conditions are found to be favorable and the fry remain.

Results of this study suggest that off-channel rearing ponds or back-sloughs could be used to provide added summer and overwinter rearing areas in the Naches, as well as other locations in the basin. Subsequent to this work, the Yakima Subbasin Salmon and Steelhead Production Plan (Yakima Indian Nation et al. 1990) has identified "off-channel winter refuges" as one of the alternative strategies (Strategy 5, Action 8) for increasing spring chinook production in the Yakima Basin. If fully implemented, a total of 18 canals located throughout the basin could be utilized as "canal refuges" for juvenile spring chinook (See Appendix 4, Supplement 1 of the Yakima River Subbasin Plan for a complete description of these canals). The Tributary Planning Model/System Planning Model procedure predicts an increase in escapement to the basin of 199 fish, and an increase in terminal harvest of 202 fish. The Yakima Subbasin Plan points out that though this is a modest increase in production, the degree of risk and cost involved is minimal. Indeed this is the case, as many of these canal systems could be "watered up" throughout the winter without significant changes to current operational procedures.

REARING DISTRIBUTION

Overview

The distribution of juveniles in the tributaries to the Yakima River were generally confined within the first river mile. A couple of exceptions were the Teanaway River where juveniles were found in the North Fork (RM 1.5), Middle Fork (RM 0.5 to RM 2.5) and West Fork (confluence to RM 4.2). Densities ranged from 0.14 to 0.51 fish per square meter. Researchers also found juveniles in the Wilson Creek system. Juveniles found farthest upstream were in Naneum Creek at RM 1.8. Other tributaries where juveniles were found beyond one river mile were Swauk, Dry and Manastash creeks. Researchers have documented spring chinook spawning in the Teanaway River and Manastash Creek, and suspect spawning occurs in the Wilson Creek system.

It is suspected that little juvenile rearing occurs in the Cle Elum River because of the high late spring and summer flows that exist once water is released from Cle Elum Reservoir for irrigation. Above Lake Easton, researchers have found an occasional juvenile in Cabin Creek.

Below Roza Dam, the number of tributaries declines and juveniles were not found in any of them during the summer months. However, during the winter, researchers found juveniles in Wenas, Wide Hollow and Ahtanum creeks, and Wanity Slough.

In the Naches system, juvenile rearing in the American River corresponds with the adult spawning range. Juveniles were found primarily from Union Creek (RM 11.5) to Hell's Crossing (RM 5.8). Juveniles were found at the lone sample site in the Bumping River at RM 0.9. However, it is likely juveniles rear as far upstream as Goose Prairie (RM 14.3), the upper end of adult spawning. In the Little Naches River, juveniles were distributed in correspondence with adult spawning. Juveniles extended upstream to RM 6.1, though in limited numbers. With the completion of Salmon Falls fish ladder at RM 5 in 1988, it is likely that juvenile rearing above the falls will steadily increase over time, as adult spawning continues to increase above this point.

Juveniles were collected as far upstream as RM 4.8 (the highest sample site) in Rattlesnake Creek. Again this is within current spawning distribution.

Spring distribution of juveniles in the Yakima mainstem were greatest at Selah (RM 118) with 40.4% of the total and at Cle Elum (RM 181) with 33.4% of the total. These coincide with two main spawning areas upstream.

Summer distribution of juveniles in the Yakima mainstem were found almost exclusively above Roza Dam (RM 135). The absence of fish below this point is a function of poor rearing conditions, primarily temperature. Greatest percent of the summer totals were found in the Yakima Canyon (67.4%) and at Ellensburg (RM 169) with 19.5% of the

total. The shift downstream to these two areas indicate juveniles are moving downstream from their natal areas throughout the summer.

With the cooling of the lower river in the fall, juveniles begin to migrate into this portion of the Yakima River. This coincides with the initiation of the fall outmigration in the Naches and upper Yakima rivers. The highest percent of total fish were at Toppenish (RM 95) with 60.1% and at Selah with 15.696, reflecting this migration pattern.

Winter distribution in the mainstem Yakima shows a continued increase of juveniles moving into the lower river. Within the lower river, Selah and Prosser had the highest percent of total fish captured with 13.1% each.

Tributary Distribution

Methods

Tributary sampling was conducted using a Smith-Root Type VII backpack electroshocker. A crew consisted of one person operating the backpack shocker and two persons netting. Each stream reach sampled was generally 100 meters long and sampling was conducted moving upstream. When feasible, block ends were placed at the downstream and upstream end of the reach. In these instances, the Leslie “two-pass removal” method (Ricker 1975) was used to estimate the population size. However, often the stream reach was too large to feasibly place block nets. In these cases, in place of a population estimate, the catch per unit effort, based on electroshocking time, was used as a comparison of spring chinook abundance amongst sample reaches. When this method was used, one single, upstream pass was conducted.

Fish captured were anesthetized with MS-222. Data collected included species identification (salmonids), number of fish by species and fork length. Researchers also recorded length of stream reach and mean width.

Results

Results of tributary electroshocking surveys are presented in Table 15. Distribution of juvenile spring chinook within tributaries to the Yakima River are generally confined to the first river mile.

Table 15. Summary of tributary electroshocking surveys in the Yakima and Naches basins for all years.

Locat ion	Date	Yakima River Hi les	Creek River Miles	CPUE \a Fish/min	Fish/m2	Average X(mm)	Length SD	N (mm)
YAKIMA BASIN								
Cabin Creek	07-31-84	205.0	2.4	0.00	--	--	--	--
Tucker Creek	05-15-84	199.9	0.1	--	--	41	6.0	24
Big Creek	02-17-85	195.8	1.5	0.03	--	98	--	1
Big Creek	07-03-85	195.8	0.1	0.25	--	61	10.3	18
Big Creek	02-18-85	195.8	0.1	0.00	--	--	--	--
Big Creek	07-17-84	195.8	0.1	0.05	0.07 (.06-.08)	72	10.6	2
Little Creek	07-I 7-84	194.6	1.5	0.00	--	--	--	--
Little Creek	07-02-84	194.6	0.7	0.00	--	--	--	--
Little Creek	07-12-85	194.6	0.3	0.00	--	--	--	--
Little Creek	08-18-83	194.6	0.3	--	--	83	10.5	18
Cle Elum	01-12-83	183.1	1.5	0.33	0.02	99	6.7	21
Cle Elum	12-09-82	183.1	1.5	0.96	--	95	7.4	29
Thorton Creek	08-28-86	177.5	--	--	0.35	78		
Teanauay	01-14-83	176.1	4.2	0.00	--	--	--	--
Suauu Creek	08-29-84	169.9	4.5	0.00	--	--	--	--
Swauk Creek	07-19-85	169.9	2.2	0.12	--	--	--	--
Swauk Creek	07-18-85	169.9	1.0	0.21	--	61	3.9	9
Suauk Creek	07-26-83	169.9	0.8	0.20	--	71	4.6	4
Suauu Creek	08-02-84	169.9	0.8	0.13	0.02 (.01-.03)		11.5	11
Suauk Creek	07-28-83	169.9	0.7	0.16	--	71	5.4	6
Suauk Creek	01-22-85	169.9	0.3	0.12	--	109	11.1	6
Swaun Creek	08-01-84	169.9	0.3	0.03	--	--	--	--
Taneum Creek	07-26-85	166.1	0.2	0.08	--	--	--	--
Taneum Creek	01-25-85	166.1	0.1	0.03	<.01	116	--	1
Tanuem Creek	08-05-86	166.1	0.1	--	--	--	--	--
Taneum Creek	08-03-84	166.1	0.1	0.07	--	83	7.8	2
Dry Creek	02-01-85	157.6	0.7	0.00	--	--	--	--
Manastash Cr .	02-28-85	154.5	1.4	0.00	--	--	--	--
Manastash Cr .	08-15-84	154.5	1.4	0.03	--	103	2.1	2
Manastash Cr.	07-22-83	154.5	1.4	0.00	--	--	--	0
Manastash Cr.	07-16-85	154.5	1.4	0.24	0.01 (.03-.04)	--	--	--
Manasyash Cr.	07-22-83	154.5	0.7	0.39	--	88	5.7	12
Manastash Cr.	07-26-84	154.5	0.7	0.11	0.04 (.02-.06)	83	5.7	11

\a Catch per unit effort.

Continued Table 15

Table 15 Continued. Summary of tributary ● electroshocking surveys in the Yakima Naches and Yakima basins for all years.

Location	Date	Yakima River Miles	Creek River Miles	CPUE \a Fish/min	Fish/m2	Average X(mm)	Length SD	N (mm)
Manastash Cr.	08-18-83	154.5	0.7	0.18	--	90	2.9	7
Manastash Cr.	07-09-85	154.5	0.7	0.06	--	--	--	--
Manastash Cr.	02-27-85	154.5	0.5	0.58	0.07 (.07-.08)	111	6.6	28
Manastash Cr.	07-17-85	154.5	0.5	0.60	0.03 (.03-.04)	84	6.7	19
Manastash Cr.	07-30-84	154.5	0.5	0.17	0.04 (.03-.05)	81	7.9	25
Umtanum Creek	07-22-83	139.8	4.5	0.00	--	--	--	0
Umtanum Creek	01-17-84	139.8	0.3	0.00	--	--	--	--
Umtanum Creek	07-22-83	139.8	0.2	0.03	--	--	--	1
Umtanum Creek	01-17-84	139.8	0.1	0.00	--	--	--	--
Umtanum Creek	06-12-84	139.8	0.1	0.05	--	--	--	--
Squaw Creek	01-17-84	135.0	0.1	0.00	--	--	--	--
Wenas Creek	01-21-85	122.4	0.1	0.04	--	--	--	--
Wenas Creek	05-06-84	122.4	0.1	0.00	--	--	--	--
Wd Hollow Cr.	08-21-84	107.4	0.9	0.00	--	--	--	--
Wd Hollow Cr.	01-02-85	107.4	0.9	0.58	--	118	7.0	--
Wd Hollou Cr.	01-18-84	107.4	0.9	0.49	--	122	12.1	19
Ahtanum Creek	01-18-84	106.9	1.0	0.00	--	--	--	--
Ahtanum Creek	11-15-84	106.9	1.0	0.09	--	--	--	--
Ahtanum Creek	07-30-85	106.9	1.o	0.00	--	--	--	--
Ahtanum Creek	08-21-84	106.9	1.0	0.00	--	--	--	--
Ahtanum Creek	07-I 8-83	106.9	0.3	0.00	--	--	--	0
Wanity	02-13-85	103.9	0.1	0.02	--	--	--	--
Wanity	01-11-84	103.9	0.1	0.00	--	--	--	--
Toppenish Cr.	01-18-85	80.4	2.4	0.00	--	--	--	--
Toppenish Cr.	01-24-85	80.4	0.1	0.00	--	--	--	--
Satus Creek	12-20-83	69.6	0.1	0.00	--	--	--	--
NACHES BASIN								
N. Fk. Cowiche	07-29-86	2.7	--	--	--	--	--	--
S. Fk. Cowiche	07-28-86	2.7	--	--	0.03	85	--	--
Rattlesnake Cr.	01-18-83	27.8	0.2	0.00	--	--	--	--
Rattlesnake Cr.	01-25-83	27.8	4.8	0.03	--	124	5.7	2
Little Naches	11-08-82	44.6	0.1	0.27	--	84	5.7	23
Little Naches	11-01-82	44.6	6.6	0.0	--	--	--	--

\a Catch per unit effort.

Continued Table 15

Table 15 Continued. Summary of tributary electroshocking surveys in the Yakima Naches and Yakima basins for all years.

Location	Date	Yakima River Miles	Creek River Miles	CPUE \a Fish/min	Fish/m2	Average X(mm)	Length SD	N (mm)
Little Naches	11-03-82	44.6	3.4	0.0	--	--	--	--
Little Naches	11-02-82	44.6	--	0.0	--	--	--	--
Bumping River	01-07-83		0.9	0.12	0.02	90	8.0	11
American River	01-28-83	3.5	11.5	0.04	0.01	75	--	1
American River	11-17-82	3.5	9.6	0.33	--	74	7.9	20
American River	11-17-82	3.5	9.6	0.44	--	73	10.7	14
American River	11-16-82	3.5	5.8	0.87	--	80	7.7	22
American River	11-16-82	3.5	5.8	0.39	--	79	6.1	13
American River	01-28-83	3.5	0.5	0.00	0.00	--	--	--
Rattlesnake Cr.	07-25-83	27.8	0.2	--	--	1	0.03	13
Nile Creek	07-25-83	29.4	0.9	--	--	0	0.00	--
American River	08-02-83	3.5	7.3	0.65	1.70	60	10.6	126
American River	08-05-85	3.5	7.3	0.53	0.02 (0.02)	56	11.7	50
American River	08-01-85	3.5	9.5	1.16	0.10 (0.10)	60	13.6	155
Little Naches	07-29-85	44.6	6.1	0.04	--	--	--	--
Little Naches	M-09-85	44.6	3.2	0.20	0.11 (.09-.I4)	64	9.8	41
Union Creek	08-07-85	11.5	0.3	0.11	--	56	5.7	2
Quartz Creek	08-07-85	3.4	0.1	0.12	--	61	3.8	3
Crow Creek	08-07-85	3.2	1.0	0.43	--	54	8.2	17
Rock Creek	08-21-85	33.5	0.2	0.69	--	--	--	--
Lost Creek	08-23-85	38.4	0.1	0.44	--	67	5.0	13
Bear Creek	07-31-86				--	--	--	--
North Fork	07-15-86				--	--	--	--
Crow Creek	07-17-86				--	--	--	--
Middle Fork	07-23-86				--	--	--	--
Pile-Up Creek	07-24-86				--	--	--	--
Jungle Creek	07-28-86				--	--	--	--
Quartz Creek	07-12-86				0.01 (0.01)	--	--	--
Masatchee Creek	07-08-86				--	--	--	--
Kettle Creek	07-21-86				--	--	--	--
Union Creek	07-14-86				--	--	--	--
Rock Creek	07-22-M				--	--	--	--
Milk Creek	08-04-86				0.06a	75	--	--
Lost Creek	07-16-86				--	--	--	--
Lt. Rattlesnake	07-23-86				O.Ola	--	--	--

\a Catch per unit effort.

Continued Table 15

In the Teanaway River, spring chinook reside in all three forks. In the Nork Fork, juveniles were found at RM 1.5 (0.37 fish/m^2), but not farther upstream. Juveniles were found in the West Fork from the confluence (0.14 fish/m^2) up to RM 4.2 (Dingbat Creek confluence); and in the Middle Fork from RM 0.5 (0.33 fish/m^2) up to RM 2.5 (0.51 fish/m*). Presence of juveniles in these areas corresponds with spring chinook spawning that has been documented in 1989 and 1990 in these areas. Sampling of the mainstem Teanaway River was conducted once in the winter (1983) and no juveniles were found. It is unlikely that juveniles reside in the mainstem except during the fall or winter, as it is nearly or totally dewatered by irrigation diversions during the summer.

Researchers suspect that little juvenile rearing occurs in the Cle Elum River because of the high late spring and summer flows that exist once water is released from the Cle Elum Reservoir for irrigation. These high flows generally coincide with fry emergence; it is thought that the majority of newly emerged fry are flushed from the Cle Elum River into the Yakima River.

In the upper Yakima River, above the Cle Elum River, juveniles were found in Cabin Creek up to RM 4 (Yakima Species Interaction Study, pers. commun., 1990); in Tucker Creek up to RM 0.1; in Big Creek up to RM 1.5; in Little Creek up to RM 0.3; and in Thor-ton Creek up to RM 1. No juveniles were seen in Cabin Creek when researchers sampled there in July 1984. However, in 1989, the new Easton fish ladder was completed, which would allow for better adult passage. This could explain why researchers of the Yakima Species Interaction Study found juveniles there the summer of 1990.

In the Yakima River between the Cle Elum River and Roza Dam, juveniles were found in Swauk Creek up to RM 2.2; in Taneum Creek up to RM 0.2; in Dry Creek up to RM 2 (YSIS, pers. commun., 1990); in Manastash Creek up to RM 0.7; and in Umtanum Creek up to RM 0.2. No juveniles were ever found in Squaw Creek. Spawning in the aforementioned tributaries has only been documented in Manastash Creek. It is most likely that fish found in the remaining creeks are the result of upstream migration.

The Washington Department of Wildlife's Yakima Species Interaction Study (pers. commun., 1990) recently documented, for the first time, juveniles in the Wilson Creek system. The findings were also substantiated by the Washington Department of Fisheries (unpublished, 1990). Juveniles found the farthest upstream were located in Naneum Creek at RM 1.8, a total of 3.8 river miles upstream to the Yakima River. Spring chinook were found in Wilson Creek up to RM 2.1 (fish were located above this point, however, they probably entered via Bull diversion ditch), about 0.1 RM upstream from the Naneum Creek confluence; in Cherry Creek upstream to RM 1.3; Badger Creek upstream to RM 0.6; and in Coleman Creek upstream to RM 0.5. No spring chinook spawning has been documented to date in the Wilson Creek system, however, limited spawning habitat exists within the system. Spawning surveys have been hampered by poor water clarity.

Below Roza Darn, the number of available tributaries to the Yakima River suitable for spring chinook rearing diminishes. This appears to be related to unfavorable rearing conditions during late spring through summer (high water temperatures and limited flow). For example, juveniles were not found in Wenas, Wide Hollow and Ahtanum creeks or in Wanity Slough during the summer. However, spring chinook pre-smolts were documented in all of these during late fall and winter, with the highest densities occurring in Wide Hollow Creek up to RM 0.9. No chinook were found in the lower reaches of Toppenish or Satus creeks in the late fall or winter. Though spring chinook adults have been documented in Snipes Creek (due to false attraction from the Roza canal overflow), no redds or juveniles have been found.

A summary of the distribution survey in the Naches Basin is presented in Table 15, above. In the mainstem American River, juvenile spring chinook were distributed similar to that of redd distribution. Juveniles ranged from Union Creek (RM 11.5) downstream to Hell's Crossing (RM 5.8). Though juveniles were not found below RM 5.8, some probably inhabit this reach. The low percentage of redds combined with the poor rearing conditions of this reach (high gradient) make this reach of limited rearing value for spring chinook. No juveniles were found in Mestachee, Union or Kettle creeks, the principal tributaries to the American River.

Spring chinook were found at RM 0.9 on the Bumping River, the lone site sampled (winter 1983). It is likely that low densities of juveniles rear farther upstream to Goose Prairie (RM 14.3), coinciding with redd distribution. Excessive late summer flows (after flip-flop) and reduced winter flows (during controlled storage) probably limit the rearing capacity of this river.

The distribution of juvenile spring chinook in the mainstem Little Naches River generally coincides with the distribution of redds. Juveniles were found from near the confluence (RM 0.1) upstream to RM 6.1, though in limited numbers. This may in part be a consequence of the low numbers of redds (16 in 1981 and 41 in 1984) in the, system during 1982 and 1985, when sampling was conducted. Juveniles found during summer 1985 at RM 6.1 would seem to indicate that adults successfully negotiated Salmon Falls (RM 5.0) and spawned. Completion of the Salmon Falls fish ladder in 1988 allowed better passage of adults above this point, and thus has increased the rearing distribution of spring chinook. In 1990, researchers found 10 redds above the falls up to the Middle Fork (RM 13.2).

Based on beach seining results, which demonstrated a gradual increase in the number of juveniles in the upper Naches River (see "Rearing Distribution: Mainstem Distribution"), it appears that juveniles steadily outmigrate from the Little Naches River from the time of emergence. A similar argument could be made for the American and Bumping rivers as well. Thus one cannot definitively say the observed increase in juveniles in the upper Naches River is due exclusively to fish outmigrating from the Little Naches River. Certainly results from fry trapping on the American River (see "Emergence/Early Rearing: Lost Creek

Study") indicate newly emergent fry are outmigrating from their natal areas shortly after emergence.

Juvenile spring chinook were only found in two tributaries to the Little Naches River, Quartz (RM 3.4) and Crow (up to RM 3.2) creeks. In 1989 and 1990, spawning has been documented in Crow Creek.

The only tributaries to the upper Naches River where juvenile spring chinook were found are Milk Creek (at RM O.l), Rock Creek (at RM 0.2) and Lost Creek (at RM 0.1). To date no spawning has been documented in these tributaries, indicating upstream movement of fish from the mainstem.

Limited information is available concerning distribution of juveniles in the mainstem Rattlesnake Creek. However, juveniles were collected as far upstream as RM 4.8 (the upper most site), which is within the spawning distribution of spring chinook. Juveniles were also found up to RM 0.5 (upper most site) in Little Rattlesnake Creek.

In the lower Naches River, no juveniles were found in the first RM 0.5 of Nile Creek, but were found in the lower reach of Cowichie Creek (up to RM 0.7). Spring chinook juveniles found in Cowichie Creek presumably are entrained into a ditch off the Naches River that enters Cowichie Creek near RM 0.2.

Mainstem Distribution

Methods

Reach seining was confined to the mainstem Yakima and Naches rivers. Researchers sampled three sites in the Naches River (lower, mid-point RM 8.2; middle, mid-point RM 24.3; and upper, mid-point RM 42.5) and 11 sites in the Yakima River (RM8, RM25, RM44, RM82, RM95, RM118, RM135, RM152, RM169, RMl81 and RM195) on a monthly basis. For sample sites in the Naches River, the mid-point was defined as the mean river mile averaged from the upper and lowermost seining location within a sample site (lower, middle and upper). This was necessary as it was difficult to find suitable seining locations within a confined reach of river. In contrast, in the Yakima River all seining locations for a given site were confined within four kilometers of each other. Exceptions to this were during months of excessive ice flow in the winter, and months of excessive river discharge in the spring and summer.

Five seine hauls were made during daylight hours at each sampling location and were normally conducted within 1 km to 4 km of each other (except in the Naches River). Seine hauls were made using a 30.5 m x 2.4 m seine net with 6.3 mm mesh. Seine hauls were initiated from a gravel bar, where the net was set out to the shear zone, usually 3 m to 3.25 m deep. The net continued to be set by moving downstream immediately beyond the shear zone. A person stationed at the upper end of the shear zone "fed" the net out to the lead

person and kept the net from collapsing. Once the net was fully deployed, the lead person brought the lead end of the seine net back to the gravel bar. Finally, the net was pursed onto the gravel bar. At sites where the water depth precluded setting the net by foot, researchers employed a jet sled, following the same procedure.

Researchers electroshocked on the mainstem using a Smith-Root, 14-foot jet sled, powered with a 5 GPP Smith-Root power unit. The boat itself was the cathode, while the anodes consisted of two booms extending from the bow of the boat. Sampling reaches were about 1 km in length. Electroshocking was conducted moving downstream slightly slower than the current, in a zig-zag pattern between the bank and the thalweg. Two persons with nets stationed in the bow captured stunned fish. Fish captured were anesthetized with MS-222, and fork lengths were recorded.

Results

To elucidate temporal/spatial trends in juvenile spring chinook distribution in the Yakima and Naches rivers, results were analyzed by season, incorporating data for all three years (1984-1986). Spring represents April, May and June; summer represents July, August and September; fall represents October, November and December; and winter represents January, February and March. These results are presented in Table 16 and Figures 19 and 20. Results are expressed in terms of the mean percent fish found at a particular station in relation to all stations for the season. Though the results present a good overview of distribution, the data appears to be somewhat misleading at some stations, based on other field data. These will be pointed out during the discussion.

Spring juvenile distribution noticeably increased beginning at Selah (RM 118). The two highest levels occurred at Selah, with 40.4% of the season total, and at Cle Elum (RM 181), with 33.4% of the season total. At both sites young-of-the-year dominated the catch. Roth of these areas have significant spawning occurring immediately upstream. The absence of significant percentages of fish occurring below Selah is misleading, as spring chinook smolts (and fall chinook) are migrating through the lower river. Date of 80% passage occurs about May 17 (1983-1990 data) indicating that spring chinook smolts are still outmigrating through the lower river throughout this spring period. Similarly, the absence of juveniles (primarily fry) at Easton (RM 195) is misleading in that major spawning occurs throughout this reach. Throughout the course of this study, the results obtained at the Easton station do not appear to reflect distribution accurately. A discussion of snorkeling surveys in the Faston reach is presented later on in the winter season distribution discussion.

Table 16. Composite beach seining results in the Yakima and Naches 1984-1986

Location	RM	Spring Mean fish/set	Spring Total fish/set	Spring Percent of total	Summer Mean fish/set	Summer Total fish/set	Summer Percent of total	Fall Mean fish/set	Fall Total fish/set	Fall Percent of total	Winter Mean fish/set	Winter Total fish/set	Winter Percent of total
Yakima Basin													
West Richland	8	02	1	0.1%	0.07	0.6	0.2%	0	0	0.0%	1.0	2.0	5.1%
Benton	25	0.3	1.6	0.2%	0	0	0.0%	0	0	0.0%	0.1	0.2	0.5%
Prosser	44	0.6	3.6	0.5%	0	0	0.0%	0	0	0.0%	1.7	5.1	13.1%
Granger	82	1.1	7.7	1.0%	0.2	1.8	0.5%	0.6	2.4	7.2%	2.5	10.0	25.6%
Toppenish	95	2	16	2.1%	002	0.2	0.1%	4	20	60.1%	2.1	8.4	23.5%
Selah	118	43	301	40.4%	1.2	7.2	2.1%	1.3	5.2	15.6%	1.7	5.1	13.1%
Yakima Canyon	135	12.1	86.7	11.4%	32.3	225.1	67.5%	1.3	3.9	11.T%	3.9	7.8	20.0%
Ellensburg	152	6.7	40.2	5.4%	10.9	65.4	19.5%	02	0.6	I.8%	0	0.0	0.0%
E'burg.Canyon	169	8.1	32.4	4.3%	2.1	6.3	I.9%	0	0	0.0%	0	0.0	0.0%
CLe Elum	181	35.6	249.2	33.4%	3.2	19.2	5.7%	0.5	3	9.0%	0.1	0.4	1.0%
Easton	195	1.3	7.8	1.0%	1.4	8.4	2.5%	0.04	0.2	0.6%	0	0.0	0.0%
Naches Basin													
Lower Naches	25	27.3	163.0	65.6%	9.1	75.2	37.3%	0	0	0.0%	0.1	0.2	16.7%
Middle Naches	35	13.4	80.4	32.2%	6.5	52	25.8%	0.8	2.4	70.6%	1.2	1.0	83.3%
Upper Naches	40	1.1	5.5	2.2%	10.6	74.2	36.8%	0.3	1	29.4%	0	0.0	0.0%

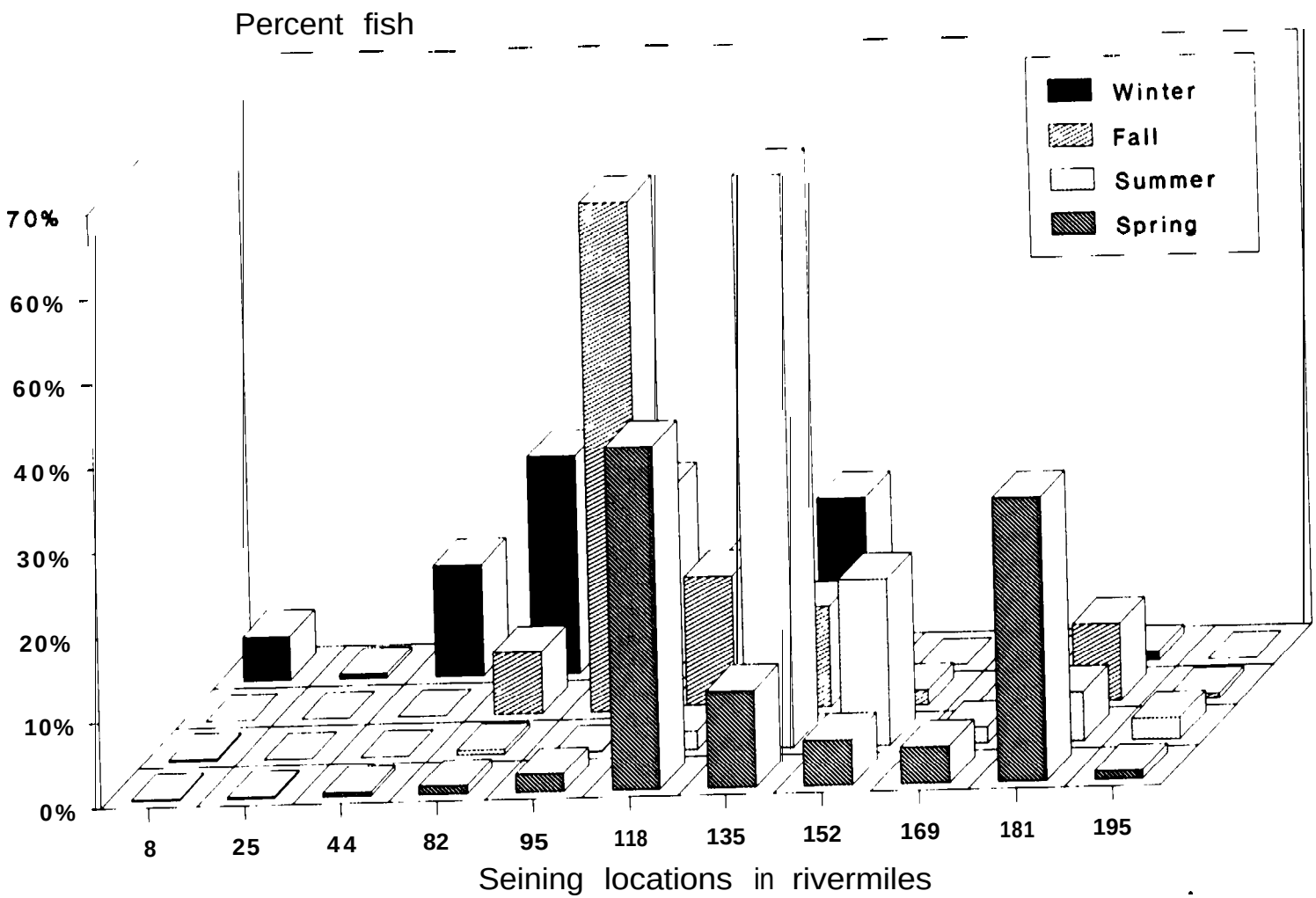


Figure 19. Mean percent seasonal beach seine captures of **juvenile spring chinook** in the Yakima River.

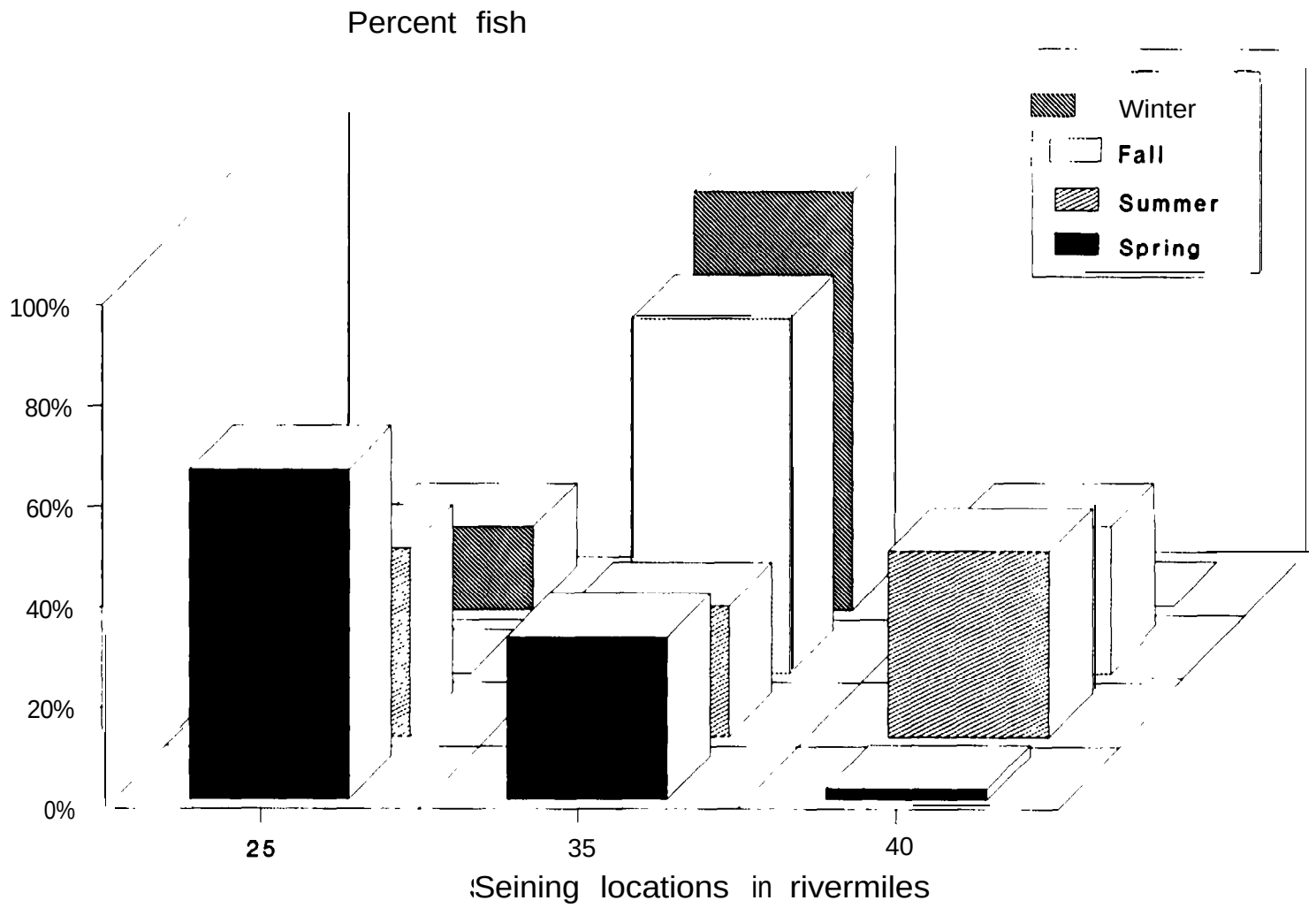


Figure 20. Mean percent seasonal beach seine captures of juvenile spring chinook in in the Naches River.

Summer distribution is almost exclusively restricted to the Yakima Canyon (RM 135) and points upstream. Highest juvenile levels occurred at the Yakima Canyon (67.4% of the season total) and Ellensburg (RM 169; 19.5% of the season total). Of significance is the decline of juvenile fish (mostly fry) levels at Cle Elum from spring to summer. This suggests that young-of-the-year spring chinook migrate downstream from their natal areas in the spring and into the Yakima Canyon throughout the summer. This finding is supported by the fact that nearly 4,000 newly emerged fry were enumerated at Roza juvenile trap in March and April 1990 (Hubble et al., 1990). In addition, downstream fry movements from their natal areas were observed in both the American and upper Yakima rivers in fry trapping studies conducted in 1984 and 1985 (see "Emergence/Early Rearing: Lost Creek Study"). The absence of juveniles downstream from Toppenish (RM 95) is probably a function of suboptimal stream temperatures during the summer months. Based on 1990 temperature data at Prosser, the monthly mean water temperature was 702°F (maximum 75°F) in July, 68.6"F (maximum 74°F) in August, and 63.9"F (maximum 66.5°F) in September. The marked decline in the juvenile level at Selah from 40.4% to 2.1% of the season total indicates that young-of-the-year fry either migrate farther downstream through the summer or incur a high mortality rate. Their exact fate is not known, as relatively good rearing conditions persist between Selah and Wapato Dam (RM lO6.6), although sampling of this reach was not possible due to excessive summer flows and poor seining sites.

In the fall, juveniles initiate a fall outmigration from both the upper Yakima and Naches rivers (see "Outmigration: Fall and Winter Movements"). Summer water temperatures, which inhibit spring chinook summer rearing in the lower river, decline to a monthly mean of 44.8°F by December (based on 1989 data) at Prosser. Highest juvenile levels occurred at Toppenish, with 60.1% of the season total, and at Selah, with 15.6% of the season total, indicating a shift of juveniles into the mid to lower reaches.

Fast et al. (1987) estimated that 38.7% of Naches fall outmigrants marked and released at Wapatox outmigrated past Prosser from November through February. Correspondingly, 61.3% overwintered between Wapatox and Prosser (most likely in the Yakima River) and smolted the following spring. Similarly, a release of Wapatox pre-smolts in December 1989 showed that only 15.3% passed Prosser in the winter, while the remainder outmigrated as smolts in the spring. Again the seining data probably underestimates the lower river juvenile fish level.

Winter distribution shows a continued increase in juvenile levels in the lower Yakima River. It appears that juvenile levels below Prosser (RM 44) were the highest since the spring period, during the smolt outmigration period. Highest juvenile levels were seen from Selah (13.1% of the season total) to Prosser (13.1% of the season total).

Hubble et al. (1990) enumerated a total of 582 pre-smolt outmigrants past Roza in December 1989. This increased to a raw count of about 4,000 fish for both January and February 1990. Thus it appears that the pre-smolt outmigration observed in the Yakima and Naches rivers extends well into the winter period.

The apparent absence of juveniles in the upper river may be misleading, as fish were probably residing in the substrate and woody areas and thus not residing in the habitat where seining was conducted. The presence of fish in the upper Yakima in the winter is supported by the aforementioned fact that about 4,000 pre-smolts were counted out of Roza juvenile trap, which was operated only 72 hours per week (counts are unexpanded) in January and February 1990 (Hubble et al., 1990). In addition, results of a pilot study in 1990 to investigate fall/winter habitat preferences of juvenile spring chinook also suggest significant numbers of fish rear in the Easton reach during the summer and fall.

Fast et al. (1987) observed during electroshocking surveys in the Yakima River in fall/winter 1986 that the mean fork lengths of spring chinook collected above Roza Dam ranged from 92 mm to 97 mm. These fish were also associated more with instream cover than were fish captured below Roza Dam (Table 17). Juvenile spring chinook collected downstream to Roza Dam were associated more with areas of little or no instream cover immediately over slow velocity riffles and runs. Their mean fork lengths were greater, ranging from 95 mm to 118 mm (Table 17). These observations seem to indicate that two behavioral patterns are observed in the winter concerning migration -- those fish that choose to over-winter in the upper river and those fish that choose to migrate during at least a portion of the winter period and reside in the mid or lower river (including below Prosser). It appears that size may play some factor in the behavior.

Spring distribution in the Naches system was greatest in the lower Naches River, with 65.6% of the Season total, and least in the upper Naches River, with 2.2 % of the season total. This is to be expected as smolt outmigration is occurring in the lower Naches River at this time. The low juvenile fish level observed in the upper Naches is substantiated by smolt outmigration timing from Lost Creek ponds. Smolts began outmigrating from the pond in February, indicating that smolts residing in these upper reaches probably initiate smoltification earlier than fish rearing in the lower reaches. Peak smolt outmigration at Wapatox occurs in mid-April.

Summer distribution of juvenile spring chinook was generally evenly distributed in all three reaches of the Naches. The juvenile fish level was 37.3% of the season total in the lower Naches, 25.8 % of the season total in the middle Naches, and 36.8% of the season total in the upper Naches. Of significance is the noticeable increase in the upper Naches from the spring (2.2% of the season total). As in the Yakima River, this suggests that fry are migrating downstream from their natal areas in the American and Bumping rivers and rearing during the summer in the upper and middle reaches. This is also supported by fry trapping studies in the American River in 1984 and 1985. The absence of many juveniles outmigrating past Wapatox in the summer indicates that these two uppermost reaches are the main summer rearing areas in the Naches River.

Table 17. Winter 1986-87 distribution of spring chinook in the Yakima River.

Laat1cn	RM	Date	Mean fork lenght (mm)	Habitat type	Estimated velocity (ft/sec)	Depth (ft)
Cle Elum	180	01/06/87	92	large rock, rip-rap and root wads	<1.o	3-6
Throp	165	12/15/86	96	stream banks and large rocks	<1.0	2-4
Ellensburg	156	10/16/86	93	stream banks root wads ad substrate	<1.0	2-4
Roza pool	128	12/17/86	97	large rock, substrate 1-2" dia. and riffles	1-3	1-3
Union Gap	108	01/07/87	98	stream run and in stream column	2-3	5-8
Parker Dam	104	12/02/86	99	stream banks sustrate and stream colum	<1.0	2-4
Toppenish	94	10/23/86	102	stream runs and in the stream column	4-8	2-4
Zillah	91	11/13/86	111	stream runs and in the Stream column	4-8	2-4
Marion Drain	83	12/17/86	115	stream banks	1-2	2-3
Granger	85	12/09/86	103	stream run with fish associated with the bottom	<1.0	1-2
Granger	81	12/09/86	108	stream run and in the stream column	2-3	3-5
Satus area	81	12/12/86	109	stream run with fish associated with the bottom	<1.0	3-5
satus area	76	12/12/86	118	stream run with fish associated uith the bottom	<1.0	1-2
Horn Rapids	19	12/19/86	112	stream banks and substrate 1-3" dia.	<1.0	1-3
Horn rapids	19	01/08/87	114	stream banks and substrate	4.0	1-3

The middle Naches reach contained 70.6% of the spring chinook juveniles sampled in the fall while 29.4% of the season total occurred in the upper Naches. No juveniles were captured in the lower Naches. This is not accurate, however, as large numbers of juveniles are enumerated past Wapatox (RM 17) every fall (see discussion under "Outmigration: Spring Movements"). The percentage reported for the middle Naches River is probably actually lower since the percentage of the total fish would have decreased if pre-smolts would have been captured in the lower Naches.

In the winter, the highest juvenile level occurred in the middle Naches (83.3% of the season total), as it did in the fall. No juveniles were captured in the upper Naches. However, this may be a function of sampling conditions, with fish being buried in the wood debris and cobble. As stated earlier, results from the Lost Creek pond study indicate smolts begin to outmigrate in February. Thus it is expected that the majority of the juveniles are in the middle and lower two reaches.

Snorkeling Surveys

Methods

Researchers conducted snorkeling surveys from early September through the end of October to see if "flip-flop" had an effect on juvenile rearing. The study area concentrated on the upper Yakima River between Easton Dam and Irene Reinhardt Park at Ellensburg. The Cle Elum River was included initially, but was dropped after the first survey.

The competing needs of spawning fish and irrigation in the Yakima Basin have resulted in the "flip-flop" system of river flow control. Runoff must be stored for irrigation in headwater impoundments during the late fall, winter and early spring. Spawning salmon, on the other hand, must have sufficient water in the fall for spawning and sufficient water in the winter and early spring for incubation. Flip-flop represents a compromise benefitting both interests. Releases from upper Yakima reservoirs are cut back in mid-September while releases from Naches system reservoirs are increased. This flip-flop in reservoir releases allows water to be collected for irrigation in upper Yakima reservoirs, and forces upper Yakima salmon to spawn more to the center of the channel, where water depths are adequate. After the spawning season, upper Yakima releases are cut back again, leaving sufficient water for incubating eggs and increasing the proportion of runoff stored for irrigation.

The hypothesis of the study was that juvenile stranding would occur as the flip-flop and subsequent incubation flows were set. The plan was to snorkel each reach before and after setting spawning and incubation flows. Snorkeling surveys were conducted by one or two people snorkeling upstream with the exception of two long reaches, which were surveyed downstream. Most of the reaches in the Ellensburg area were side channels that were too fast to survey previous to flip-flop and thus were dropped. Some of the side channels that

were slow enough to snorkel below the Cle Elum **confluence** were dry after spawning flows were set. Thus, researchers were not able to carry out the study as originally planned.

Results

The most significant observation was the relocation of spring chinook parr after setting spawning flows and previous to setting incubation flows. Researchers were, however, unable to determine whether these changes in distribution were the results of flow regulation or were a natural movement. The changes after spawning flows were set included increases of pat-r in several of the sampling reaches near Easton (Table 18). It is believed that these increases of numbers at sampling sites were the result of juveniles displaced from other areas by decreasing flows. Observations at two of the sites were significant, increasing from 18 parr to 45 parr at Easton and from 88 parr to 275 parr at Sun Island.

Parr numbers decreased in about half of the sites monitored before incubation flows were set. With a few exceptions, most parr appeared to have moved out of the Easton reach before incubation flows were imposed. (It should be noted that incubation flows are typically less than spawning flows.)

Approximately 300 spring chinook parr were observed in the Run Acres reach (RM 197) previous to flip-flop. No spring chinook parr were observed at this site the next time it was surveyed, which was before incubation flows were imposed. Similar observations were made in the Teanaway reach, with counts dropping from 177 parr in the "pre-flip-flop period" to seven parr in the period preceding incubation flow control. One side channel a short distance above the Teanaway reach held 23 parr previous to flip-flop, but was dry during subsequent trips. In some cases, the egress may have been natural because a number of reaches were not completely dewatered as (lower) incubation flows were imposed, but retained as much as several feet of water (such as in the Run Acres reach). In the Teanaway reach, however, the juvenile rearing area was nearly dry after flip-flop; thus .researchers concluded that fish in this area were forced to leave by declining flows. On the initial **survey** in this particular site, parr were observed behind a log jam protected from high flows. On subsequent surveys, the former rearing area was nearly dry and the parr were observed on the opposite side of the log jam in greatly reduced numbers. This displacement placed the parr in much deeper water than was initially observed and in the immediate vicinity of a sizeable number of squawfish.

Table 18. Number of juvenile spring chinook observed by snorkeling in a number of reaches in the Easton area of the upper Yakima during imposition of "flip-flop" flow control in the fall of 1990.

Location	RN	Channel Type	No. observed, by period			
			Pre flip	Post flip	Pre Inc.	Post Inc.
Easton Exit	201	side	11	15	5	
Easton Exit	201	main	18	45	55	0
Sun Island	199	side	16			
Sun Island	199	main	88	275	45	40
Sun Island	199	main		85	80	0
Run Acres	197	main	300		0	
Run Acres	197	side	43			
Run Acres	197	main	140		35	
Cle Elum R.		side	4			
Cle Elum R.		side	4			
Cle Elum Br	183	side	30	dry	dry	dry
Teanaway Jct	179	side	23	dry	dry	dry
Teanaway Jct	179	side	177	55	7	
Town Ditch	161	side		51	40	
Town Ditch	161	side	41	35	46	
Sandstone		side		23	1	
I.R. Park	155	side		130	100	

In two side channels -- “memorial side channel” near Easton (so named because of its early inclusion in the Instream Flow Incremental Method Data Base) and the Town Ditch side channel above the Town Ditch at Ellensburg -- spring chinook parr were observed in pools and channels cut off from the mainstem after flip-flop. The parr observed in the memorial channel were observed in four isolated pools. These juveniles were significantly smaller than those observed in the adjacent mainstem. These parr were also more vulnerable to bird predation due to lack of depth and cover. The side channel at Town Ditch also lacked depth, but had substantial cover; most fish were counted beneath fallen tree limbs and other cover. The counts at Town Ditch remained the same after spawning flows were imposed and before flows were reduced to incubation levels if both sites in the area are considered together. Researchers observed other side channels near Cle Elum with stranded salmonids after flip-flop. However, these areas were not snorkeled due to extremely shallow water around rip-rap.

The presence and absence of parr during snorkeling surveys shed new light on the distribution of juvenile spring chinook. The presence of juveniles in the Easton reach in the fall was not reflected by the other sampling methods used to study distribution, although the snorkeling survey indicated that the Easton reach supported higher densities than any other area. One site in the Easton reach supported approximately 275 parr that were concentrated in one small log pile less than 12 cubic yards in volume. In most cases, parr were observed in “clusters” of 25 to 100 fish, usually in association with woody debris and log jams.

In contrast, the Cle Elum River proved to be nearly devoid of parr. The side channel in the Cle Elum River that was surveyed looked very promising, but held only four parr in approximately 400 yards of channel. Washington Department of Wildlife personnel snorkeled the mainstem earlier in the season and made similar observations (Nick Hindman, WDW, pers. commun., 1990). The virtual absence of parr in the Cle Elum River in the fall is probably attributable to high flows in the summer, when large volumes of water must be released from Cle Elum Reservoir to meet downstream irrigation demands (the mean discharge in June and July of 1990 was 3,260 cfs and 3,902 cfs, respectively).

Observations of parr below the Yakima-Cle Elum confluence were limited to side channels with slower velocities than were seen in the mainstem. In most cases, the velocities in the Ellensburg area, at least before flip-flop, were too great for juvenile rearing. The surveys in this area were not repeated until late October, by which time only minimal numbers were observed.

OUTMIGRATION

Overview

Summer, Fall and Winter Movements

At Wapatox, the movement of juvenile chinook in the summer (July and August) represents only a small fraction of the total outmigration seen each year. Passage estimates range from a low of 878 fish in 1986 to 1,794 fish in 1987. Mean fork length for all years combined was 80 mm in July and 83 mm in August.

By far the greatest period of outmigration at Wapatox occurs in the fall. Wapatox monitoring ceases when the river begins to ice up and threatens the screens. Accordingly, fall/winter monitoring at Wapatox ceases on different dates every year, and comparisons of the relative magnitude of fall movements between years becomes difficult. For brood years with comparable monitoring periods, fall migrants represented from 47% (1988 brood year) to 89.7% (1984 brood year) of the total brood year production. On an absolute basis, the estimated number of fall migrants has ranged from 8,988 fish in 1989 to 60,186 fish in 1986. Most Naches system fall migrants do not migrate to the lower Yakima during the fall and winter. Of 20,000 fall migrants branded and released at Wapatox during the fall of 1986, only 38.7% of the fish that survived to Prosser actually passed Prosser in the winter of 1986-87; the bulk of the survivors (61.3%) passed Prosser in the spring (March 1 through June 30). Similarly, 17.2% of the Naches fall migrants branded and released at Wapatox during the fall of 1988 passed Prosser during the winter of 1988-89, while 82.8% passed Prosser the following spring. Chapman and Bjomn (1969) concluded from studies in the Salmon River drainage that decreasing stream temperatures in the fall trigger a search for suitable winter habitat which, if unsuccessful locally, results in a downstream migration. Something similar may be occurring in the Naches system, and perhaps also in the upper Yakima. There is, however, also some evidence that winter migrations may, to some degree, be driven by a genetic predisposition for winter movements (see below).

Mean fork length of winter migrants at Wapatox over all years was 85 mm in September, 96 mm in October, and 95 mm in both November and December.

The smolt trap at Roza has never been operated in the summer, and has been operated for only one winter, from December 12, 1989 through April 17, 1990. Although the Roza facility has not yet been calibrated (the relationship between diversion and entrainment has not yet been determined) and total passage cannot yet be estimated, it appears from inspection of raw catches alone that the seasonal distribution of movements at Roza is similar to Wapatox; many more fish pass in the fall and winter than in the spring. The raw catches of spring chinook juveniles (primarily pre-smolts) in December, January, February, March and April were 582, 1,486, 2,558, 469 and 73 fish, respectively. The mean fork lengths observed over these months were 106 mm, 107 mm, 105 mm, 107 mm and 115 mm, respectively. **Also** like winter migrants observed at Wapatox, most Roza winter migrants do

not move into the lower Yakima during the winter; only 24.6% of the Prosser observations of fish branded and released at Roza the winter of 198990 occurred before March 1. This observation and the similar observation at Wapatox indicate a major overwintering area must exist in the middle Yakima, somewhere above Prosser Dam. There is some evidence indicating that this area is concentrated in a reach bordered by Marion Drain and Satus Creek (see below).

Considerable numbers of chinook fry (mean length 36 mm) were observed at Roza, some as early as February. As the nearest spring chinook redd to Roza in 1989 was 12 miles upstream, this suggests fry are moving considerable distances downstream immediately after emergence.

The seasonal distribution of juvenile movements at Prosser is considerably different from Wapatox and Roza. Here, the passage of spring smolts (from March 1 through June 30) is always much larger than the passage of winter migrants (and the passage of juvenile salmonids in the summer is essentially zero). Over four years of year-round operation (1986-1990), winter migrants have made up only 19.9% to 23% of "total brood year production" (winter migrants + spring smolts). The constancy of the relative contribution of winter migrants is striking in view of the fact brood year egg deposition has ranged from 5.56 million to 15.07 million. This constancy has led to speculation that winter movements may, at least in part, be genetically controlled -- that -20% of the Yakima population inherits the predisposition to migrate during the winter. This hypothesis is supported by the fact that 280,000 spring smolts passed Prosser in 1988, while the total brood year production in 1989 was only 116,000, of which 23,000 were winter migrants. If winter migration were completely the result of an inadequate quantity of winter habitat, there should have been no winter migrants in 1989; the passage of 280,000 spring smolts the year before demonstrated that the quantity of winter habitat was more than adequate.

Winter migrants are not seen at Prosser until late November, and passage usually reaches a peak in December. Over all years, 63% of the passage of winter migrants has occurred in November and December.

It is believed that the winter migrants observed at Prosser originate from both the upper Yakima and the Naches system. This belief is based on the fact that, month by **month,** branded Naches system winter migrants are always significantly smaller than unbranded fish. (Because of colder water temperatures and lower overall productivity, the Naches system produces spring chinook that are smaller than upper Yakima fish at all life stages; the larger unbranded fish were therefore assumed to originate from the upper Yakima.) Moreover, in the winter of 19861987, the proportion of branded Naches system fish observed at Prosser was much smaller than the proportion marked and released at Wapatox.

Although winter migrants at Prosser probably originate from all parts of the basin, the movements of (branded) Naches system fish and presumptive (unbranded) upper Yakima fish is remarkably synchronous. This synchrony may reflect a common mid-Yakima

overwintering site for winter migrants throughout the basin. In a basinwide electroshocking survey of the Yakima in the winter of 19861987, the greatest catch per unit effort of both branded and unbranded juveniles occurred in the middle Yakima, between the outlet of Marion Drain and the mouth of Satus Creek. The major spring chinook overwintering area in the basin may be concentrated in this reach.

Spring Movements

As mentioned, the passage of spring smolts at Wapatox is always less than the passage of winter migrants. Spring smolt outmigrations have ranged from 6,671 in 1986 to 41,511 fish in 1985. Outmigrations at Wapatox are, however, difficult to estimate, because the low elevation of the trap causes the trap to flood, rendering the trap inoperable a considerable portion of every year. Operations are further complicated by the fact that the trap cannot be operated until the screens in the Wapatox canal are installed, which usually occurs about April 1. The fact that smolts are captured in large numbers the first day of operation leads to the conclusion that smolt outmigration on the Naches typically begins considerably earlier than April 1. The observed portion of the outmigration at Wapatox is heavily concentrated in April, although some smolts are observed as late as June. Over all years, the mean fork lengths of smolts observed in April, May and June are 95 mm, 100 mm and 109 mm, respectively.

The Roza facility has been operated through the entire spring only once, from April 1, 1989 through August 31, 1989. Again, the Roza trap has not been calibrated, so passage cannot be estimated. Nevertheless, it is interesting to note that the raw catches of young-of-the-year were 12 times as numerous as smolts (5,581 vs. 446 fish). This observation may suggest that most upper Yakima chinook have moved below Roza some time prior to smolting. The mean fork length of all smolts observed at Roza in 1989 was 115 mm.

As is the case at Wapatox, the smolt outmigration at Prosser is concentrated in April. From 1983 through 1990, a mean of 63% of all smolt passage occurred in April, although the proportion has ranged from 4 1.7% in 1984 to 90% in 1990. Mean May passage is 32 % , and has ranged from 7.8% in 1990 to 52.4% in 1984. Very little passage occurs in March and June, which has accounted for a mean of only 1.8% and 3.3%, respectively. The date of median passage has ranged from April 16 in 1990 to May 4 in 1984, and the overall median passage date is April 25.

Early April represents a kind of threshold for outmigration at Prosser One might speculate that some seasonal cue -- perhaps photoperiod, water temperature or their combination -- characteristic of early April triggers a behavioral “predisposition to migrate” in the majority of the population. In any case, after the first few days of April, abrupt increases in discharge begin to trigger disproportionately large increases in outmigration. Note that “flow pulses” have no discemable effect in March, when most of the population may be presumed to consist of pre-smolts, nor in June, when most of the population has already emigrated. The migratory response is especially large when the pulse follows a

prolonged period of declining flows. Note that abrupt increases of flow stimulate movement; stable and declining flows depress movement, even when the absolute measure of discharge during a period of decline is still quite large. While outmigration is stalled because of declining flows, smolts are subject to extended periods of vulnerability to predators, especially if they have "holed up" in the perilous reach between Sunnyside and Prosser An analysis of the correlation between passage and flow shows that stimulatory pulses increase discharge a minimum of 20% (over "base flow") in a period of two days or less. Larger pulses occurring after prolonged periods of declining flows can trigger spectacular responses, as occurred in 1988, when over 330,000 hatchery coho and 69,000 spring chinook passed Prosser in a single day.

The length of spring chinook smolts at Prosser generally decreases through the season. Over all years, mean fork lengths in March, April, May and June were 138 mm, 130 mm, 125 mm and 129 mm. respectively. As all spring chinook smolts are age-I+, this trend presumably indicates that larger fish smolt earlier. Condition factor remains essentially constant through the outmigration.

Over all years, total spring outmigration has ranged from 282,514 fish in 1988 to 92,934 in 1989 (mean = 177,561). This considerable range of production and rearing density is associated with significant impacts on mean size and condition factor between years. Egg-to-smolt survival is positively correlated with both mean length and mean condition factor; estimated egg deposition is negatively correlated with mean length and mean condition factor. Interestingly, these statistically significant relationships hold only for the month of *April;* there is little statistical evidence of a density-dependent impact on growth in May. This observation has prompted speculation that the outmigration of one of the three known substocks of Yakima spring chinook (American River, Naches system and upper Yakima) precedes or follows the other two, and that the stock status (the "seeding level") of this "asynchronous" substock is substantially different from the other two.

An examination of the relationship between the rapidity of outmigration (of wild smolts) and spring flows in a number of reaches along the migratory pathway was essentially fruitless. No relationship was found between median migration date and any flow-related parameter along the migratory route above Prosser A very weak relationship was, however, found between mean spring water velocity below Sunnyside Dam and "middle 80% passage time" -- the period separating cumulative passage of 10% and 90% of the run. The 80% passage time reflects the temporal compression of the outmigration and may be presumed to have survival value when the population must run a gauntlet of resident predators (as may be the case in the Yakima). The correlation between Sunnyside water velocity and 80% passage time was negative (faster water decreased passage time), but was not significant. This relationship became significant at the .05 level if data for 1987 and 1989 were omitted. If such a relationship were ultimately to be validated, the implications for managing Yakima spring chinook would be significant; passage times of less than a month would, in most years, require the release of some water from storage reservoirs.

Summer, Fall and Winter Movements

Wapatox Smolt Trap

Methods

The main purpose of the Wapatox juvenile fish trap is to monitor spring smolt outmigration and fall pre-smolt migration in the Naches drainage. Summer movements were also monitored in some years.

The Wapatox smolt trap is located about 0.5 km downstream of the Tieton River confluence, at RM 17 on the Naches River. General periods of trap operation were from April 1 to June 30 for smolt outmigration; July and August for summer outmigration; and September 1 to November 30 for fall migration. Occasionally the trap began operation before April 1 and continued after November 30.

The trap is located in the fish bypass ditch and is linked directly to the bypass pipe coming off the Wapatox Diversion Canal. The bypass pipe empties into a screened (3.2 mm mesh) channel extending 3 m from the end of the bypass pipe. The screened channel allows dissipation of excess discharge. The downstream end of the channel connects with a 10.2 cm PVC pipe that leads directly into a livebox Fish entrained into the canal are shunted into the bypass pipe by a series of rotary screens at right angles to the canal.

In 1985 and 1986, researchers attempted to develop a relationship between percent discharge diverted (PDD) into the canal and percent entrainment of outmigrating juveniles. However it was not possible to collect an adequate number of fish to make the required number of releases of marked fish to describe this relationship. Consequently, researchers assume that entrainment is approximated by PDD. Daily passage is estimated by dividing the daily raw catch by daily PDD.

The fish bypass ditch, as well as the livebox, is located in the floodplain. Consequently, at least once a season (and usually more frequently), the river backs up into the bypass ditch, eliminating the hydraulic head from canal to ditch, and therefore eliminating flow from the canal to the livebox. During such periods, operation of the trap was not possible, and passage was estimated by interpolating between known numbers of outmigrants preceding and following the period of downtime.

Results

Summer (July and August) movements of spring chinook parr were minimal (Tables 19 and 20). Estimated passage was 1,710 fish in i985, 878 fish in 1986, 1,794 fish in 1987 and 1,380 fish in 1989. Overall mean fork length was 80 mm in July and 83 mm in August (Fig. 21).

Annual variation in downstream movements of spring chinook pre-smolts in the fall is obscured by variable closure dates from year to year. The estimated number of fall migrants ranged from 8,988 fish in 1989 (screens removed December 12) to 60,186 fish in 1986 (screens removed December 1; Table 21). Fall migration usually begins in mid-October and continues through the entire period of fall monitoring. In 1986 most of the movement occurred between November 18 and December 1, when the trap was closed because of icing. In all brood years, save one (1988), the number of fall migrant pre-smolts exceeded the number of spring smolts. The proportion of "total brood year outmigrants" represented by fall migrants can be compared over the brood years 1984, 1985, 1987 and 1988 because the monitoring period at Wapatox was similar. Over these years, fall outmigrants represented from 47% (1988 brood) to 89.7% (1984 brood year) of total brood year production.

In 1986, approximately 20,000 pre-smolts were freeze branded and released as they passed Wapatox in the fall. Subsequent recaptures of marked fish at the Prosser trap on the lower Yakima indicated that Naches River fall migrants move into the Yakima River, and that some (38.7%) move below Prosser Dam in the winter. However, most (61.3%) of the marked fish that survived and moved past Prosser did so as smolts the following spring. Three marked fish moved 102 km downstream in a period of only nine days, a migration rate of 11.3 km/day.

The downstream movement of spring chinook in the fall and winter is not unique to the Yakima River system. Similar behavior has been observed in several tributaries in the Salmon River drainage (Chapman and Bjomn 1969) and in the Warm Spring River (Stainbrook et al. 1985). Bjomn (1971) found that fall-winter emigration from the Lemhi River system was greatest during October through November. This coincides with what is observed in the Naches River (see Outmigration, Spring Movements, Wapatox Smolt Trap).

The cause of fall migrations of pre-smolts in the Naches River, and the upper Yakima River as well, is not yet known. It is at least possible that fall movements in both systems are attributable to an inadequate quantity of winter habitat, or to the inaccessibility of much potentially suitable winter habitat. Chapman and Bjomn (1969) observed that pre-smolt emigration coincided with declining stream temperatures in several Idaho streams. In the Lemhi River, the median stream temperature was about 10°C, 7.5°C and 5°C in September, October and November, respectively (Bjomn 1971), which defined most the fall-winter emigration. Similarly at Wapatox, the primary emigration period was September through November (though the trap was not generally operated in December). Mean stream temperature was 12°C in September, 8°C in October, and 4°C in November based on 1986 data. However Chapman and Bjomn (1969) concluded that pre-smolt emigration behavior was not a direct response to declining water temperatures. They theorized that pre-smolts require winter habitat, and that winter hiding behavior is induced by decreasing stream temperatures.

Chapman and Bjomn (1969) conducted laboratory experiments in which "hiding" chinook were electroshocked from the substrate in December from Johnson Creek, and

placed in troughs with cobble substrate. The mean stream temperature of Johnston Creek at the time was 1.6°C. As the water temperature was increased in the troughs they observed that about half or more of the fish consistently remained in the water column (out of the cobble) at a temperature of 7.2°C. Though the "hiding" behavior of chinook was more erratic, Chapman and Bjomn (1969) demonstrated a casual relationship of temperature with "hiding" versus "non-hiding" behavior. With both chinook and steelhead pre-smolts, Chapman and Bjomn (1969) demonstrated in the laboratory that quality of substrate -- gravel (1 cm to 5 cm) versus rock (15 cm to 45 cm) -- was important to the degree of emigration observed in the troughs. For both species, though more dramatic with steelhead, more fish emigrated with a gravel substrate than did with a rock substrate. Chapman and Bjomn (1969) concluded that pre-smolt emigration resulted from the inability of fish to find suitable overwinter habitat where they were located and that this winter hiding behavior response was induced by declining stream temperatures.

If fall migration in the Naches system is entirely attributable to insufficient or inaccessible winter habitat, one would expect to see an inverse relationship between brood-year egg deposition and the proportion of brood-year production attributable to fall migrants. Such a relationship has, however, not been observed at the Prosser trap; over brood years with egg depositions ranging from 1.67 million to 15 million, fall migrants have represented a nearly constant 20% of total brood year outmigrants.

However, it remains uncertain whether winter habitat is limiting in the Naches Basin above Wapatox. Researchers attempted, as was done at Prosser, to correlate the magnitude of the fall emigration at Wapatox to total egg deposition in the basin. No relationship was found. However, fall estimates from year to year are confounded by the inability to operate the facility through the winter, and by lack of an experimentally defined flow-to-fish-entrainment relationship from which to accurately expand the raw counts. For example the trap ceased operation October 29 for the 1987 fall outmigrants, which were produced from the highest redd count (3,106 redds) in the basin during the course of the study. Thus what occurred after this date remains unknown. Further research is necessary to fully address this question.

The mean fork length for all years was 85 mm in September, 96 mm in October (Fig. 22), and 95 mm in both November and December (Fig. 23).

Table 19. Estimated weekly catch of spring chinook at Wapatox summer 1985-1990.

Date (week ending) (date)	1985	1986	1987	1988	1989	1990
07/01-07	57 \a	98	59	-- \e	143 \f	-- \e
07/08-14	48 \b	45	68	-- \e	81	-- \e
07/15-21	14	216	182	-- \e	65	-- \e
07/22-28	26	54	120	-- \e	51	-- \e
07/29-08/04	86	130	448	-- \e	242	-- \e
08/05-11	583	83	103	-- \e	144	-- \e
08/12-18	475 \c	134	243	-- \e	323	-- \e
08/19-25	239 \d	45	359	-- \e	172	-- \e
08/26-09/Ol	182	73	212	-- \e	159	-- \e
Total	1,710	878	1,794		1,380	

\a Trap not fish-tight July 1-7, was interpolated.
\b Trap not ftsh-tight July 8-12, was tnterpolated.
\c Trap not In operation August 18, was interpolated.
\d Trap not in operation August 19 and 20, was interpolated.
\e Trap closed for the summer.
\f Trap In operation 6 days, no interpolation.

Table 20. Summary of monthly spring chinook outmigration at Wapatox for years 1985 through 1990.

Year	Date started	Date ended	March	April	May	June	July	August	September	October	November	December
1985	Apr. 01	Nov. 10	--	38,856	2,458	197	193	1,496	4,933	37,060	15,573	
1986	Mar. 22	Dec. 02	250	3,062	2,752	607	509	169	2,138	7,794	50,264	
1987	Apr. 01	Oct. 29	--	15,204	2,248	253	608	1,158	3,485	9,556	--	
1988	Mar. 04	Nov. 23	11,128	27,732	1,292	263	\a	\a	1,391	11,596	13,439	
1989	Apr. 01	Dec. 12	--	18,435	724	193	365	974	969	368	4,360	3,332
1990	Apr. 03	Dec. ?	–	8,093	1,986	68	\a	\a	\a	4,245	2,988	--

\a facility was not in operation.

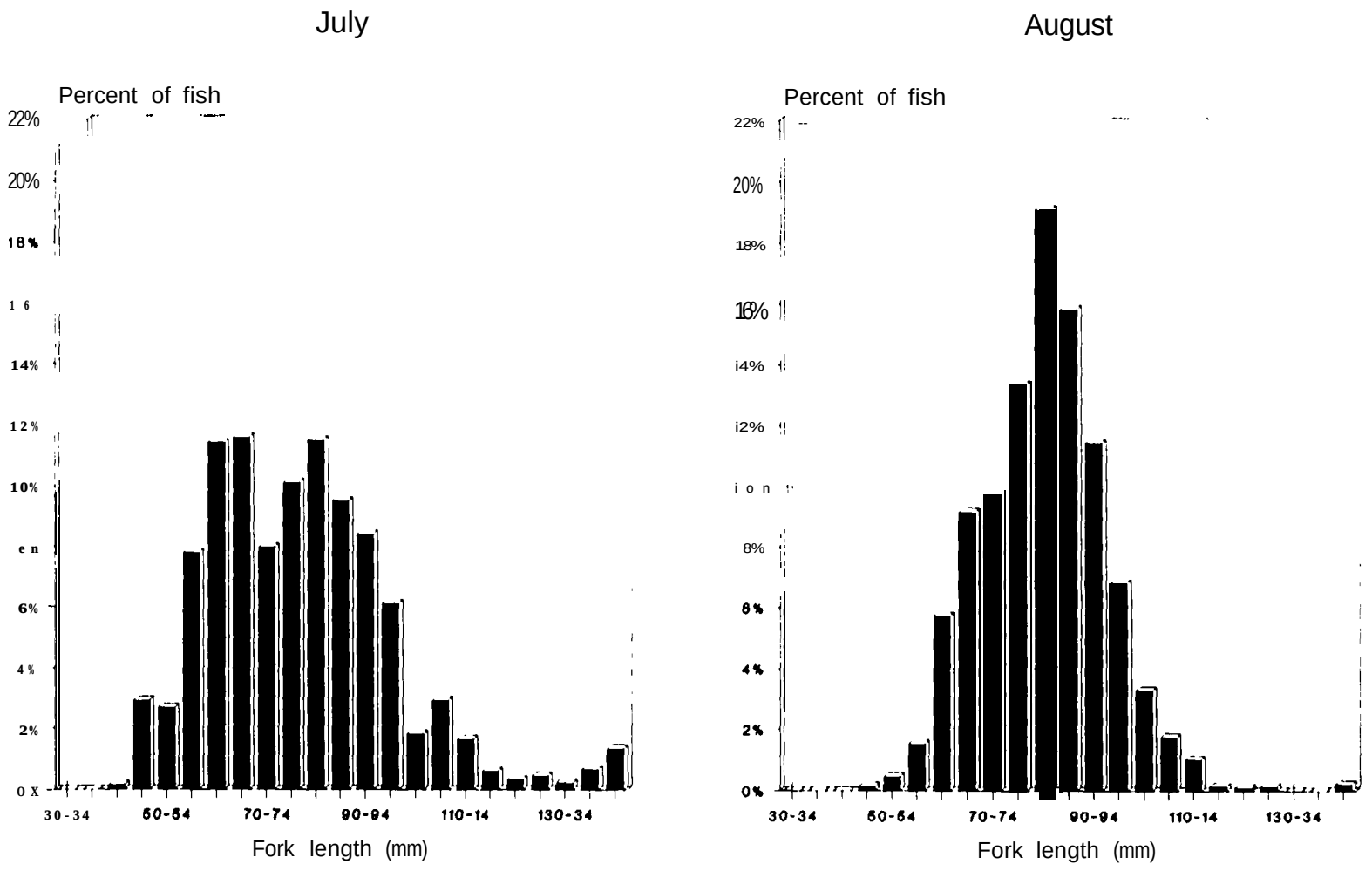


Figure 21. Mean monthly length distribution of juvenile spring chinook at Wapatox in July and August.

Table 21. Estimated weekly catch of spring chinook at Wapatox fall 1985-1990.

Date (week ending) (date)	1985	1986	1987	1988	1989	1990
09/02-08	219	125	99	116	153	
09/09-15	2,740	865	356	311	483	
09/16-22	628	551	635	597	181	
09/23-29	1,264	536	2,029	317	99	
09/30-10/06	429	357	2,561	175	173	
10/07-13	1,489	1,611	3,690	749	90	
10/14-20	2,247	1,651	1,570	2,644	117 \e	927 \
10/21-27	21,515	1,980	2,047	4,581	-- \f	2,961
10/28-11/03	16,017	3,930	54 \c	6,519	-- \f	458
11/04-10	11,297 \a,b	1,856	--	8,947	-- \f	1,080
II/II-17		1,609		972	3,485 \g	843
11/18-24		23,247		490 \d	556	964 \
11/25-12/01		21,868			475	-- \
12/02-08					2,531	
12/09-15					705 \h	
Total	57,845	60,186	13,041	26,418	8,988	

\a Trap was fish-tight 2 days, interpolatrion performed.
\b Facility closed November 10.
\c Facility closed October 29.
\d Facility closed November 23.
\e Trap was fish-tight 2 days, no interpolation performed.
\f Trap was fish-tight 0 days, no interpolation performed.
\g Trap was fish-tight 5 days, no rnterpolation performed.
\h Facility closed December 12.

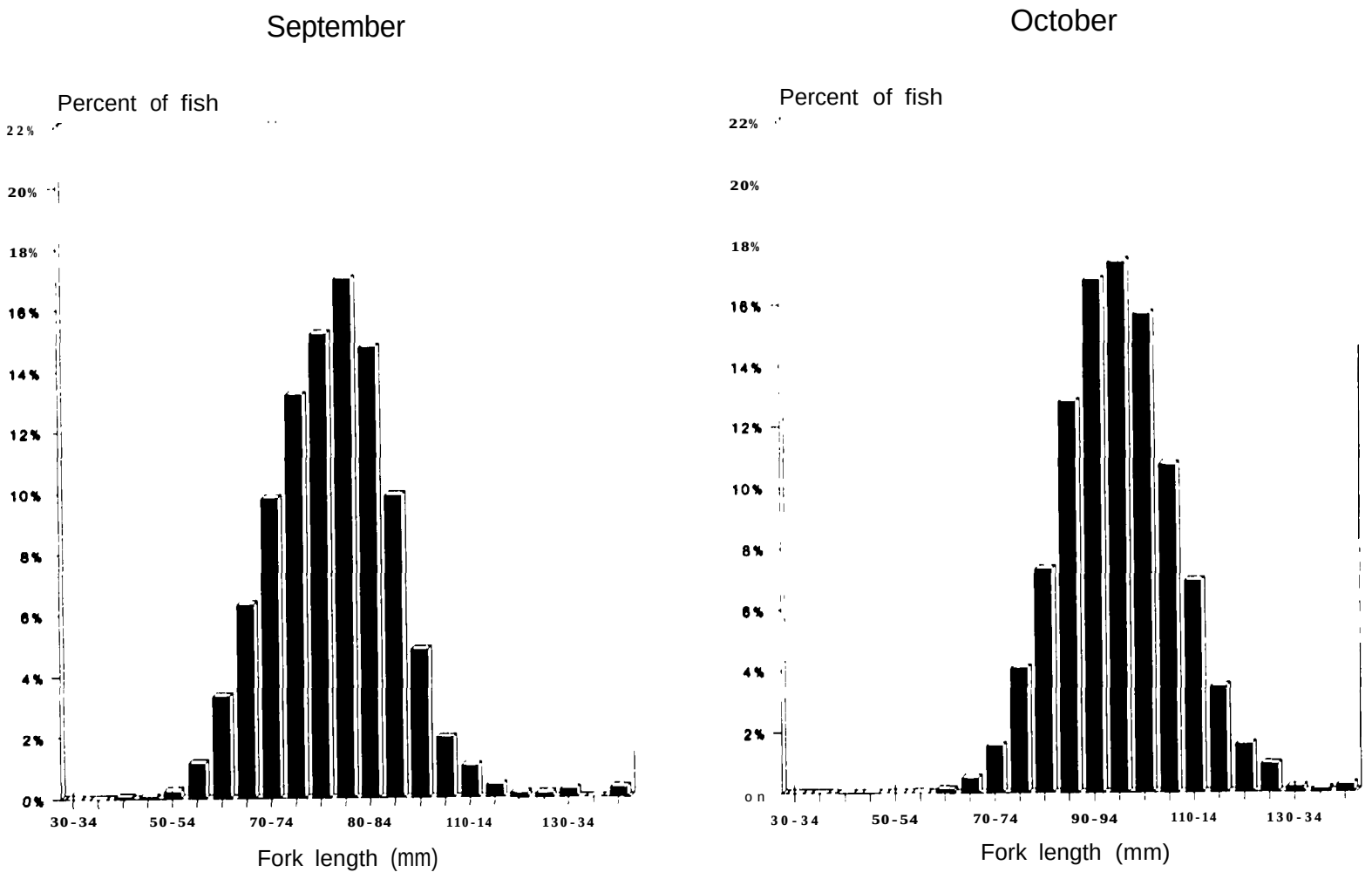


Figure 22. Mean monthly length distribution of juvenile spring chinook at Wapatox in September and October.

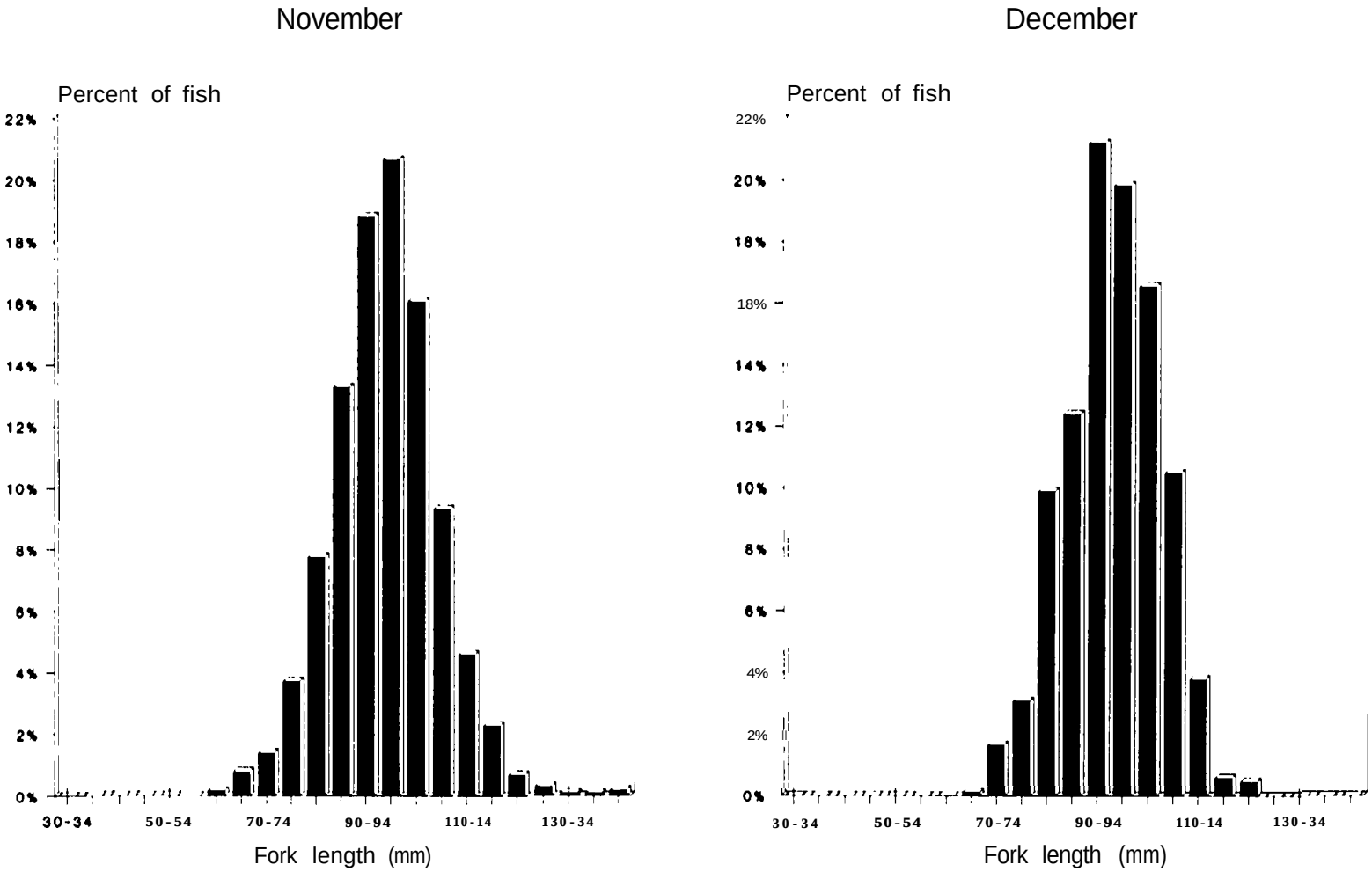


Figure 23. Mean monthly length distribution of juvenile spring chinook at Wapatox in November and December.

Roza Smolt Trap

Methods

The Roza juvenile fish trap was operated on an experimental basis on two separate occasions, the first being April 1, 1989 through August 31, 1989. The primary objective during this period of operation was to determine the facility's effectiveness in monitoring juvenile salmonid outmigration from the upper Yakima River. The second period of operation was from December 12, 1989 through April 17, 1990. There were two objectives during this period of operation, the first being a continuation of determining the facilities trapping effectiveness, and the second being the estimation of the spring chinook survival rate of outmigrants to Prosser Dam. This was done by freeze-branding pre-smolts and smolts at Roza and recording the brands of fish that were recaptured at Prosser.

The incline plane trap caught fish that were directed into a fish bypass by a series of rotary drum screens in the forebay. Fish were removed from the livebox and anesthetized with MS-222. Researchers identified fish by species and recorded fork lengths, weights and took scale samples from a portion of each day's catch. During the first season, the trap was fished on a 24-hour basis. Except for two periods (April 14-19 and April 28-30), the trap was monitored daily during the month of April. Beginning in May, the trap was fished for a 72-hour period once a week. Heavy ice build-up reduced operation to seven hours total for the week of February 13, 1990.

Results

A weekly catch summary of the second period of operation, December 12, 1989 through April 17, 1990 is presented in Table 22. Spring chinook catch totals for the months December 1989, January and February 1990 were 582 fish, 1,496 fish and 2,558 fish, respectively. Mean fork lengths of spring chinook in December, January and February were 106 mm, 107 mm and IO5 mm, respectively (Fig. 24). The condition factors for this period were as follows: December 10.3, January 10.3 and February 10.2. Spring chinook catch totals for March and April 1990 were 469 fish and 73 fish, respectively. Mean fork lengths of spring chinook were 107 mm and 115 mm, respectively; condition factors were 10.2 and 10.4, respectively.

Spring chinook fry were first observed on February 7 during the 1990 study. The mean fork length (36 mm) and date of capture indicate that newly emergent fry are outmigrating past Roza from spawning areas farther upstream. The nearest redd deposited in 1989 was located 12 river miles upstream, indicating that some fry are moving a considerable distance shortly after emergence. The fact that young-of-the-year spring chinook were captured throughout late winter and spring supports evidence collected from distribution studies in 1983 through 1985 (Fast et al., 1985) that juvenile spring chinook continuously migrate downstream from spawning areas in the Yakima Canyon.

Table 22. Summary of the spring chinook catch at Roza dam juvenile trap December 1989 through April 1990.

Dates	Spring chinook smolts	Spring chinook fry
Dee 12 - Dec 15	327	0
Dec 19 - Dec 22	144	0
Dec 26 - Dec 29	111	0
monthly totals	582	0
Jan 2 - Jan 5	258	0
Jan 9 - Jan 12	317	0
Jan 16 - Jan 19	590	0
Jan 23 - Jan 26	157	0
Jan 30 - Feb 2	174	0
monthly total	1496	0
Feb 6 - Feb 9	120	5
Feb 13 - Feb 14 /a	460	1
Feb 21 - Feb 23	1051	109
Feb 27 - Mar 2 /b	927	38
monthly total	2558	153
Mar 3 - Mar 9	24	20
Mar 12 - Mar 16	93	63
Mar 20 - Mar 23	257	1314
Mar 28 - Mar 30 /c	95	525
monthly total	469	1922
Apr 4 - Apr 6 /d	0	400
Apr 9 - Apr 13	52	800
Apr 16 - Apr 17 /e	21	700
monthly total	73	1900
Total	5178	3975

/a Start time was 0920 the 13th, and end time was 1600 the 13th.
/b Installation of new Iivebox/holding tank
/c Start time uas 0945 the 28th, and end time was 1430 the 30th.
/d Start time was 1000 the 4th, and erd time was 1230 the 6th.
/e Start time uas 1000 the 16th, and end time uas 1400 the 17th.
/f Estimate of total fry cmt.

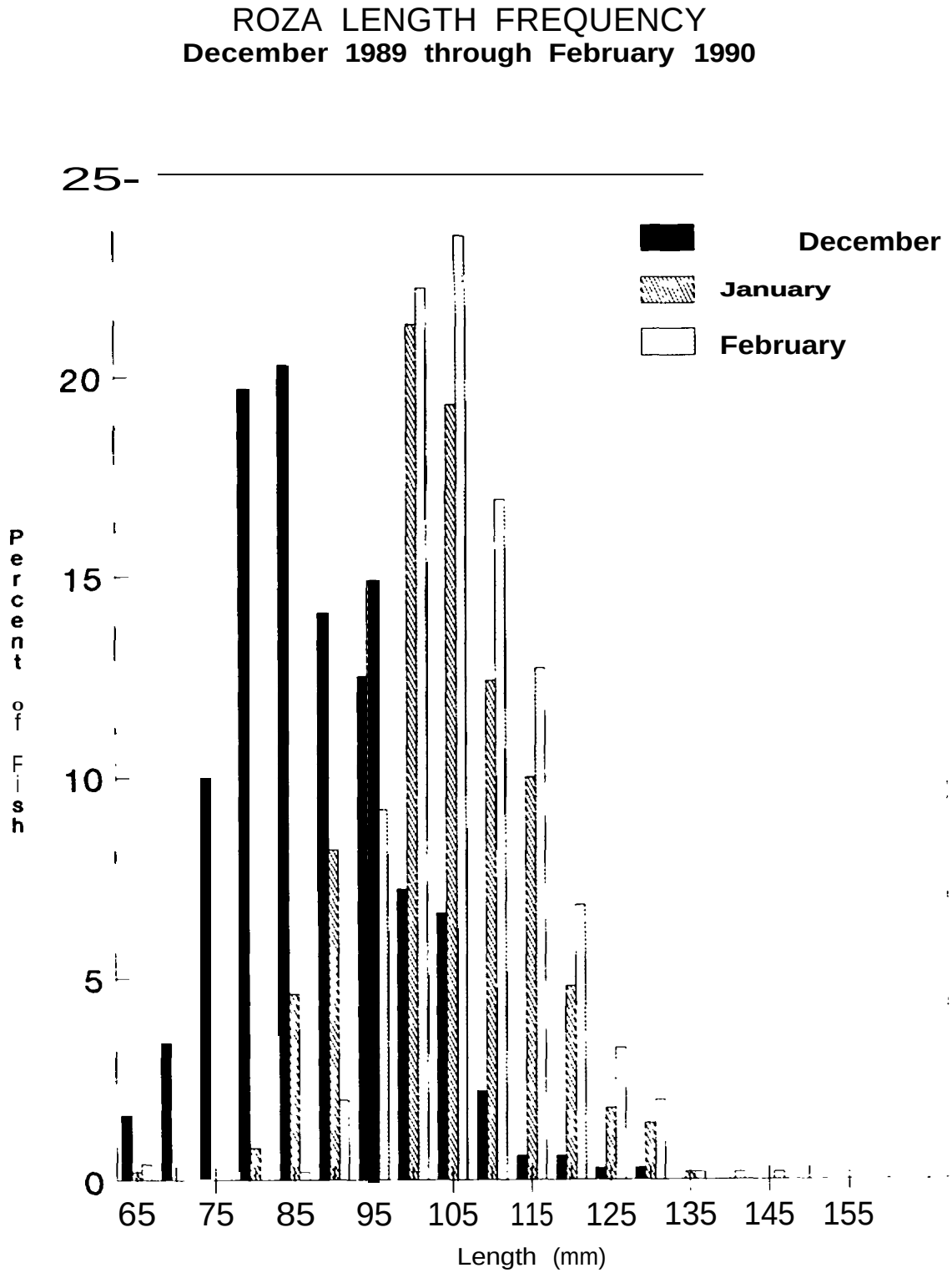


Figure 24. Spring chinook length frequency distribution at Roza Dam from December 1989 through February 1990.

The results of the winter freeze-brand releases from Roza in 1990 indicate that only a small percentage of the juveniles reach Prosser before March 1. Of the 1,303 fish with brands released between December 12 and January 16, only 9.2% passed Prosser during the winter season. Of the 3,267 fish released from January 17 through March 1, only 1.3% reached Prosser in the winter season. This information reinforces the beach seining data, indicating major rearing occurs between Roza and Prosser dams in the winter months.

Prosser Smolt Trap

Methods

The Prosser smolt trap has been operated every year since 1983. By definition, March 1 is the beginning of the spring season, which extends through June (very few chinook outmigrants are seen after July 1, and all but a negligible fraction of these are fall chinook). Prosser has been operated through all or most of the spring season since 1983. Winter trapping began in November of 1986 and continued through 1990 (extensive canal "remodeling" precluded operations in the winter of 1990-1991). By definition, the winter season begins November 1 and extends through February. However, winter monitoring has never actually begun before November 14, as Chandler canal is normally dewatered the first two weeks of November for maintenance.

The Prosser trap operates from a bypass pipe that shunts fish from rotary drum screens in Chandler canal back to the mainstem Yakima River. During the outmigrations of 1984 through 1987, trapping efficiency (the percentage of outmigrants passing Prosser Dam diverted into the trap) was estimated by a series of releases of marked fish. The statistical methodology for efficiency calculations was evaluated by Douglas Chapman of the University of Washington Center for Quantitative Science. A detailed description of the evaluation process can be found in Appendix D. The basic procedure was as follows. Once each week, fish captured in the trap during the night were cold-branded. Two groups were branded differently, with one group released two miles upstream of the canal intake, and the other in the canal. Efficiency (E_i) was based on the recapture rate of branded fish as follows.

$$E_i = \frac{C_{ri}}{R_{ri}\,(C_{ci}/R_{ci})}$$

where E_i = fraction of fish diverted into the canal in the ith experiment;
R_{ci} = number released directly into the canal in the ith experiment;
Rri = number released directly into the river in the ith experiment;
C_{ci} = number recaptured from the canal release in the ith experiment; and
C_{ci} = number recaptured from the river release in the ith experiment.

Researchers have performed 68 separate efficiency tests. A relationship was developed between the combined 1984 through 1987 efficiency data and diversion (the percent river discharge diverted into Chandler canal). This relationship has been used to estimate the total number of juvenile fish passing Prosser Dam in each of the years the trap was operating. Lengths, weights and scales were taken from random samples of all species and release groups on a daily basis. In addition, unbranded, adipose-fin clipped hatchery spring chinook were sacrificed for coded-wire tag analysis on a daily basis in 1983 through 1987.

Results

As has been mentioned, virtually no juvenile salmonids move into the middle and lower reaches of the Yakima River in late spring and summer. However, beginning in September, a relatively slow downstream movement of pre-smolts begins in the upper reaches of the drainage. Although these small, early "pulses" of pre-smolts are observed at Wapatox in mid-September, migrants typically do not appear at Prosser until mid to late November. For example, a total of only 12 juvenile spring chinook were captured at Chandler trap in the 12, 24-hour periods it was operated between August 1 and October 15, 1986, whereas in excess of 8,000 fish were counted through Wapatox over the same time period. Similar observations have been made throughout the study. For this reason, Chandler trap is typically shutdown from July until mid-November, when "fall migrants" begin to appear. (Note that the use of the term "fall migrants" is not intended to imply that these spring chinook juveniles are in fact smolts in either a physiological or a behavioral sense. Rather, the term simply denotes an aggregation of fish participating in a directed, seasonal movement.)

The conventional wisdom is that the winter migrant chinook juveniles observed at Chandler are spring chinook pre-smolts. The evidence corroborating this view is as follows.

At the peak of the winter migration in December of 1986, there was no evidence that Marion Drain, the only significant fall chinook spawning area above Chandler, was a source of migrating chinook. Marion Drain is a large (11 mile), 50-year-old irrigation return with perennial flows that supports from 50 to 300 fall chinook spawners per year. In an intensive study of winter migrants in the winter of 198687, representative reaches of the entire Yakima River were electrofished from a jet boat. Chinook juveniles resembling fish observed at Prosser (in size and coloration) were found throughout the system, and not just below Marion Drain (see subsequent section). Indeed, the catch per unit effort (CPUE) for juvenile chinook in Marion Drain was considerably less than in nearby reaches of the mainstem. On December 17, 1986, 26 chinook per mile were retrieved from the lower half mile of Marion Drain, whereas 112 to 128 chinook per mile were retrieved five days earlier from a number of mainstem reaches in the immediate vicinity. If a substantial portion of the chinook moving past Chandler were fall chinook, the CPUE in the presumptive source should have been greater than in the river. Neither is it likely that large numbers of fall chinook juveniles moved from the drain to the river earlier in the year, remaining above

Chandler until winter. Systematic seining surveys in recent years (Wasserman et al. 1984) indicated the Yakima River below Wapato Dam (50 miles above Prosser) supported essentially no juvenile chinook after July. Moreover, water temperatures in the lower mainstem frequently reach 23-25°C in the summer, and are probably prohibitively high for rearing chinook.

The thermal regime of Marion Dram and its probable impact on the emergence timing and growth rates of fall chinook is very different from other Columbia tributaries supporting populations of fall chinook that do emigrate in the winter. A winter outmigration of "late-0+" fall chinook has been observed in the Toutle, Kalama, Washougal and North Fork Lewis rivers (Rumers and Loeffed 1964). All of these rivers are relatively cold. Consequently, emergence occurs in May and June, and very few fish are large enough to smolt their first spring. In these rivers, outmigration begins in late spring, builds slowly to a peak in August and October, and continues into the following spring. Outmigrants from these systems are typically small at all times; the mean length of Toutle River outmigrants in June and November of 1964 was 46.8 mm and 84 mm, respectively. Marion Drain, on the other hand, receives large quantities of groundwater from the heavily irrigated lands it drams, and never becomes much colder than 7-8°C at any time of the year (Tom Scribner, YIN, pers. commun. 1990). The occasional capture of newly emergent chinook fry in January and February at Chandler indicates emergence begins in the late winter. Hallowed (unpublished, 1984) monitored redd deposition, water temperature and outmigration in Marion Drain from October 1983 through June 1984. From his redd deposition dates and thermal records, it is possible to estimate that the 1983 Marion Drain brood of fall chinook should have emerged between the second week of February and the first week of March (Yakima Indian Nation et al. 1990). Hallowed also found that the outmigration of Marion Dram fall chinook began in late March, peaked in early May, and ceased by the second week of June. He observed that the mean length of March and June migrants was 51 mm and 90 mm, respectively. Clearly, Marion Drain, the major source of fall chinook above Chandler, is not typical of regional systems that produce winter-migrant fall chinook.

Proportional magnitude of winter migration: Chandler trap has been used to estimate passage of winter migrants from the winter of 1986-87 through the winter of 1989-90. (Note that "winter" is not used in a strict calendar sense here. Specifically, it denotes the period October 1 through February 28, which correlates well with the period of "winter" movement.)

Table 23 summarizes the total winter passage estimates for the winters 1986-87 through 198990. Although the number of years of observation is small, the constancy of winter migration rate has been striking when expressed as a proportion of the total brood year production of migrants (winter pre-smolts plus spring smolts). Over brood year egg depositions ranging from 5.56 million to 15.07 million, winter migrant production has remained between 19.9% and 23%.

Table 23. Winter migrant spring chinook pre-smolts at Chandler, 1986-87 through 1990-91.

Year	Number of Winter Migrants					Brood Year EQQ Deposit ion ($x10^6$)	Brood Year Production (winter + spring migrants)	Winter Migrants as a Percent of Brood Year Production
	NOV	DEC	JAN	FEB	TOTAL			
1986-87	5,810	34,055	10,047	26,065	75,977	6.061	330,471	23.0
1987-88	8,039	55,971	7,563	1,964	73,537	15.073	355,946	20.6
1988-89	11,107	6,789	4,504	690	23,090	8.661	116,034	19.9
1989-90	not	18,600	16,607	18,597	53,804	5.563	256736	21.0

Control of the magnitude of winter migration does not seem to be related to brood year egg deposition in any obvious way. The correlation coefficient between brood year egg deposition and winter migration is only + .21. By contrast, Bjomn (1978) found egg deposition and winter migration in the Lemhi River to be very strongly related, with a correlation coefficient of +.97. Bjomn's study and the current study do, however, share some similarities. In both, winter migrants comprised a fairly constant proportion of the production of smolt-sized fish, although in the Lemhi the proportion was considerably higher and more variable -- 56% to 73% over brood years 1963 through 1973. More significantly, there is no evidence in either study that the number of winter migrants is determined by a limited amount of overwintering habitat. In 1988, 282,000 smolts passed Prosser in the spring. Obviously, the winter carrying capacity of the Yakima River above Prosser was at least 280,000 fish in 1988. Total brood year production the next year was only 116,034 fish. If the magnitude of winter migration simply represented the difference between the number of late fall pre-smolts and winter carrying capacity, no winter migrants should have been observed in 1989. Bjomn made a similar observation in the Lemhi. He reported 126,000 smolts passed the Lemhi weir in the spring of 1964, indicating that the winter carrying capacity of the upper Lemhi at this time was at least 126,000 fish. Only two years later, in 1966, he observed that the total brood year production was 106,O00, including about 70,000 winter migrants. Given the apparent winter carrying capacity of the upper Lemhi, Bjomn concluded that " . ..all of the migrants of the 1966 year-class could have remained in the upper Lemhi River and migrated during the normal smolt migration season...if they had so desired. "

Observations in the Yakima, and perhaps in the Lemhi as well, are consistent with genetic control of winter migration. Yakima research observations are consistent with the existence of a "winter movement gene" in about 20% of the population, which results in -20% of the outmigration occurring in the winter regardless of rearing density.

It should, however, be noted that the control of winter migration in the upper Yakima is clouded somewhat by the artificial control of river flow in the late fall and winter. As has

been mentioned, the competing needs of spawning fish and irrigation have resulted in the "flip-flop" system of river flow control. Runoff must be stored for irrigation in headwater impoundments during the late fall, winter and early spring. Spawning salmon, on the other hand, must have sufficient water in the fall for spawning and sufficient water in the winter and early spring for incubation. Flip-flop represents a compromise benefitting both interests. Releases from upper Yakima reservoirs are cut back in mid-September while releases from Naches system reservoirs are increased. This flip-flop in reservoir releases allows water to be collected for irrigation in upper Yakima reservoirs, and forces upper Yakima salmon to spawn more to the center of the channel, where water depths are adequate. After the spawning season, upper Yakima releases are cut back again, leaving sufficient water for incubating eggs and increasing the proportion of runoff stored for irrigation. These artificial reductions in flow may, however, have an unforseen impact on juvenile rearing. Yakima Indian Nation biologists have observed declines in the number of juvenile spring chinook rearing at a number of upper Yakima locations after flows were reduced to spawning or incubation levels the fall of 1990.

Table 23 summarizes the relative monthly timing of winter movements over the winters 1986-87 through 1989-90. Over the four winters monitored at Prosser, winter movement has been concentrated in December. The mean proportion of winter movement occurring in November, December, January and February has been, respectively, 16.7%, 46.2%, 18.5% and 18.6%.

Characteristics and origin of winter migrants: Scale analysis indicates winter migrants are just turning 1 year old. Of the 5,000+ scales examined to date, none had a complete annulus; none had wide circuli and interspaces distal to the check. Thus, researchers concluded that winter migrants are "late-O+" fish.

As is evident from Table 24, winter migrants have the appearance of small, very robust smolts. Like typical spring smolts, they have a pronounced silver color that partially obscures their parr marks. They are, however, from 10 mm to 20 mm shorter than spring smolts, and have a much deeper-bodied appearance. Somewhat surprisingly, their condition factor is quite comparable to spring smolts (see Table 31).

It is probable that juveniles from both the upper Yakima and Naches drainages contribute to the winter movement observed at Prosser. This became evident in the winter of 1986-87 when 19,867 Naches system winter migrants were freeze-branded with six distinctive marks. The number, dates of release, mean fork length at release and brand codes are summarized in Table 25.

The strongest evidence that winter migrants originate from all parts of the system, and not just from the Naches, is the consistent (and statistically significant) length difference between branded (Naches system) and unbranded fish. From November through February, the mean monthly fork lengths of branded fish were from 7% to 10% less than branded fish ($p=.01$, l-way ANOVA and Tukey's Test; see Table 26). Indeed, branded Wapatox fish

were significantly smaller than unbranded fish over the entire period of pre-smolt and smolt movement (November 1986 to June 1987), and were significantly smaller than unbranded fish for each month of comparison except May (l-way ANOVA, Tukey's Test, p=.O5).

The relative sizes of branded and unbranded migrants is consistent with an upper Yakima source for the larger migrants. The upper Yakima is both warmer and more productive than the Naches, and therefore supports higher growth rates. Indeed, the mean length differences in April, May and June between smolts observed at Wapatox and Chandler are 40 mm, 32 mm and 24 mm, respectively. Chandler smolts are, of course, a mixture from the entire subbasin; based on relative egg deposition, Chandler smolts should be primarily upper Yakima fish.

The second major reason for believing winter migrants at Chandler represent a basinwide mix of fish is that the estimated passage of branded fish (at Chandler) was a small fraction of the total winter movement. Only 2.2% (1,706 of 75,983 fish) of the estimated passage of winter migrants at Chandler in the winter of 1986-87 were branded Naches fish. The 19,867 fish branded at Wapatox the fall of 1986 represented 33% of the estimated winter movement there (60,186 fish). If Naches fish made up most of the migrants observed at Chandler, branded fish should have comprised a much larger fraction of the total. Admittedly, monitoring at Wapatox had to be stopped December 1 because of icing, and the total winter movement probably was substantially greater than the 60,186 fish estimated through December 1. One can, however, estimate how great the movement past Wapatox would have had to have been after December 1 if all of the fish at Chandler were in fact Naches fish, and 2.2% were branded. Given that 38.7% of the movement of the branded fish passed Chandler in the winter (November 1 through February 28), 289,292 fish would have had to have passed Wapatox after December 1:

$$0.022 - \frac{(19,867)(.3872)}{60,186 + x}, \text{ and}$$

$$x = \frac{(19,867)(.387) - (.022)(60,186)}{.022} - 289,292.$$

Thus, for all fish at Chandler to have been Naches fish, total winter migration past Wapatox would have had to have been 60,186 + 289,292 or 349,478 fish. Such a number of Naches system winter migrants is extremely unlikely in light of the fact the total brood year production at Chandler (winter migrants plus spring smolts) was only 330,477 fish.

Table 24. Mean monthly Length, weight and condition factor for wild spring chinook winter migrant juveniles observed at Chandler in November December January and February, winters of 1986-87 through 1989-90.

YEAR	NOVEMBER			DECEMBER			JANUARY			FEBRUARY		
	LENGTH	WEIGHT	CONDITION FACTOR	LENGTH	WEIGHT	CONDITION FACTOR	LENGHT	WEIGHT	CDNDITIDN FACTOR	LENGTH	WEIGHT	CONDITION FACTOR
1986-1987	119	19.7	11.4	115	16.6	10.6	114	16.0	10.4	121	18.6	10.4
1987-1988							115	16.3	10.4	115	17.0	10.8
1988-1989	121	20.5	10.8	119	18.3	9.5	120	18.3	10.4	123	19.4	10.2
1989-1990				120	18.9	10.9	118	17.8	10.4	136	20.7	11.9

Table 25. Wild juvenile spring chinook winter migrants branded and released at Wapatox trap the fall of 1986.

RELEASE GROUP	MEAN FORK LENGTH AT RELEASE (mm)	NUMBER RELEASED	BRAND
October 22--November 18	94.5	6,626	RA+Y(I)
November 11 --November 23	90.4	5,035	LA+Y(l)
November 23--November 25	92.4	4,646	LA+F(l)
November 26--November 28	89.7	1,237	LA+Y(2)
November 26--November 28	93.5	1,661	LA + F(2)
December 3	90.2	462	LA + F(3)

Table 26. Mean monthly fork Lengths, weights and condition factors cf branded Naches system spring chinook and all unbranded spring chinook at Chandler from November 1986 through May 1987. (Note that figures in parentheses represent standard errors.) IINM1 = the nunber of observations; "L" = mean fork length (mn); "W" = mean weight (gm); "K" = mean condition factor, where this is expressed as W/L X 10'.

GROUP	AT RELEASE	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY
Wapatox: released 10122-I I/18	L-94 5 (.24) (No weights taken)	L-1089 (1.92) N-15	L= 107.9 (42) N-330	L-1085 (91) N=66	L=116 7 (1.90) N-34	L-135.5 (12.09) N-4	L= 128.2 (.45) N-385	L=118.9 (2.38) N=8
Wapatox released 11119-I 1123	L = 90.4 (.50) (No weights taken)		L= 103.2 (.44) N=268)	L= 105.0 (.94) N-09	L=108 1 (1 26) N-27	L-121.8 (4.59) N-5	L=128.5 (.43) N-275	L = 120.6 13.38) N-4
Wapatox released 11123.11125	L-92.4 (56) (No weights taken)		L-104 6 (.56) N= 155	L= 105.4 II.051 N-43	L-1120 (1.29) N-14	L-124.3 12 67) N-3	L-128.1 (.44) N= 204	L-1198 (3.48) N-6
Wapatox: released 11/28-11/28	L=93.5 (.58) (No weights taken)		L= 107.8 (1 511 N-29	L=106.3 (1 46) N-19	L-111.7 (6 0) N-2	L=118 0 (6 0) N-2	L-128.8 (88) N=76	L-121.0 N-I
Wapatox: released 11/26-11/28	L = 89 7 II.071 (No weights taken)		L-1045 II.311 N-38	L= 108.5 11.751 N-17	L- 108.7 (2.64) N=6	NO Recaptures	L-127.8 (88) N-04	L-121 (9.01 N-2
Wapatox; released 12/3	L-90.2 (66) (No weights taken)		L-93 N-I	L-1172 (3 29) N-5	L-115 (1.41) N-5	NO Recaptures	L-1283 II.731 N-29	L-119 N-I
All Wapatox Released	L=93.3 (.18) (No weights taken)	L=106 9 (1 92),N= 15 w- 14.7 I I.N-2 K-11.4 ( ),N=2	L=105 6 (27),N=819 W-124 (.22),N=198 K-102 L051.N = 198	L=106 8 (.51),N=219 w-12 10 (26),N=117 K-100 (.10),N=117	L-112.8 (96),N=RR W= 15.7 (80),N=21 K-106 (.22),N=21	L-125.7 (3.92),N=14 w-155 (2.7),N=2 K=10.6 (.18),N=2	L-128.2 (24),N = 1039 W= 22.7 (15),N=704 K= 10.5 (.04),N=704	L-119.7 (1.58),N= 22 W=19.8 (2.58),N=8 K = 12.0 (1.1),N=8
All Unbranded Fish	Not Applicable	L=118 8 (I.N=1737 w-19.7 ( ),N=691 K-11 4 ( ),N=691	L-115.0 (.11),N=8154 W=16.6 (08),N=3870 K=10.6 (.01),N=3870	L-113.8 (.16),N=4029 W=16 0 (11),N=2193 K-104 (.02),n=2193	L=120.6 (.22),N= 1549 W=18.6 (.19),N=570 K-104 (.03),N= 570	L = i3e.4 (40),N=1613 w-44.0 (13.25),N=495 K-13.0 (2.38),N=495	L = 1 30.8 (.14),N=5628 W-24 1 (.10),N=4311 K= 10.6 (.01),N=4311	L = 1 22.e (.34),N= 1197 w = 20.5 1.271.N = 941 K=10.8 (.10),N=941

Relative timing of winter movements: Although winter migrants, as observed at Chandler, apparently come from both the Naches system and the upper Yakima, the timing of the movements of fish from both areas was remarkably similar in 1986 and 1987. As Figure 25 indicates, the timing of branded Naches system pre-smolts was well synchronized with the timing of unbranded fish through the winter. Indeed, this basic synchrony was preserved over the entire year, as is evident in Figure 26. However, over the whole year, the synchrony of Naches and upper Yakima fish is not precise. As Figure 27 shows, Naches winter migrants pass through the system slightly earlier than the majority of wild fish.

As mentioned, 38.7% of all Naches winter migrants moved past Chandler in the winter; the remaining 61.3% moved in the spring (March 1 through June 30). Therefore, it is evident that a significant overwintering area exists somewhere between Wapatox and Chandler. There is some evidence that this area may be a meandering reach of the lower Yakima with good riparian habitat between Marion Drain and Satus Creek. The apparent density of smolts observed in this area in the winter 1986-87 survey (catch per unit effort) was two to four times the density observed in any other reach. Moreover, 90% of the observations of winter migrants branded at Wapatox occurred here, indicating actively moving migrants “accumulated” in the area.

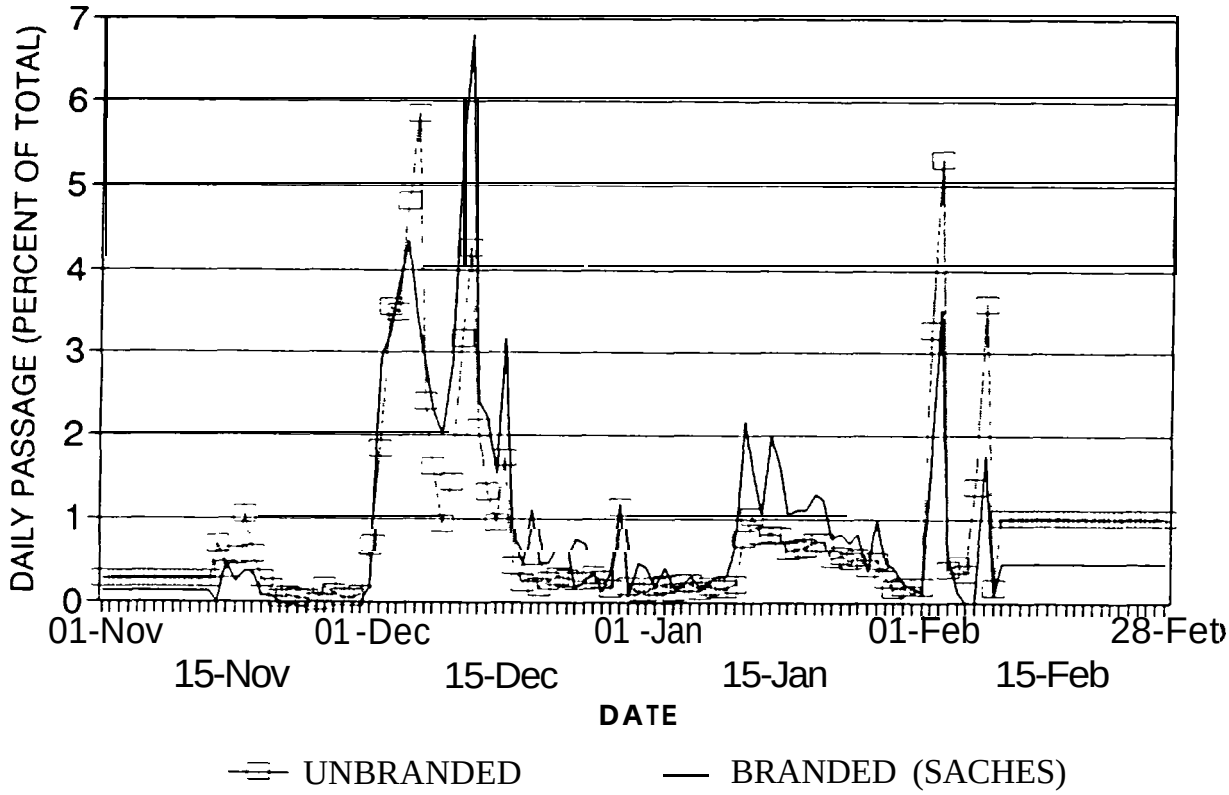


Figure 25. Passage of winter migrant spring chinook pre-smolts, Chandler smolt trap, winter of 1986-l 987.

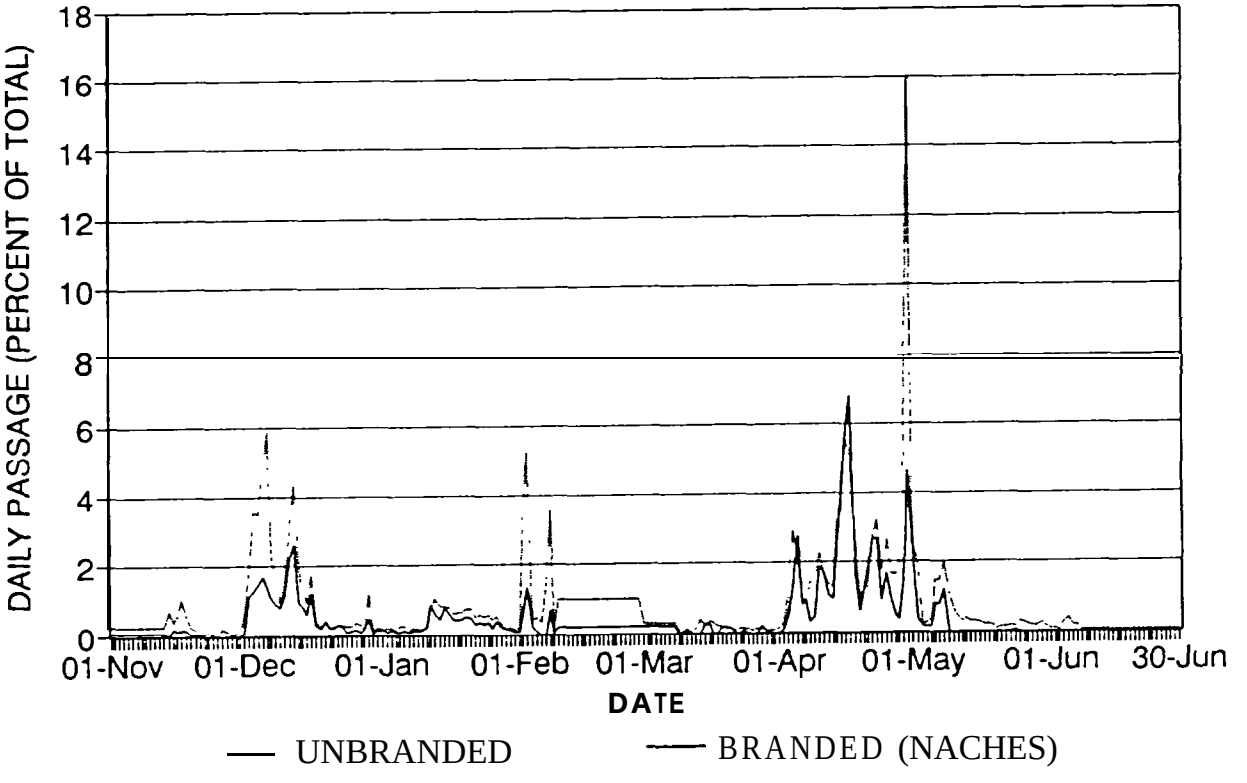


Figure 26. Year-long passage, Chandler smolt trap, 1986-l 987, branded Naches system winter migrants and all unbranded pre-smolt and smolts.

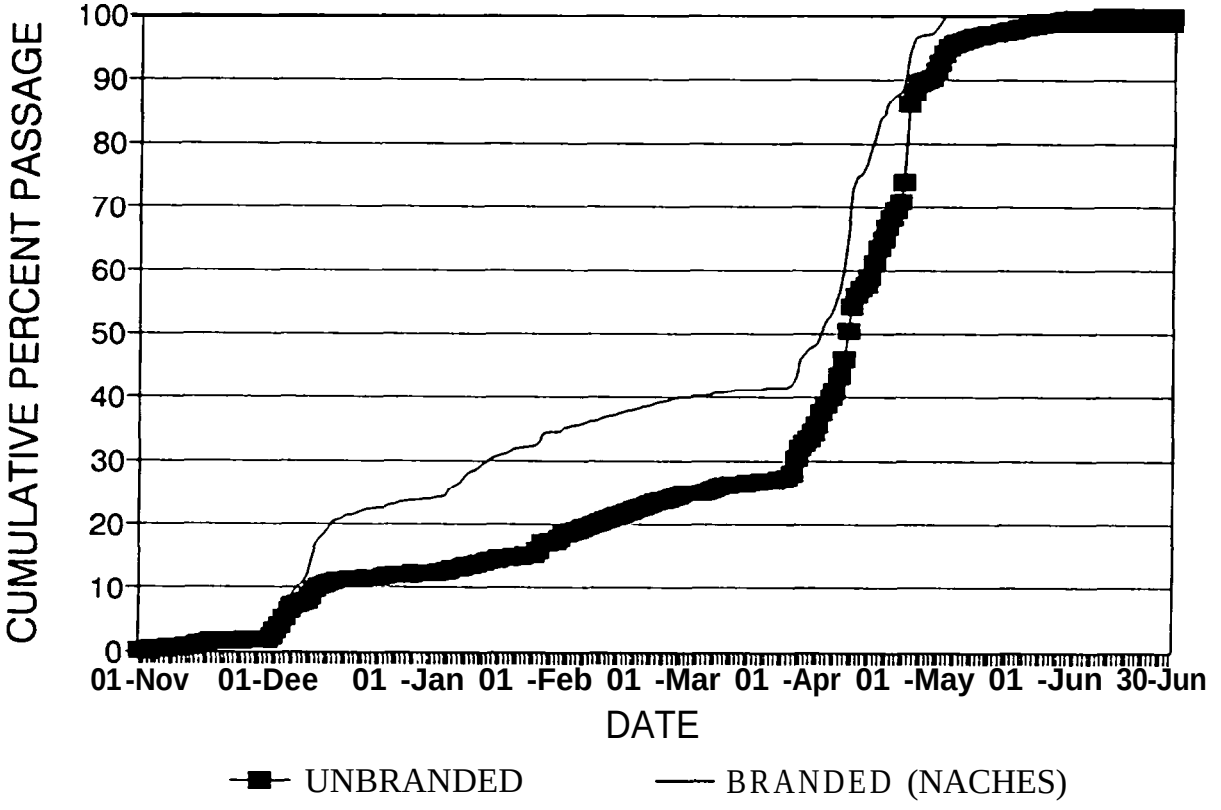


Figure 27. Cumulative, year-long passage at Prosser, branded Naches winter migrants and unbranded smolts. Naches fish branded winter of 1986.

Spring Movements

Wapatox Smolt Trap

Methods

See Wapatox methods sections under "Summer, Fall and Winter Movements," above.

Results

A summary of estimated spring outmigration past Wapatox by year is presented in Table 27 and Table 20, above. Estimated spring chinook smolt outmigration ranged from a low of 6,671 fish in 1986 to a high of 41,511 fish in 1985. March 4 in 1988 was the earliest Wapatox began operation. Results (estimated 11,128 smolts) indicate that smolt outmigration begins before the normal April 1 start-up date. Thus, total estimated smolt outmigration for these years is probably underestimated. The percent of total outmigration that occurs prior to April 1 does not appear to be constant from year to year. Estimated passage from March 22-3 1 in 1986 was 250 smolts. However, in 1988 estimated smolt passage from March 25-31 alone was 4,833 fish. Because of this, it is difficult to make any definitive statement regarding the median date of outmigration. The most that can be said is that by late April the majority of the smolt outmigration has passed Wapatox.

Mean fork length for all years combined in April (Fig. 28), May and June (Fig. 29) was 95 mm, 100 mm, and 109 mm, respectively.

Table 27. Estimated weekly catch of spring chinook smolts at Wapatox, spring 1985-1990.

Date (week ending) (date)	1985	1986	1987	1988	1989	1990
3/04-10				2,096		
3/11-17				2,589		
3/18-24		10 \b		1,610		
3/25-31		240		4,833		
4/01-07	12,872	141	4,359	13,282	4,486	2,935 \e
4/08-14	16,625	94 \c	2,012	8,758	8,301	713 \f
4/15-21	5,514	1,072	4,123	4,327	4,465	1,575 \g
4/22-28	3,512	1,294	4,123	1,253	1,126	2,561 \h
4/29-5/5	1,164	646	2,055 \d	393	246	1,078 \i
5/06-12	624	1,072	435	384	239	834 \i
5/13-19	870	429	271	371	150	173
5/20-26	39	580	246	176	103	89
5/27-6/02	132	681	104	112	59	166
6/03-09	54	202	54	138	52	17 \j
6/10-16	32	168	66	93	49	0 \j
6/17-23	49	38	73		30	6 \j,k
6/24-30	24 \a		30		46	0
Total	41,511	6,671	17,951	40,415	19,352	10,147

\a Not operatable June 28-30.
\b Facility began operation March 22.
\c Trap was fish-tight 5 days, interpolation performed.
\d Counts were interpolated a portion of this week.
\e Trap operation began April 3.
\f Trap was fish-tight 5 days, interpolation performed.
\g Trap was fish-tight 0 days, interpolation performed.
\h Trap was fish-tight 2 days, interpolation performed.
\i Mean pdc and catch for the period April 28 - May 9 was used to expand raw counts.
\j Mean pdc and mean catch for the periods June 5-12 and June 20-26 was used to expand raw count.
\k Trap was operated 6 days, due to canal repairs.

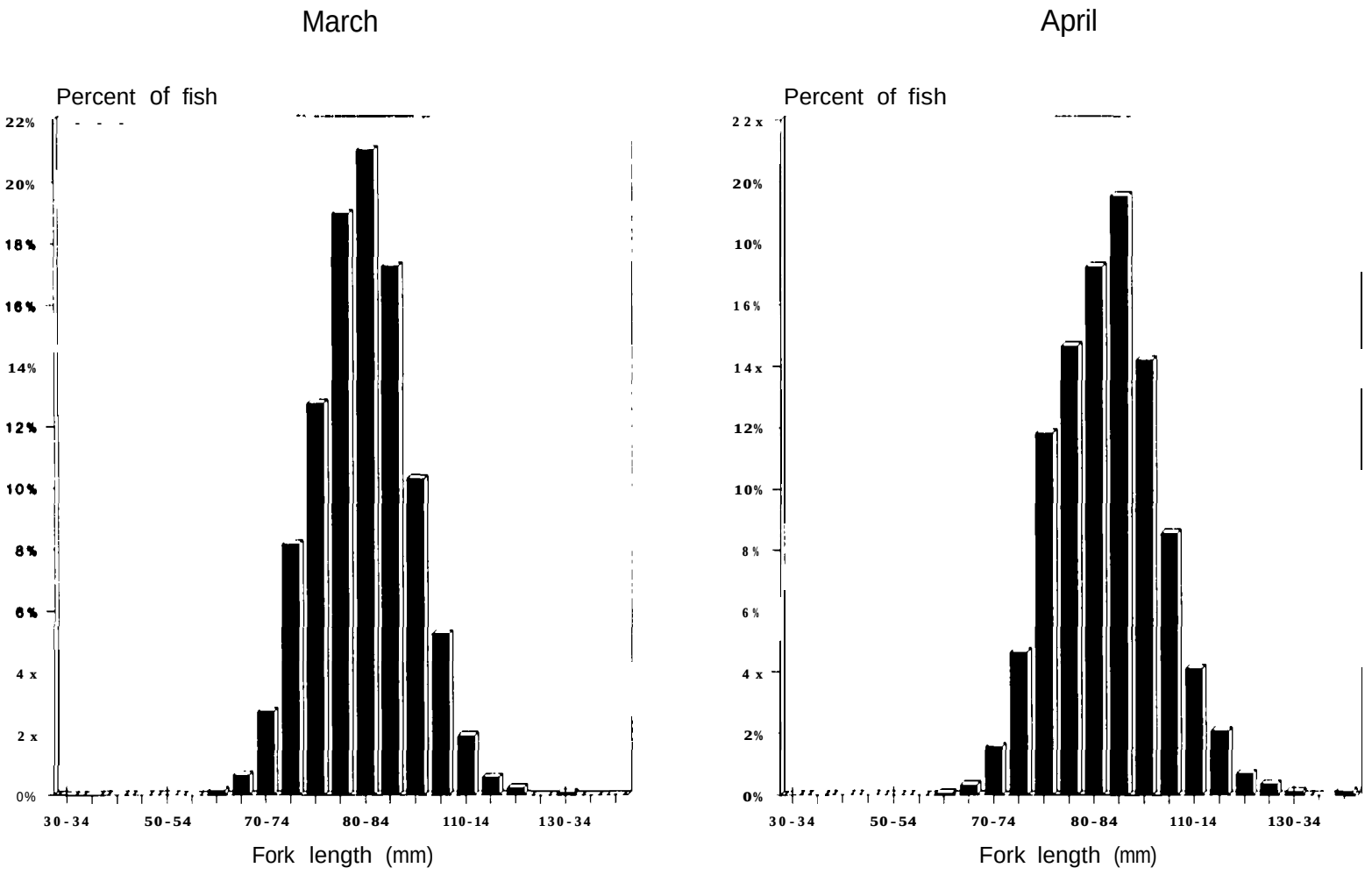


Figure 28. Mean monthly length distribution of juvenile spring chinook at Wapatox in March and April.

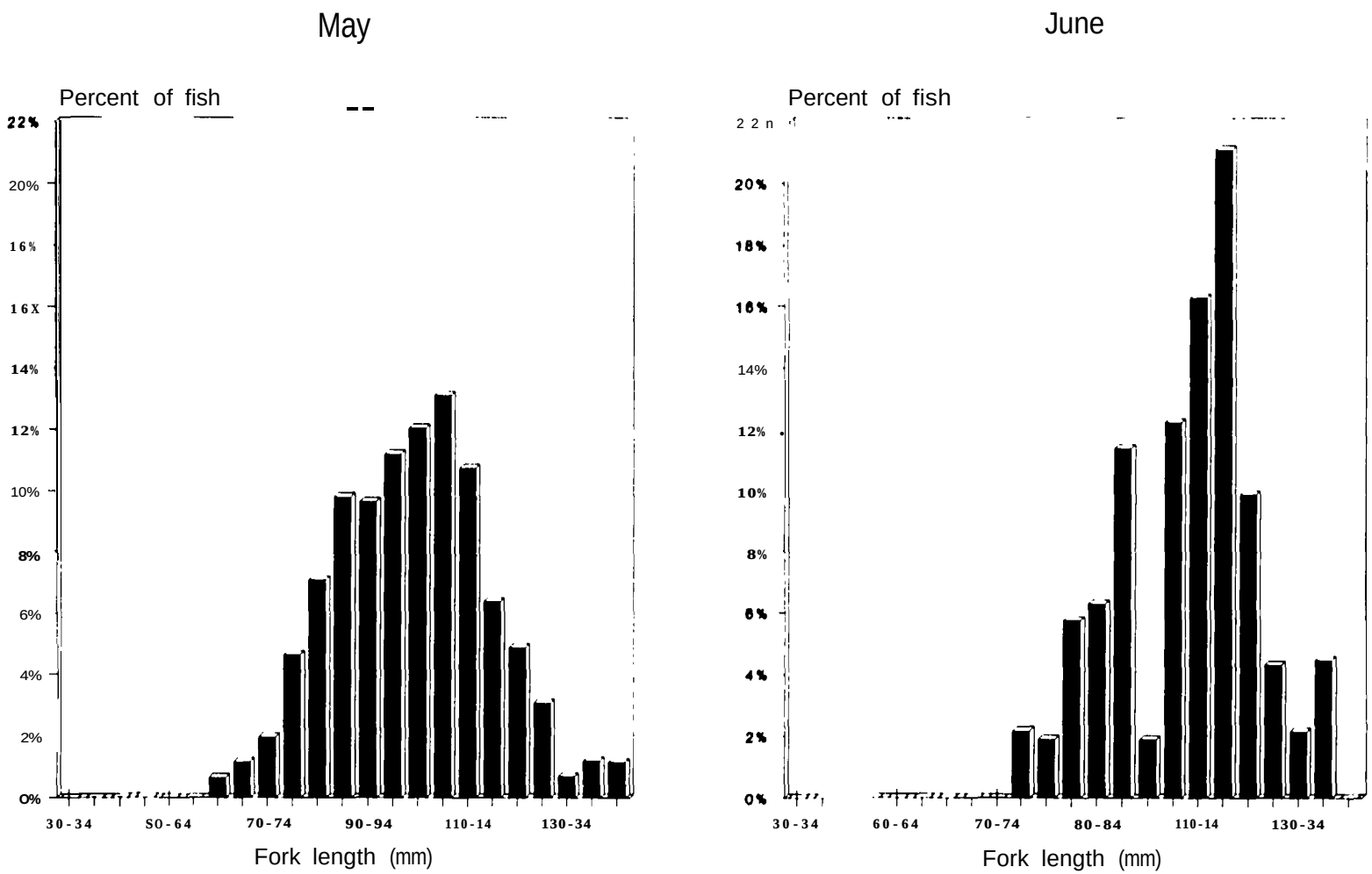


Figure 29. Mean monthly length distribution of juvenile spring chinook at Wapatox in May and June.

Roza Smolt Trap

Methods

See Roza methods sections under "Summer, Fall and Winter Movements," above.

Results

Because the diversion-entrainment relationship has not yet been described at Roza, only a qualitative analysis of the data can be made at this time. A catch summary for operation between April 1, 1989 through August 31, 1989 is presented in Table 28. Total catches from April through August 1989 were 446 spring chinook smolts and 5,581 spring chinook young-of-the-year. Spring chinook smolts were captured from April 1 through May. The mean fork length for spring chinook smolts was 115 mm. Spring chinook fry were first observed April 6, and outmigration continued throughout the summer. Mean fork length was 83 mm in July and 89 mm in August. No length data was collected on fry from April through June.

Table 28. Temporal distriution of spring chinook captured at Roza dam, April through August, 1989.

DATES	Spring Chinook Smolts	Parr	Combined Total	Discharge cfs
01-Apr	25	0	25	309
02-Apr	8	0	8	357
03-Apr	7	0	7	305
04-Apr	9	0	9	264
05-Apr	2	0	2	337
06-Apr	61	197	258	1475
07-Apr	31	325	356	2640
08-Apr	18	379	397	2968
09-Apr	23	1109	1132	2605
10-Apr	29	1032	1061	1943
11-Apr	23	497	520	1698
12-Apr	8	200	208	1805
13-Apr	15	119	134	2057
20-Apr	3	43	46	2722
21-Apr	10	83	93	2864
22-Apr	2	58	60	2604
25-Apr	28	190	218	1504
26-Apr	17	97	114	1314
27-Apr	37	114	151	1235
05-May /a	19	0	19	678
18-May /b	11	116	127	494
25-May /c	22	25	47	644
01-Jun	38	7	45	938
15-Jun	0	60	60	1401
22-Jun	0	429	429	1384
29-Jun	0	120	120	2047
06-Jul	0	202	202	1904
13-Jul	0	30	30	1905
20-Jul	0	18	18	1874
27-Jul	0	36	36	1880
03-Aug	0	10	10	1822
04-Aug	0	44	44	1817
10-Aug	0	15	15	1661
17-Aug	0	16	16	1611
24-Aug	0	8	8	1372
31-Aug	0	2	2	1253
Total	446	5581	6027	

/a Start time was 1100, the 5th, and end time was 1700 the 5th.
/b Start time was 1300 the 18th.
/c Start time was 1730 the 25th, and end time was 0945 the 26th.

Prosser Smolt Trap

Methods

See Prosser methods section under “Summer, Fall and Winter Movements,” above.

Results

The spring outmigration at Prosser Dam for 1983 through 1990 averaged 177,561 spring chinook smolts (Table 29). Spring outmigrations have ranged in size from 92,934 fish in 1989 to 282,514 fish in 1988. Over all years, April outmigrants have comprised 63% of the total (spring) passage. In 1990 nearly 90% of the outmigration passed Prosser in April, while April passage in 1984 was only 4 1.7%. On average, 32% of the spring outmigration has occurred in May, although this figure has ranged from 7.8% in 1990 to 52.4% in 1984. Only about 1.8% and 3.3% of the spring outmigration has occurred in March and June, respectively.

The average median date of passage for 1983 through 1990 is April 25. As illustrated in Figures 30-39 and summarized in Table **30,** the median passage date has ranged from April 16 in 1990 to May 4 in 1984. The middle 80% (10% - 90%) of the outmigration has passed Prosser over an average period of 39 days, and has spanned the period from April 8 to May 17 over all years. The most compressed outmigration had an “80% passage interval” of 28 days, while the 80% passage interval lasted 51 days for the most dispersed outmigration.

Table 29. Estimated number of wild spring chinook smolts migrating Fast Prosser Dam from March 1 through June 30 in the years 1983 through 1990 (brood years 1981-1988).

YEAR OF OUTMIGRATION	MARCH	APRIL	MAY	JUNE	TOTAL
1983	4,030	112.044	48,217	2,786	167,077
1984	3,153	59,812	75,148	5.218	143,331
1985	447	52,617	37,593	5,756	96,413
1986	3,341	106,154	63,115		180,789
1987	13,376	195,866	41,162	4,090	254,494
1988	1,463	159.104	118,047	3,900	282,514
1989	3,949	51,368		5,296	92,935
1990	2,081	180,403	17,110	3,338	202,932

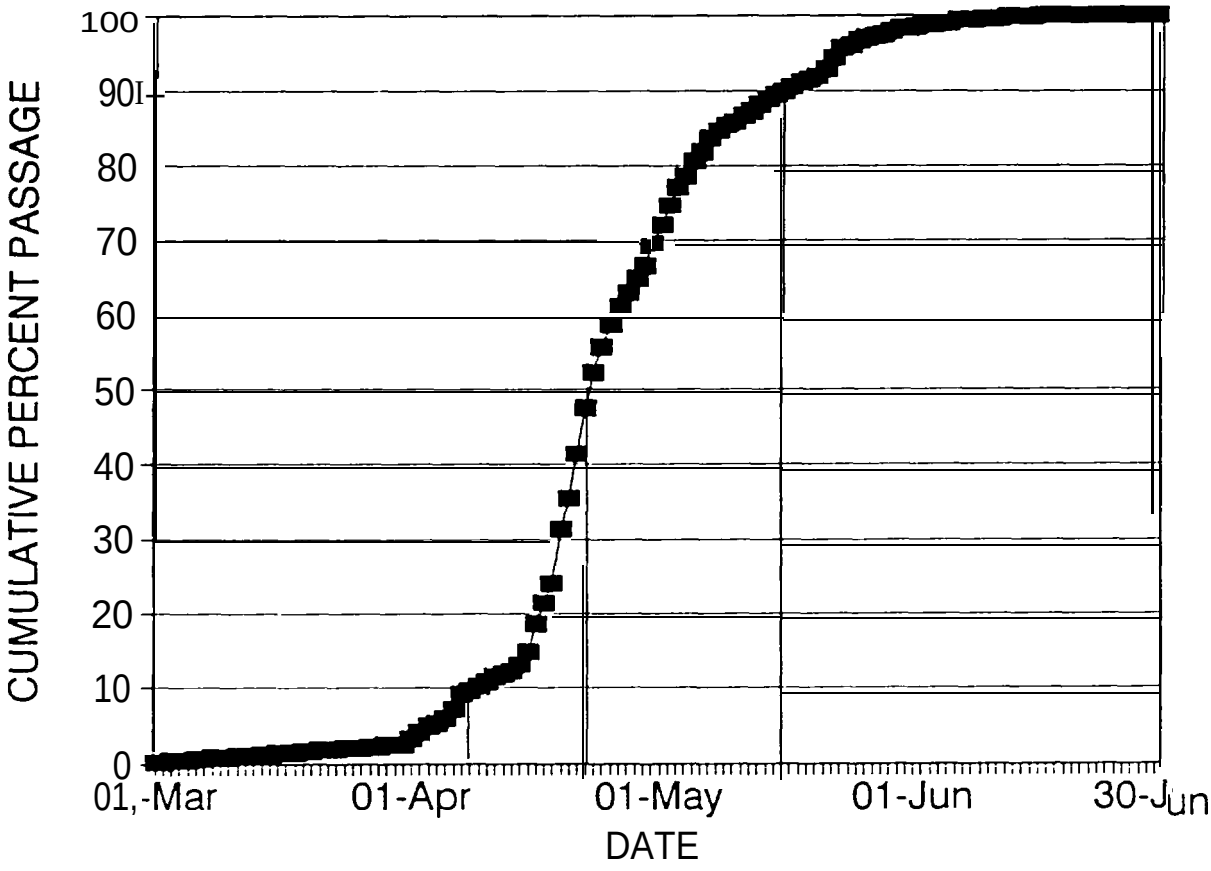


Figure 30. Cumulative passage, wild spring chinook, Prosser Dam, 1983.

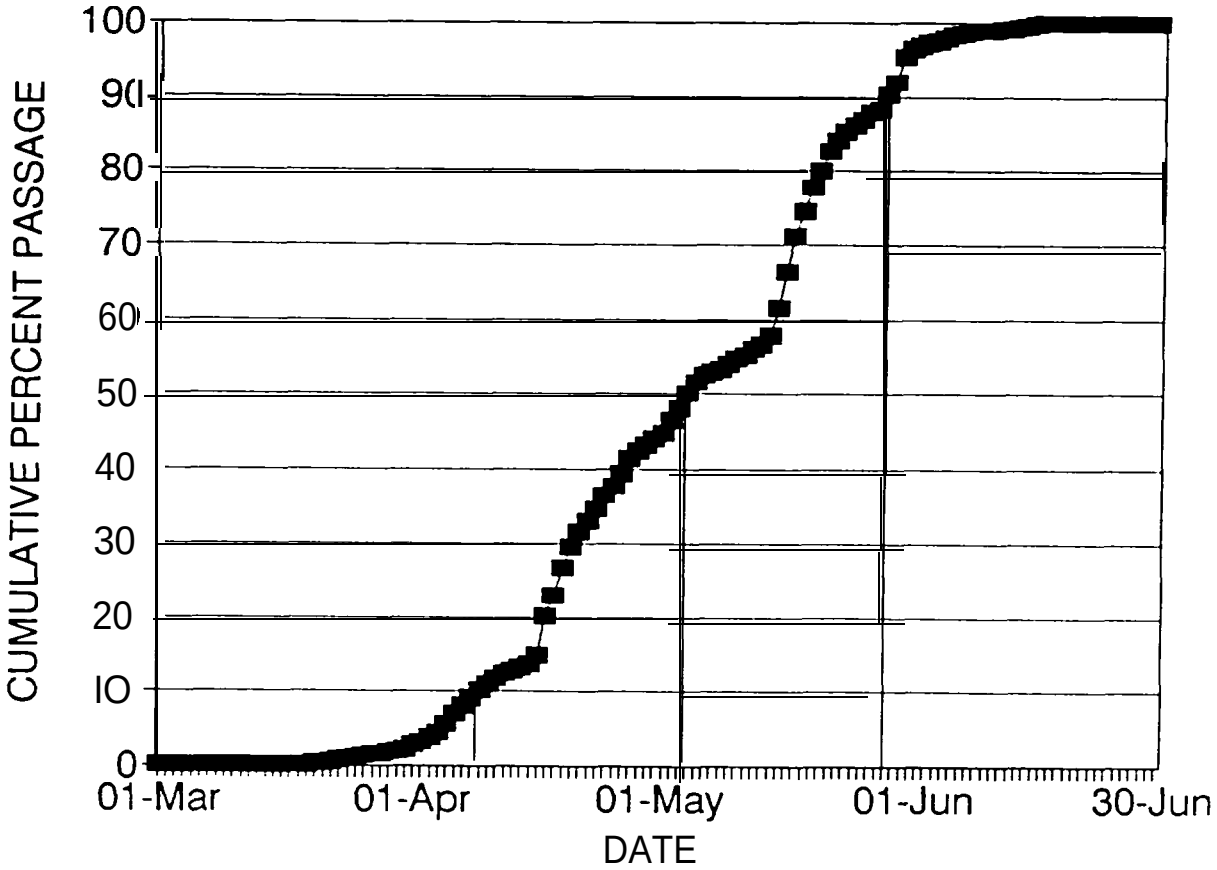


Figure 31. Cumulative passage, wild spring chinook, Prosser Dam, 1984.

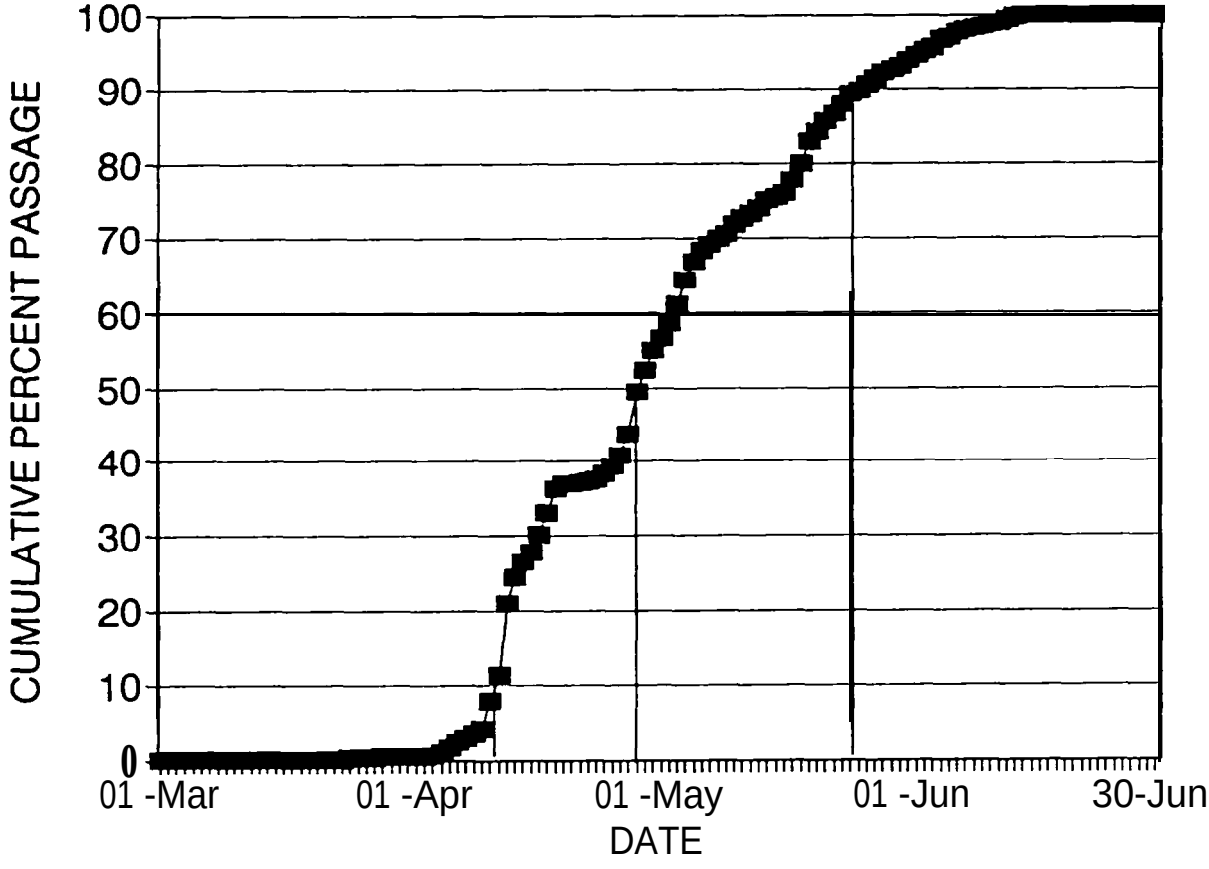


Figure 32. Cumulative passage, wild spring chinook, Prosser Dam, 1985.

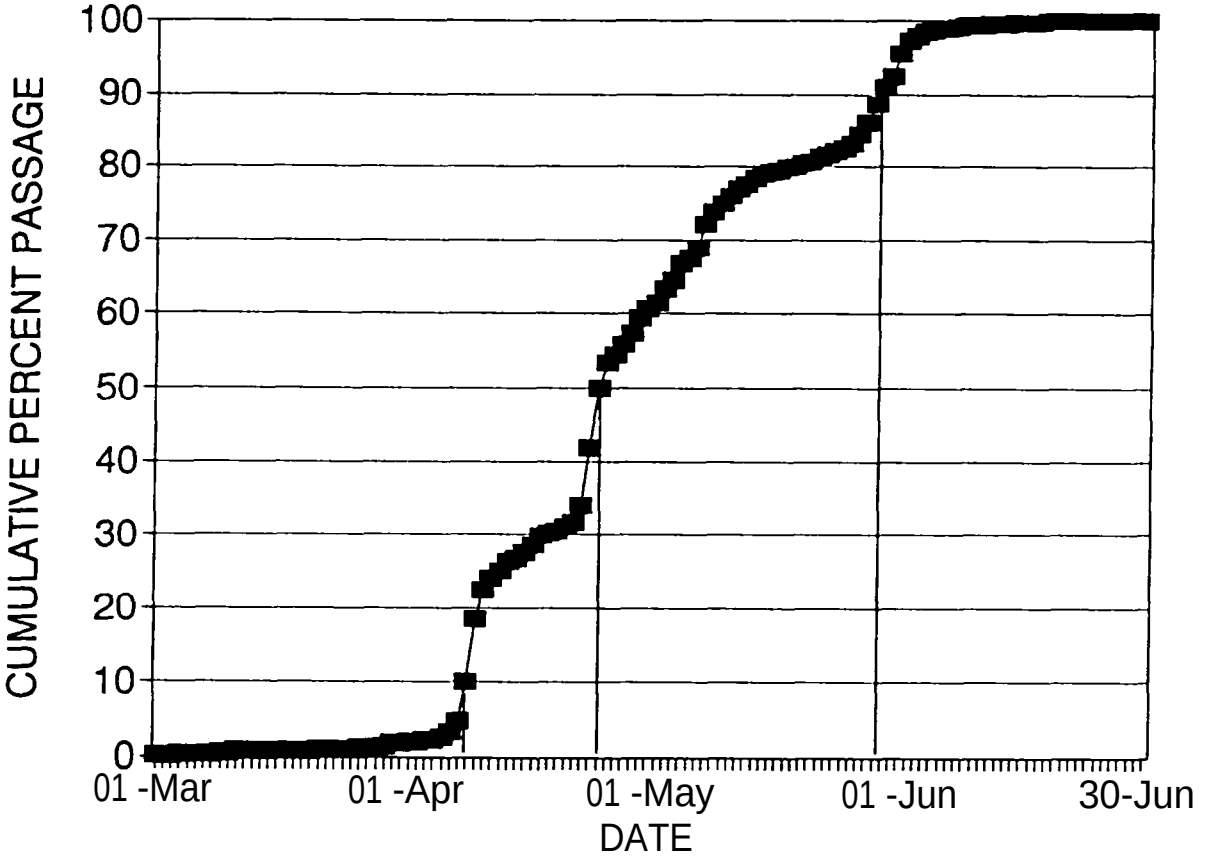


Figure 33. Cumulative passage, wild spring chinook, Prosser Dam, 1986.

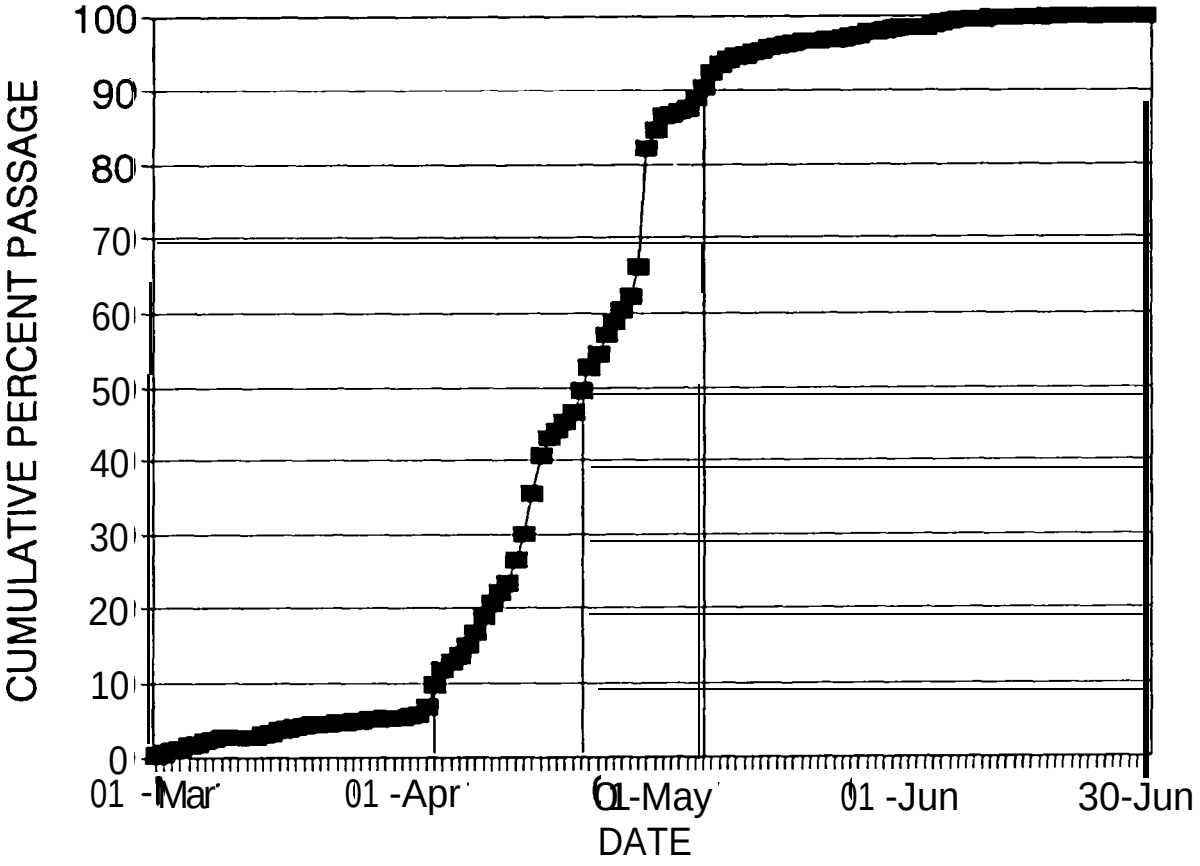


Figure 34. Cumulative passage, wild spring chinook, Prosser Dam, 1987.

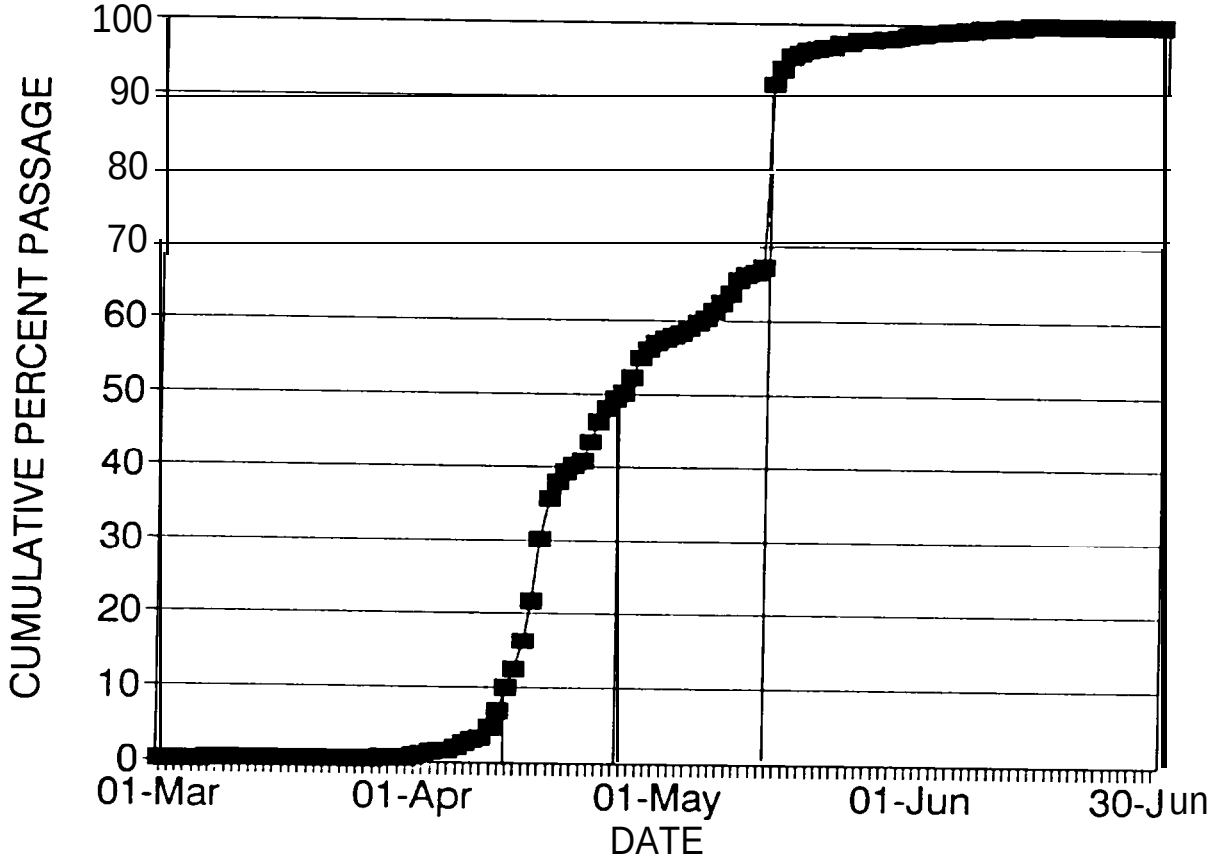


Figure 35. Cumulative passage, wild spring chinook, Prosser Dam, 1988.

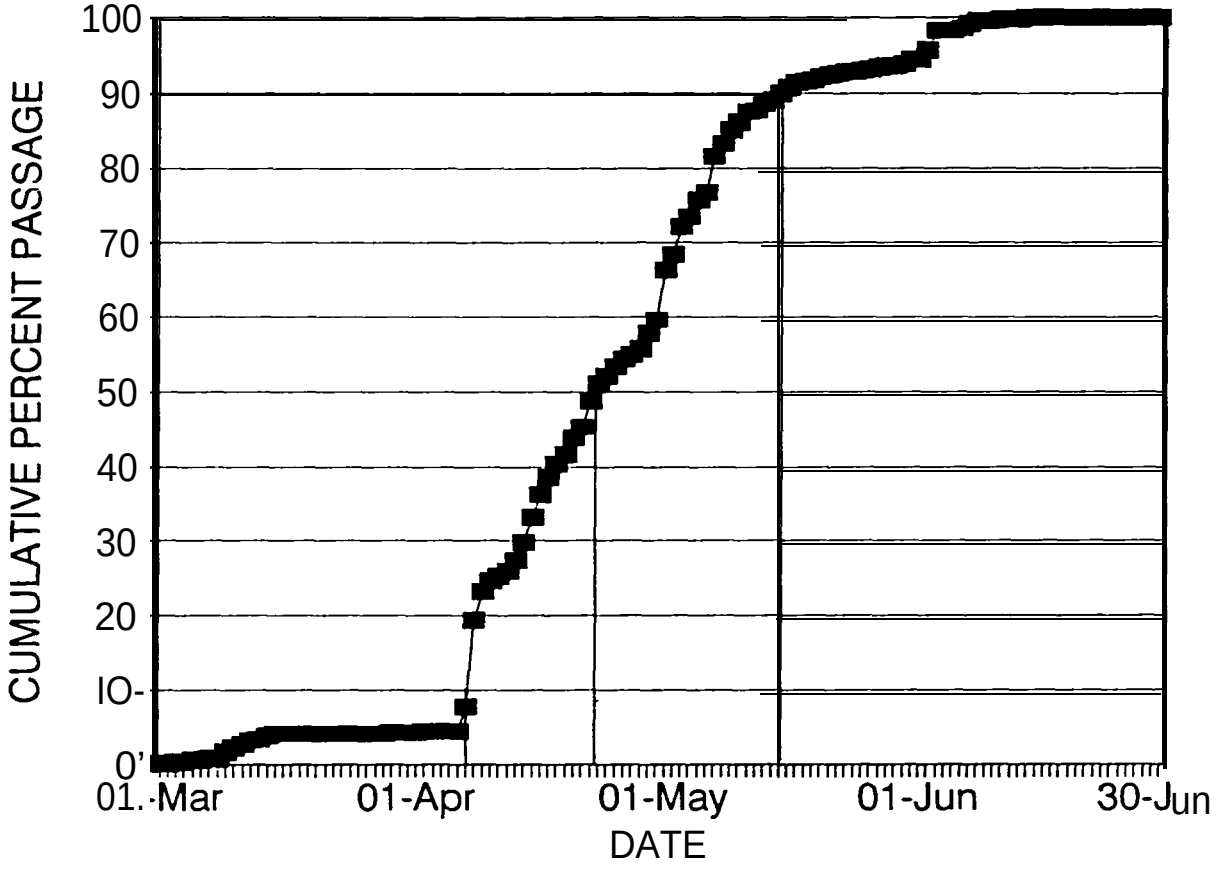


Figure 36. Cumulative passage , wild spring chinook, Prosser Dam, 1989.

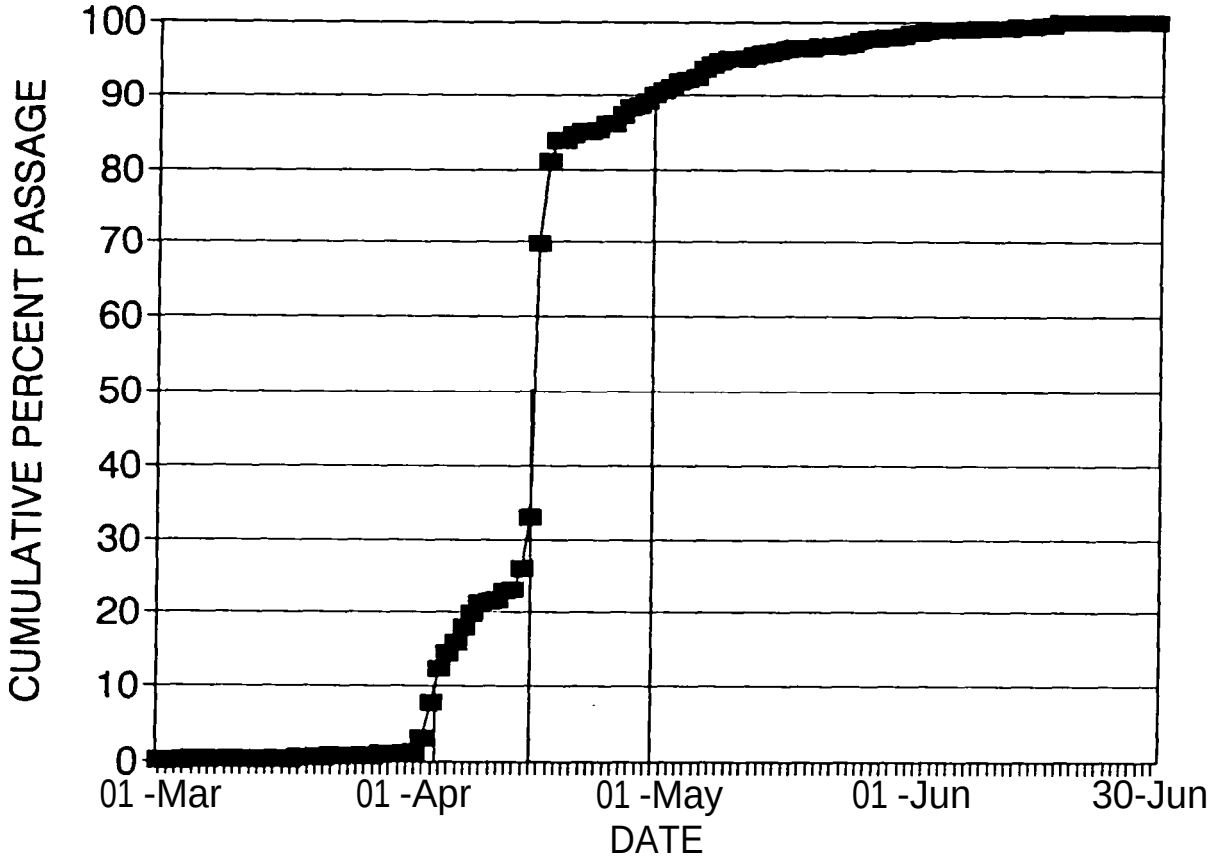


Figure 37. Cumulative passage, wild spring chinook, Prosser Dam, 1990.

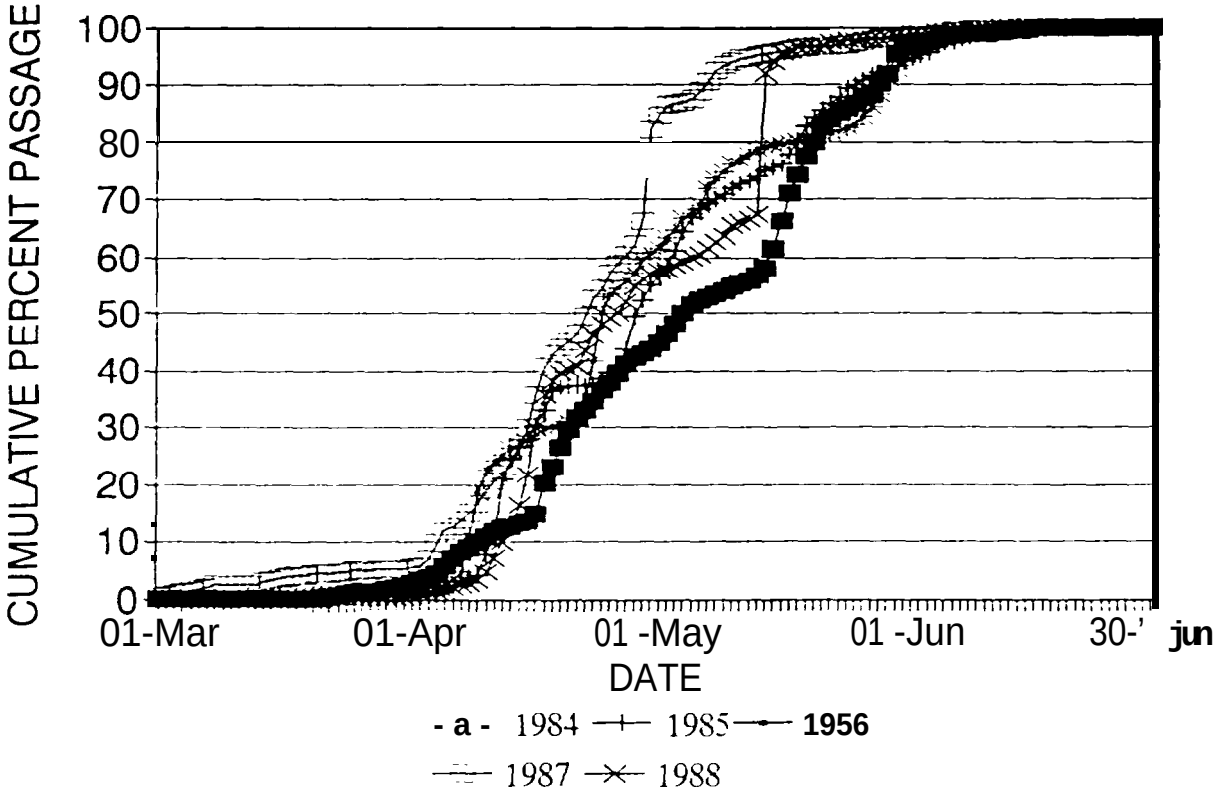


Figure 38. Passage of wild spring chinook smolts at Prosser Dam, 1984 through 1988L'median flow" below Sunnyside Dam < 3,000 cfs.

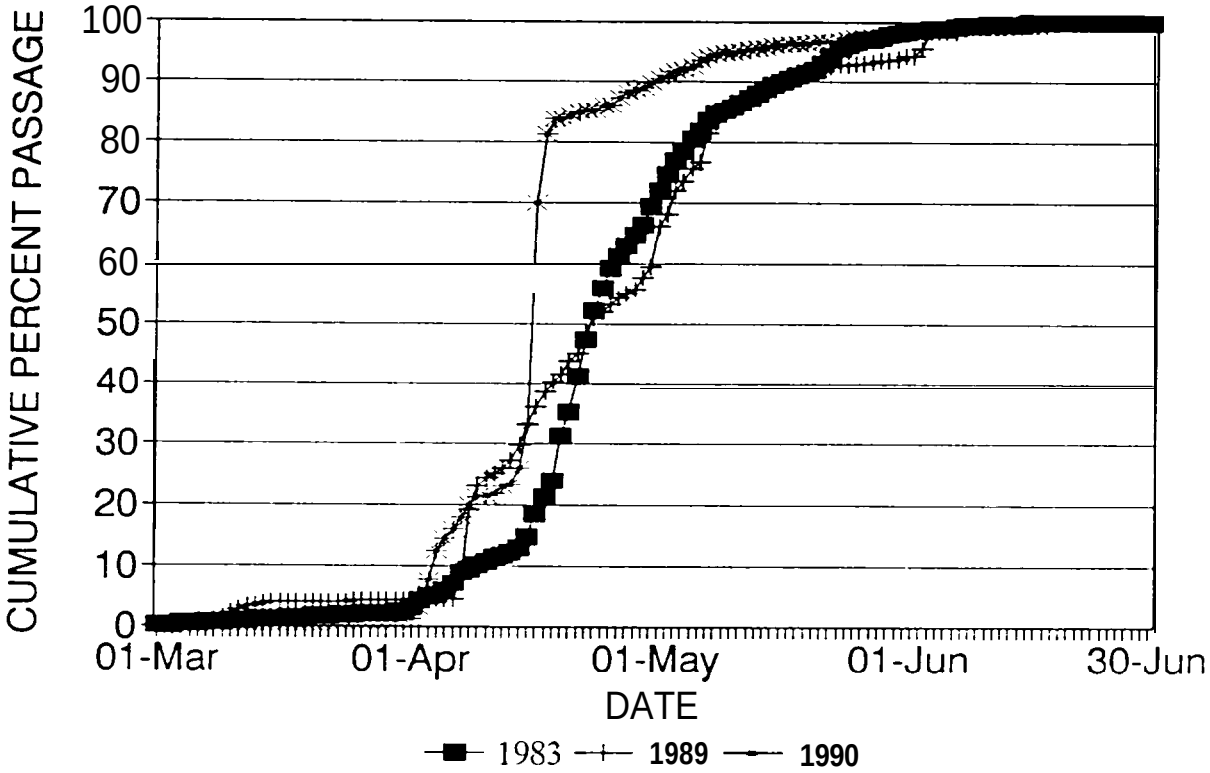


Figure 39. Passage of wild spring chinook smolts at Prosser Dam, 1983, 1989 and 1990...“median flow” below Sunnyside Dam > 3,000 cfs.

Table 30. Outmigration timing at Prosser, 1983-1990: date-s of 10%. 50% and 90% cumulative passage and the number of days separating dates of 10% and 90% cumulative passage ("80% passage interval').

YEAR	DATE OF 10% CUMULATIVE PASSAGE	DATE OF 50% CUMULATIVE PASSAGE	DATE OF 90% CUMULATIVE PASSAGE	80% PASSAGE INTERVAL (days)
1983	419	4/23	5/16	37
1984	4/9	5/4	5/28	49
1985	4/11	4/29	5/26	45
1986	4/9	4/25	5/29	50
1987	4/5	4/23	5/7	32
1988	4/12	4/26	5/14	32
1989	4/8	4/23	5/16	38
1990	4/4	3/16	5/l	27
Average	4/8	4/25	5/17	39

Outmigration normally escalates sharply after the first seven to 10 days of April. The second week of April seems to define a threshold of sorts, in that outmigration prior to this time is unresponsive to conditions that elicit large responses in late April and May. Specifically, from about the second week of April through May and early June, passage is strongly influenced by fluctuations in river flow (Figures 40-47a). One may suppose that smoltification and the behavioral predisposition to migrate do not reach full expression until early April, but that even fully smolted fish still require an ascending hydrograph before migrating in large numbers. After the early April threshold, small increases in flow above Prosser and (especially) below Sunnyside Dam are usually associated with disproportionately large increases in passage. This response is never seen in March when, presumably, fish have not yet completed smoltification, and is rarely seen in June, presumably because most spring chinook have already left the system. Flow-induced stimulation of passage is especially pronounced when it occurs on the heels of a number of days of declining flows. Interestingly, the peak of the migratory response to increased flows usually occurs before the discharge peak.

Inspection of daily passage and flow data has revealed that consecutive days of declining, or even stable, flows are usually associated with declining outmigration rates. It should be noted that descending flows stall passage, even when absolute discharge during the decline remains relatively high. During such periods, smolts accumulate somewhere between Sunnyside and Prosser dams, and are subject to longer periods of vulnerability to predators.

Stalled migrations are stimulated by rapid increases in flow. The increase need not be especially large, but should be abrupt; gradual increases do not evoke a sharp response in passage. An analysis of natural flow pulses gauged below Sunnyside Dam indicates the "minimal stimulator-y pulse" should be about 20% of the pre-pulse "base flow," and that the pulse should occur over no more than two days.

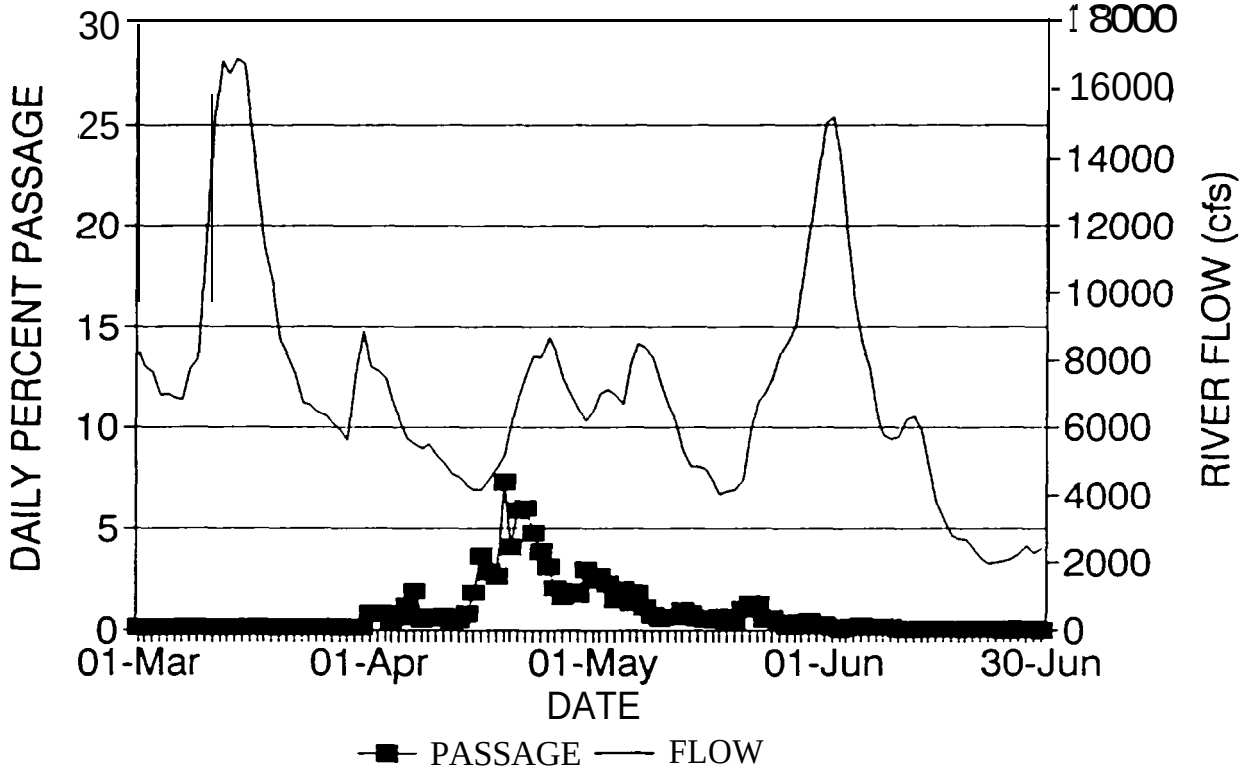


Figure 40. Daily passage of wild spring chinook smolts at Prosser Dam and daily mean flows at P rosser Dam, 1983.

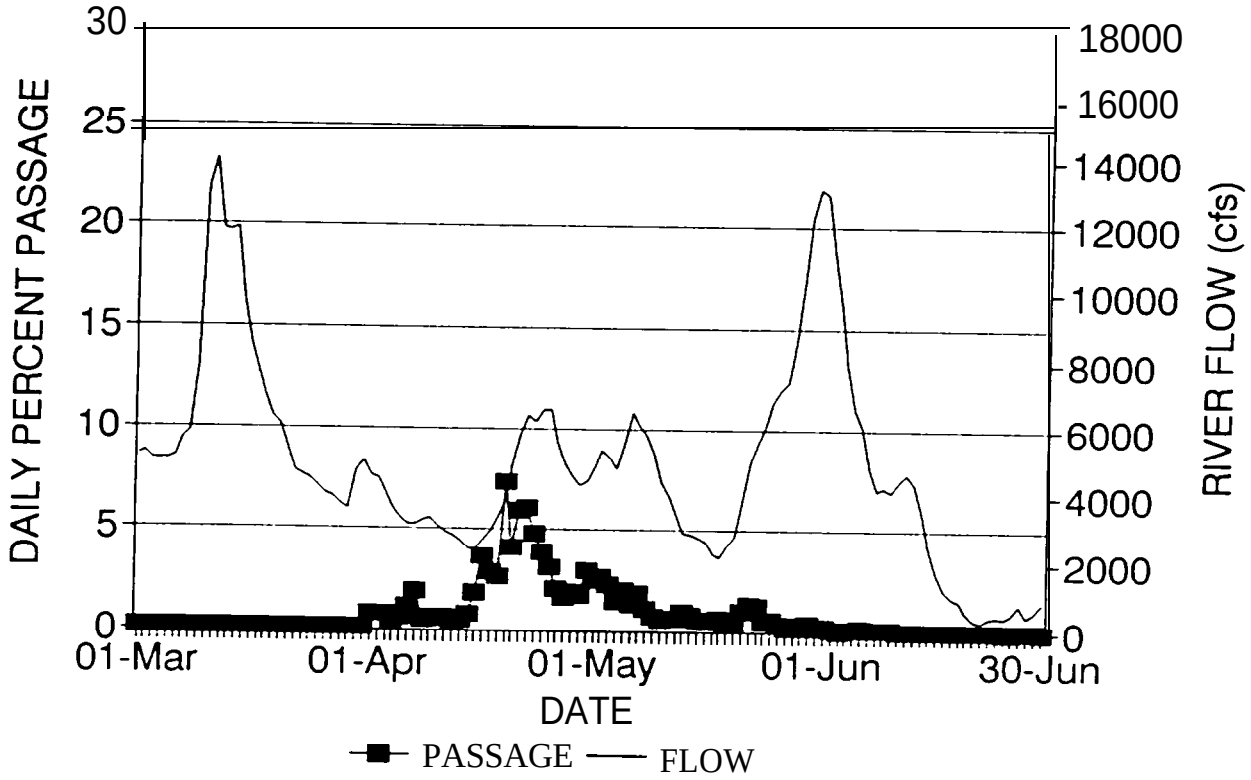


Figure 40a. Daily passage of wild spring chinook smolts at Prosser Dam and daily mean flows at Sunnyside Dam, 1983.

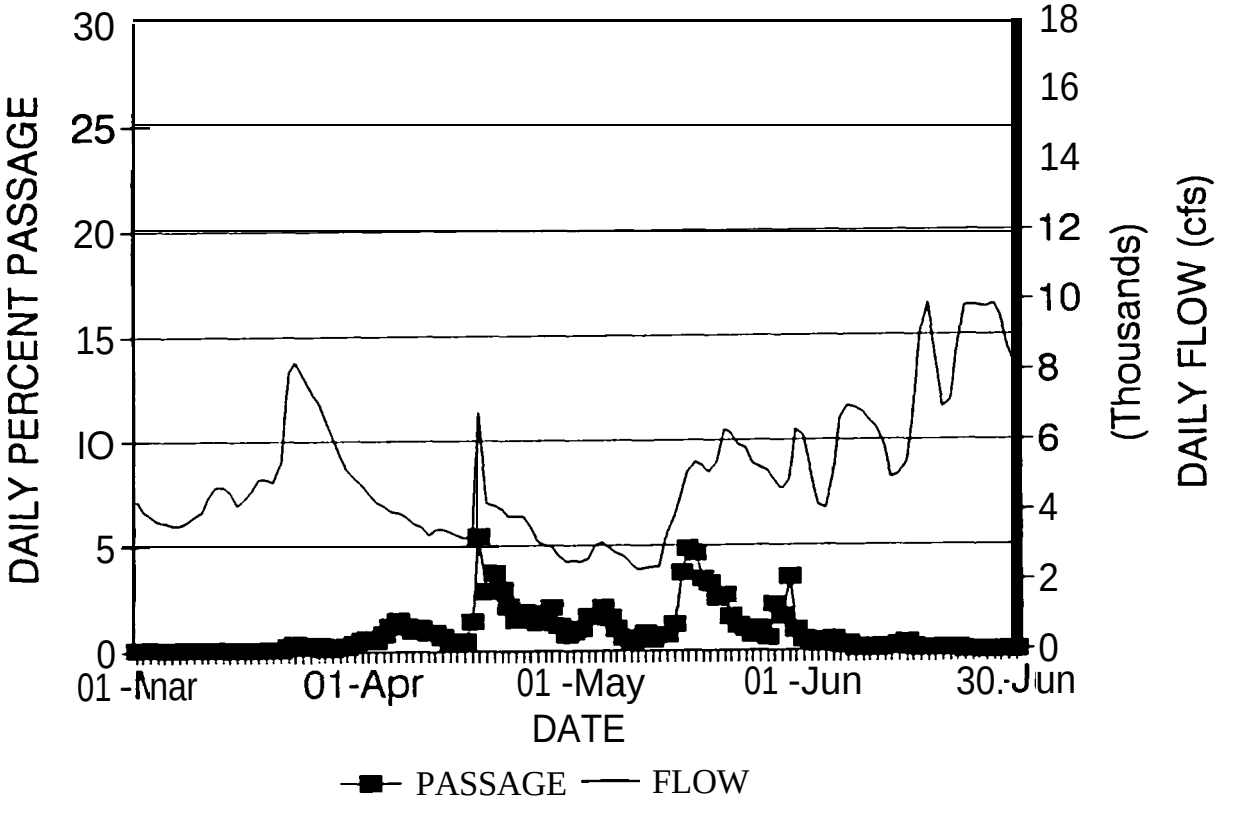


Figure 41. Daily passage of wild spring chinook smolts at Prosser Dam and daily mean flows at Prosser Dam, 1984.

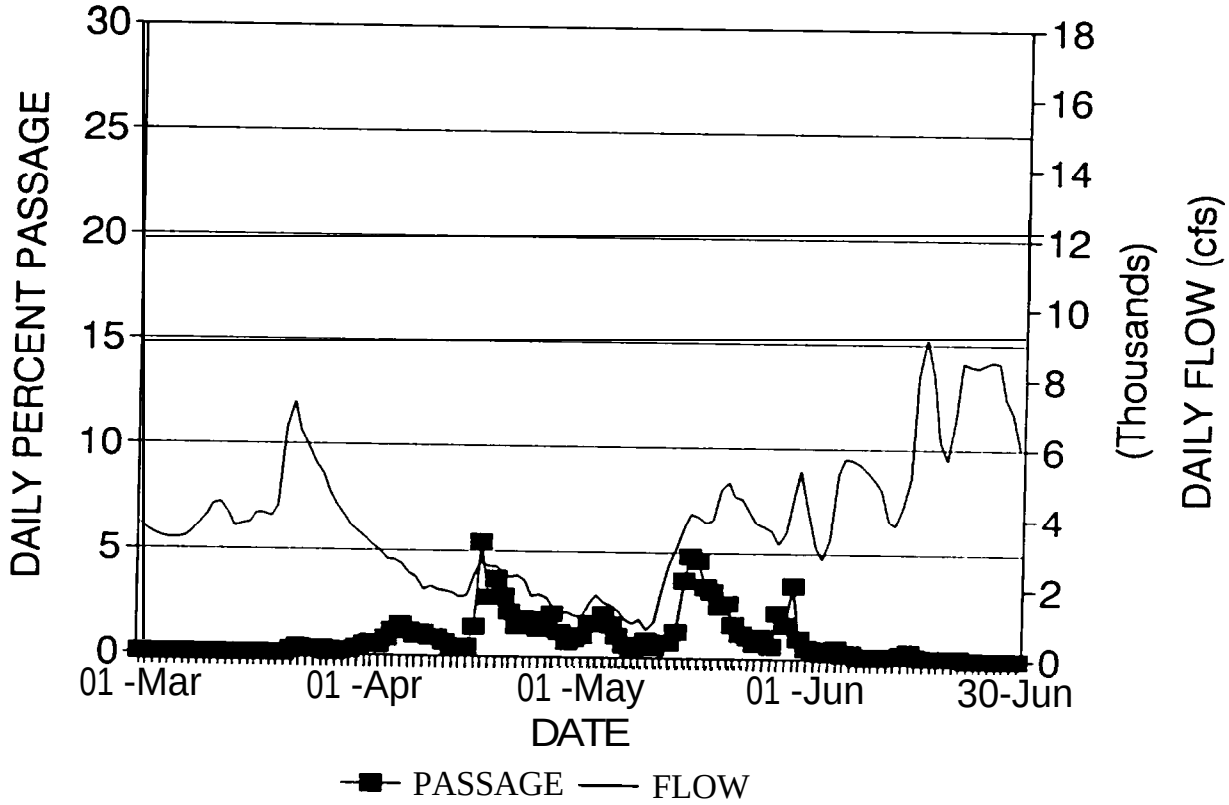


Figure 41 a. Daily passage of wild spring chinook smolts at Prosser Dam and daily mean flows at Sunnyside Dam, 1984.

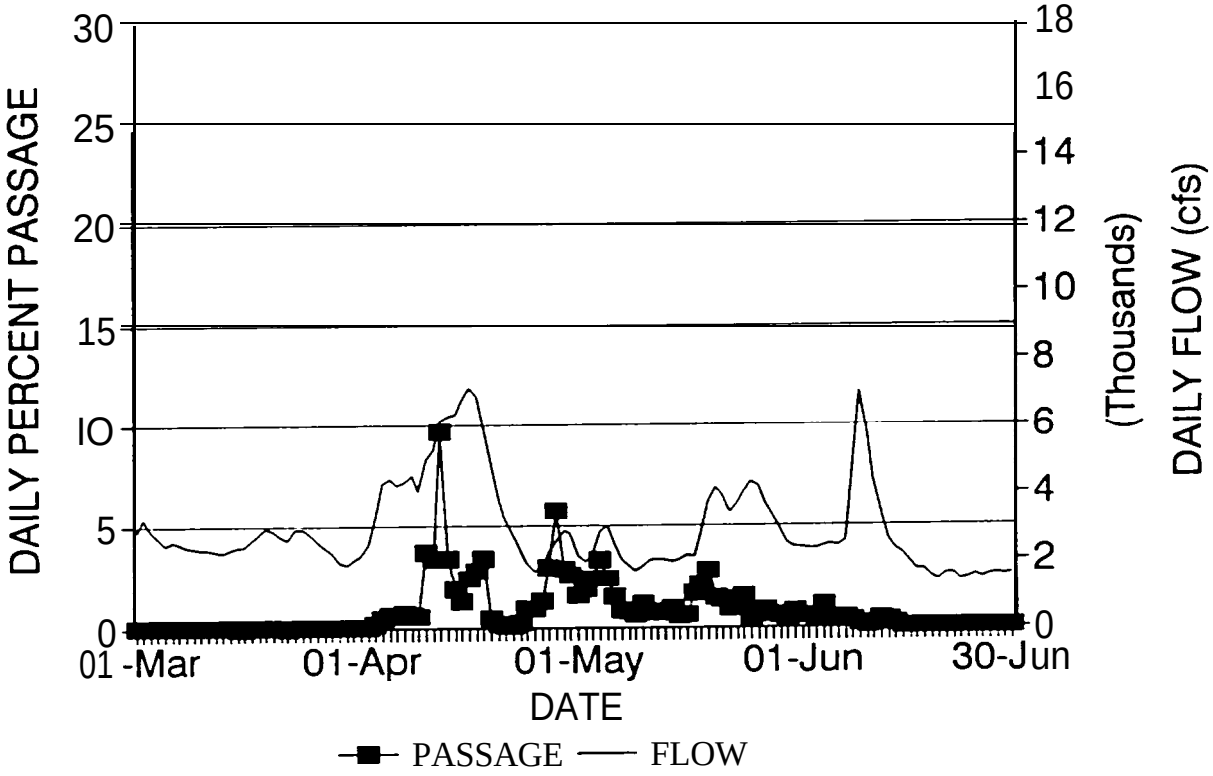


Figure 42. Daily passage of wild spring chinook smolts at Prosser Dam and daily mean flows at Prosser Dam, 1985.

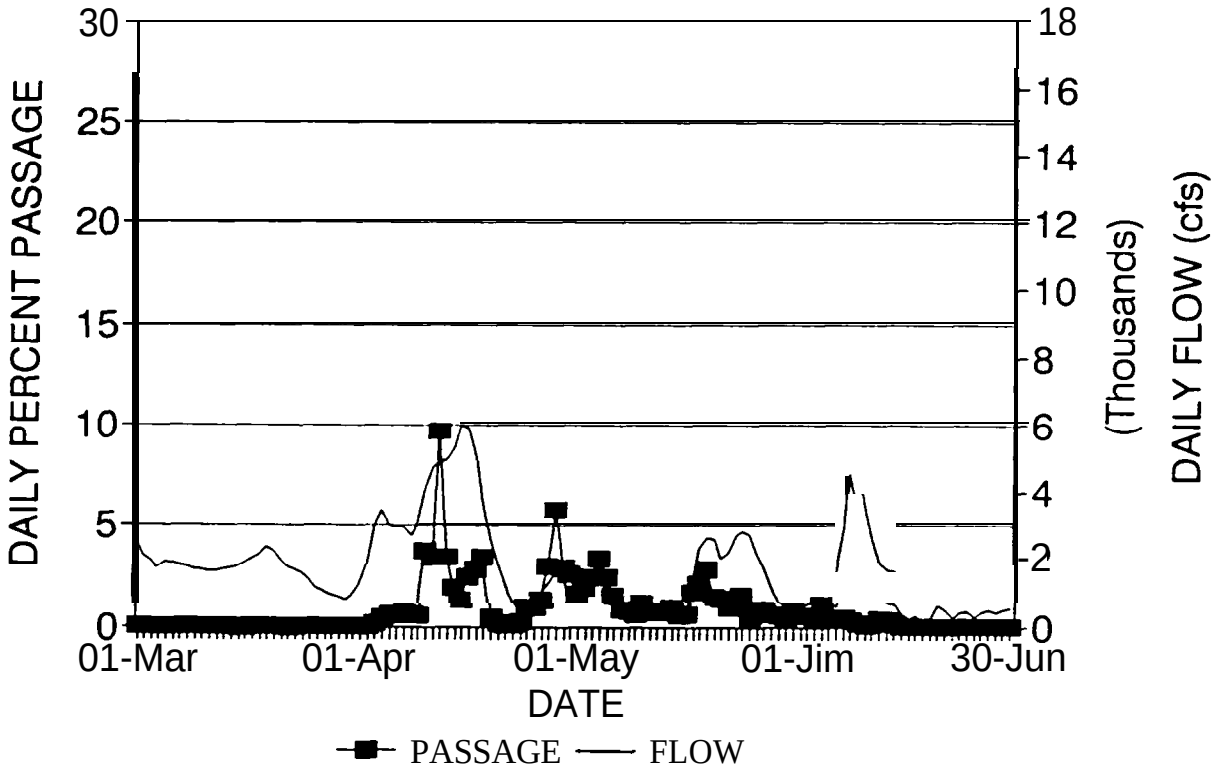


Figure 42a. Daily passage of wild spring chinook smolts at Prosser Dam and daily mean flows at Sunnyside Dam, 1985.

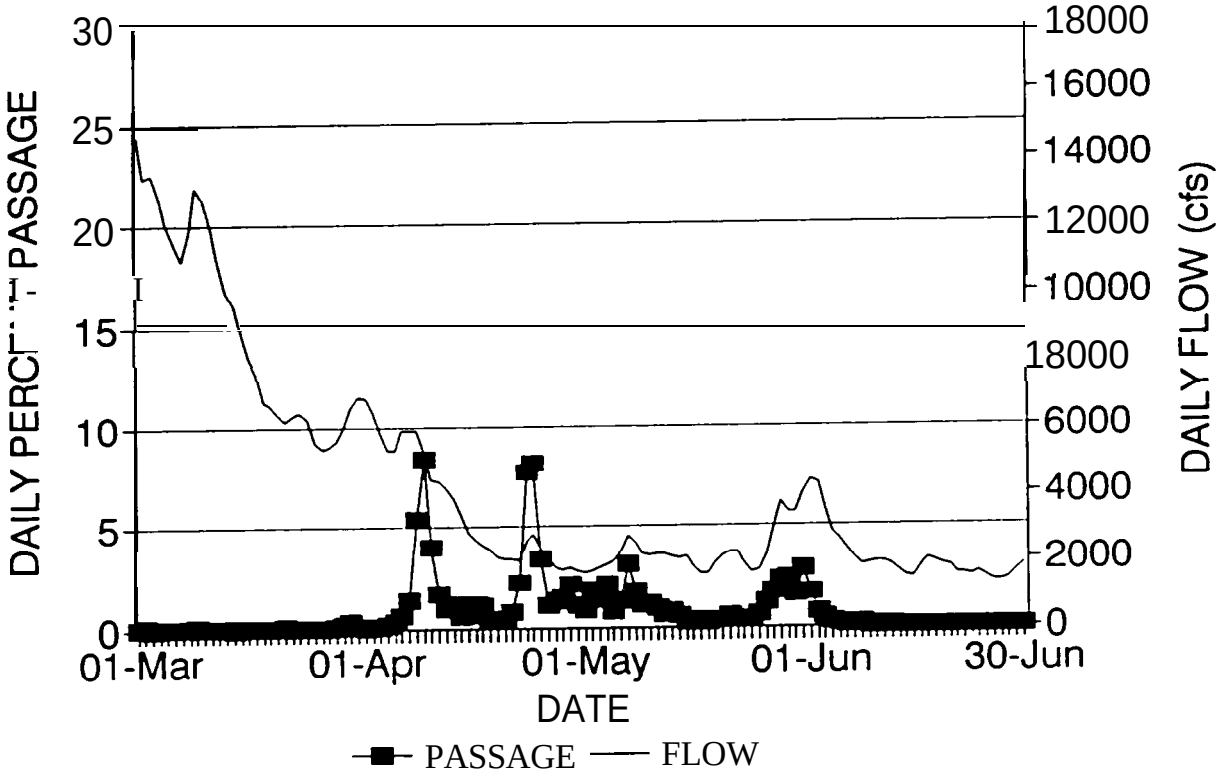


Figure 43. Daily passage of wild spring chinook smolts at Prosser Dam and daily mean flow at Prosser Dam, 1986.

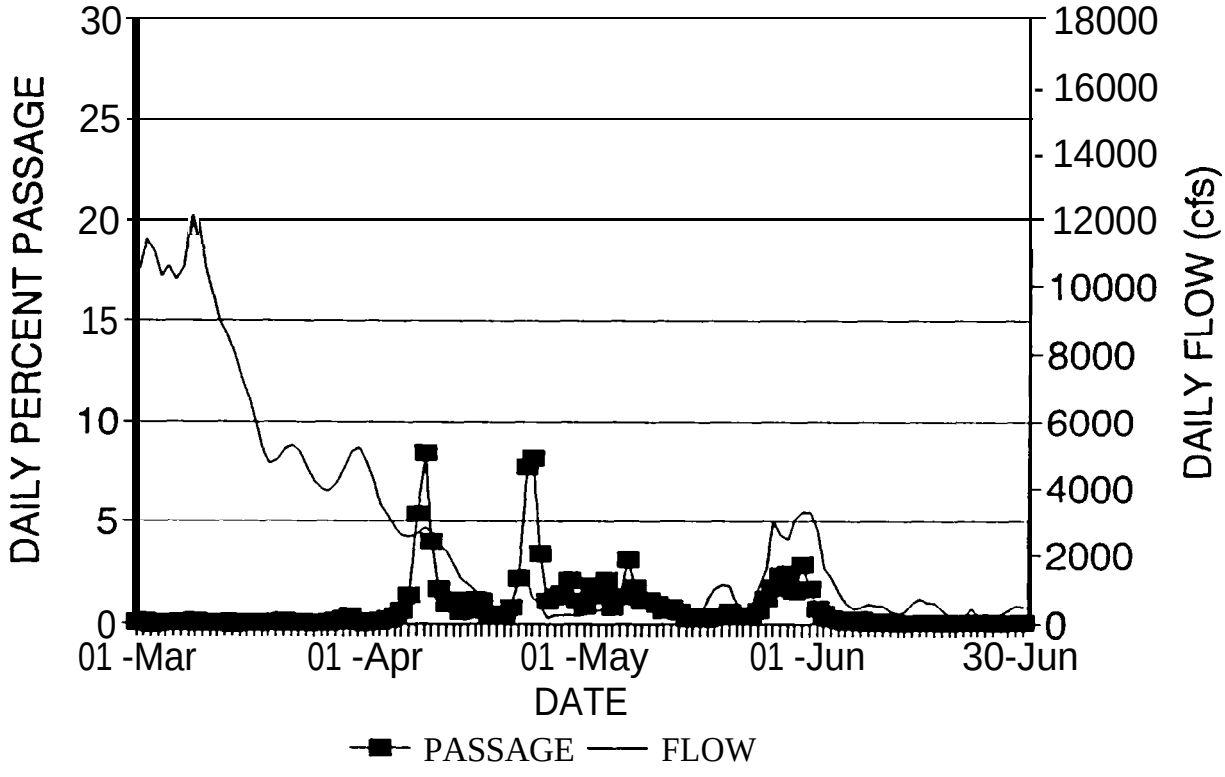


Figure 43a. Daily passage of wild spring chinook smolts at Prosser Dam and daily mean flows at Sunnyside Dam, 1986.

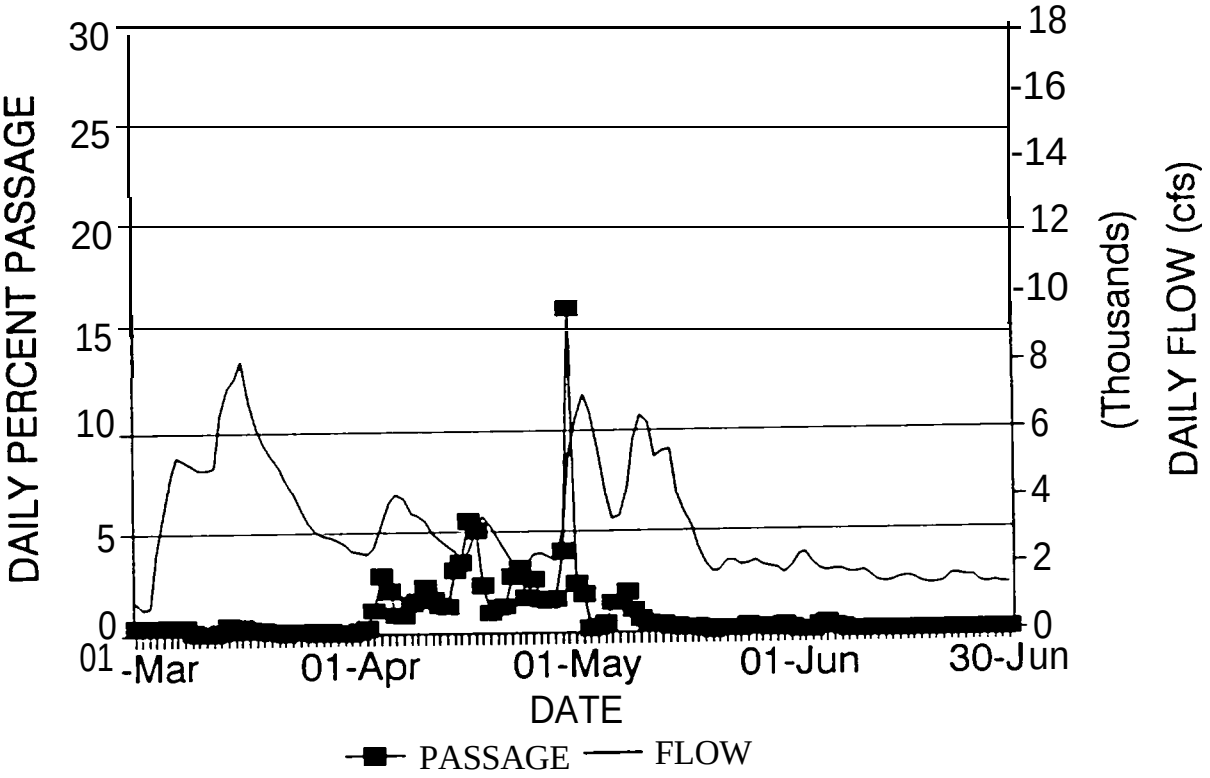


Figure 44. Daily passage of wild spring chinook smolts at Prosser Dam and daily mean flows at Prosser Dam, 1987.

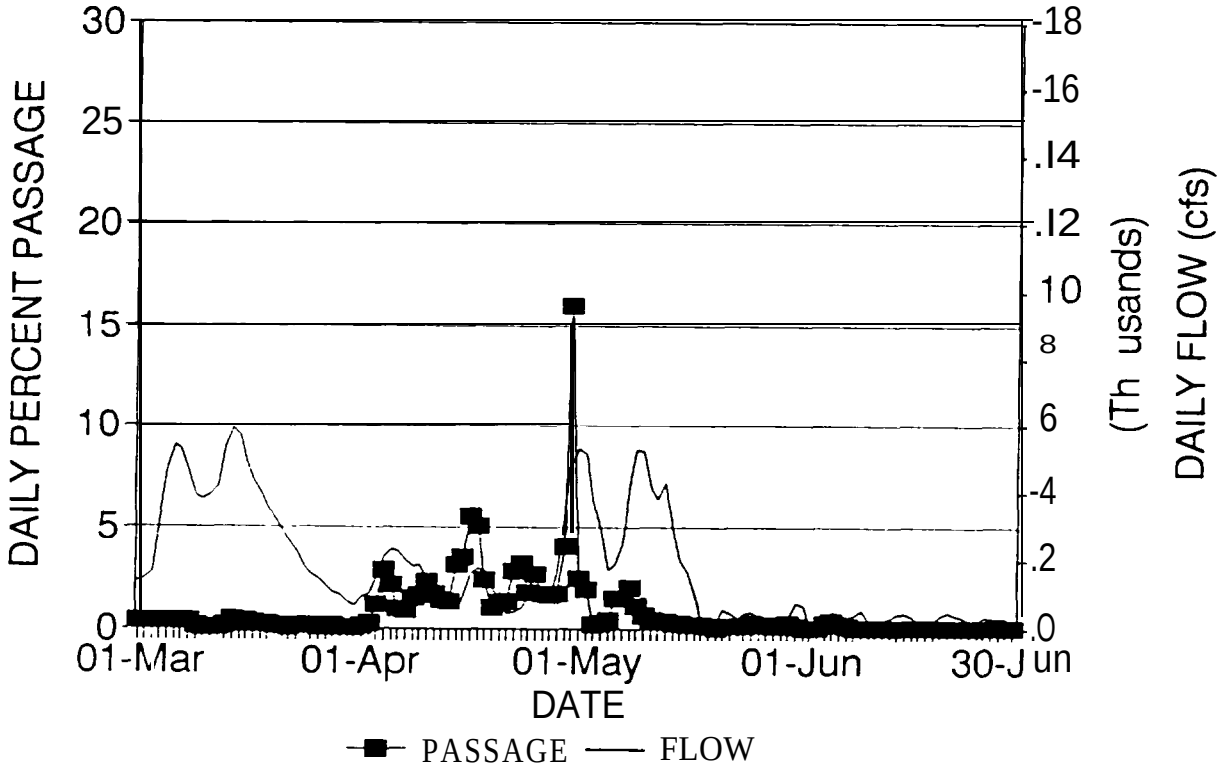


Figure 44a. Daily passage of wild spring chinook smolts at Prosser Dam and daily mean flows at Sunnyside Dam, 1987.

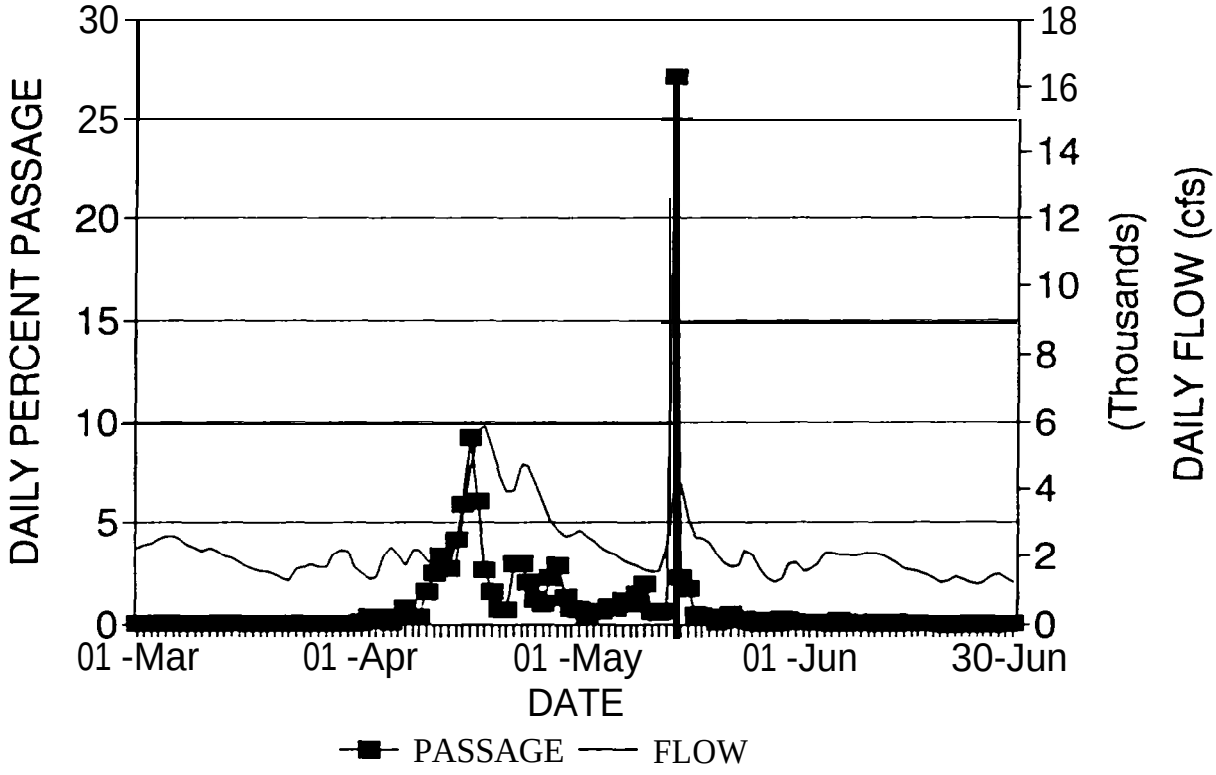


Figure 45. Daily passage of wild spring chinook smolts at Prosser Dam and daily mean flows at Prosser Dam, 1988.

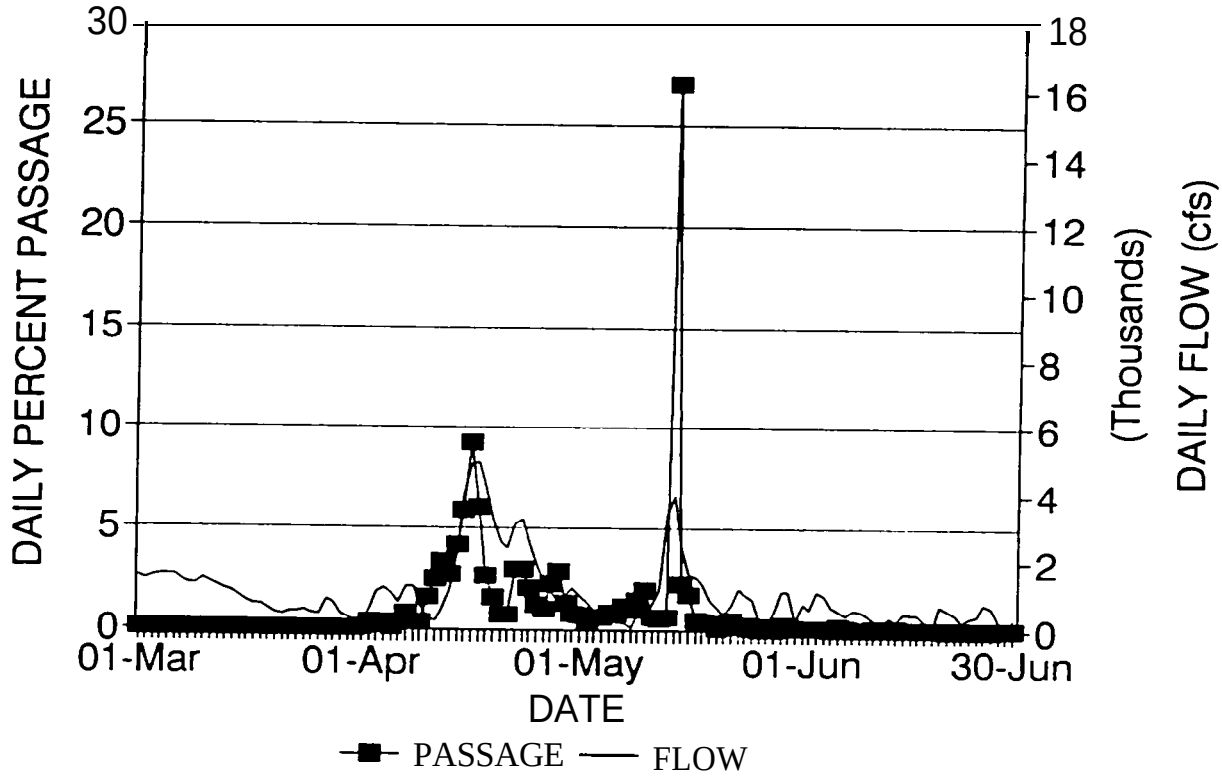


Figure 45a. Daily passage of wild spring chinook smolts at Prosser Dam and daily mean flows at Sunnyside Dam, 1988.

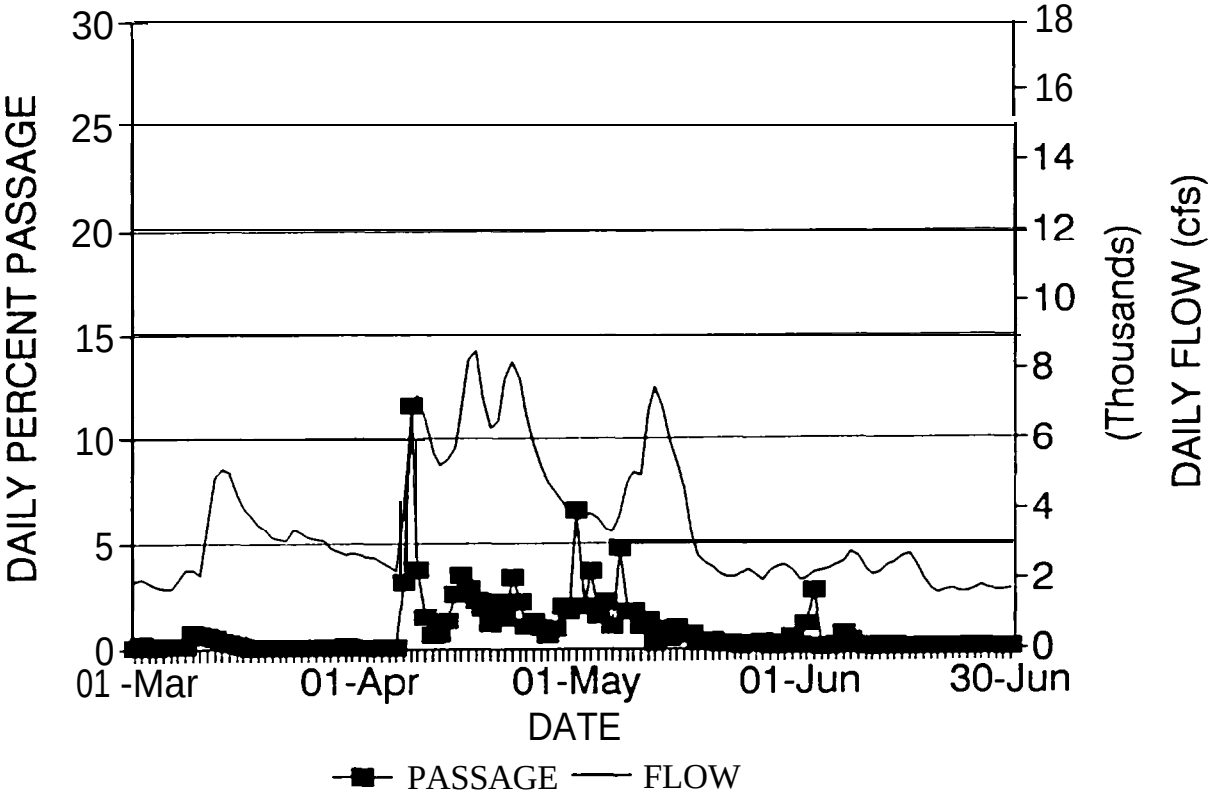


Figure 46. Daily passage of wild spring chinook smolts at Prosser Dam and daily mean flows at Prosser Dam, 1989.

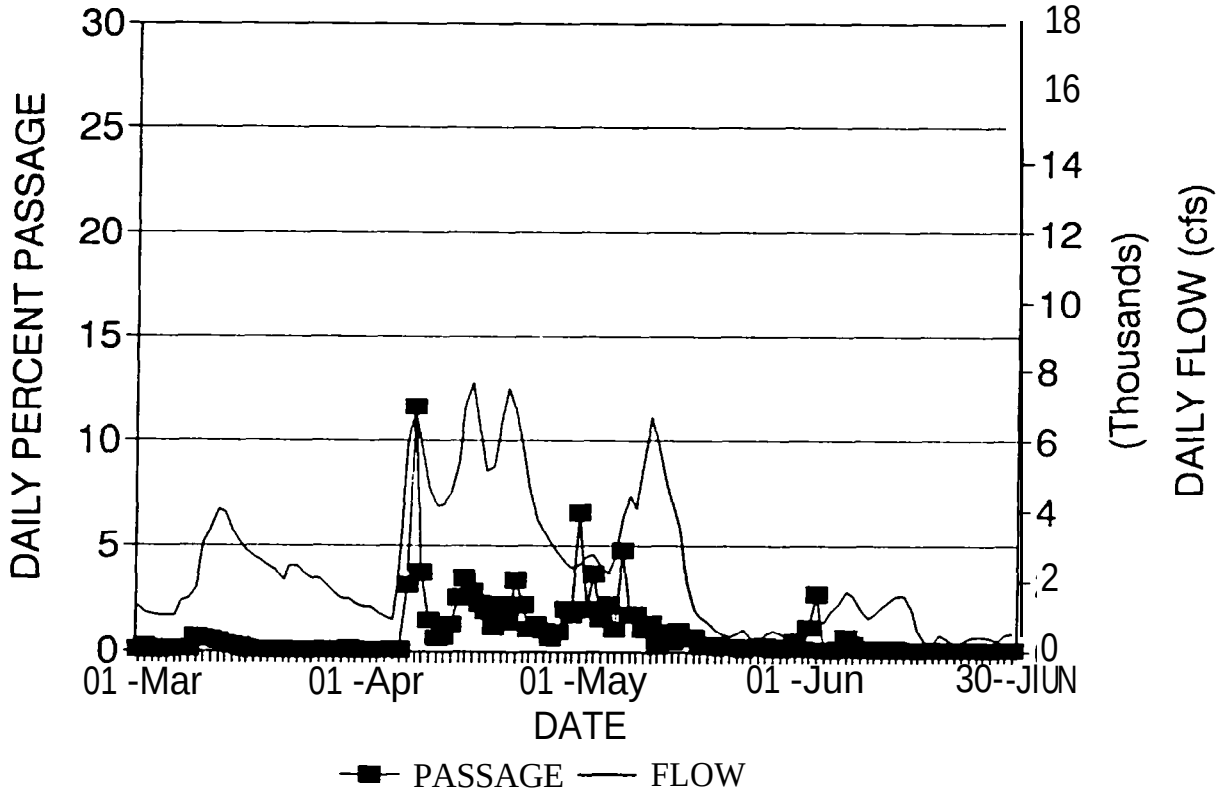


Figure 46a. Daily passage of wild spring chinook smolts at Prosser Dam and daily mean flows at Sunnyside Dam, 1989.

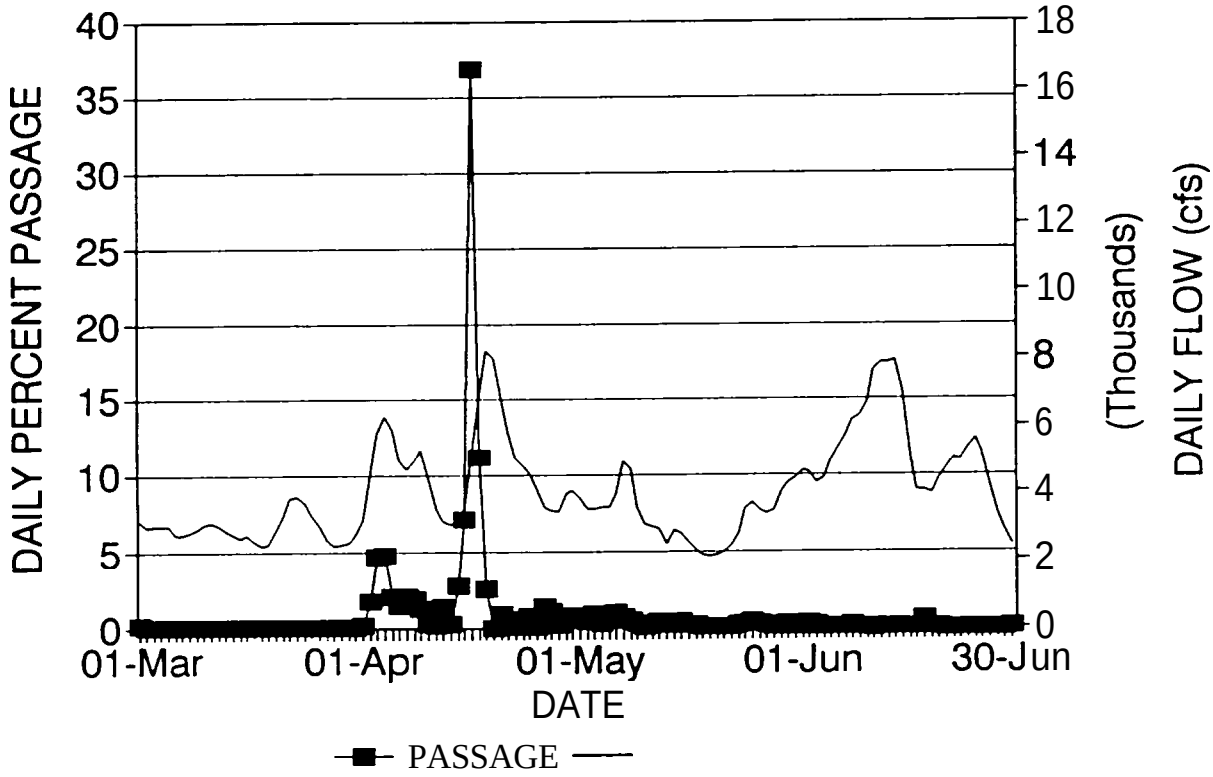


Figure 47. Daily passage of wild spring chinook smolts at Prosser Dam and daily mean flows at Prosser Dam, 1990.

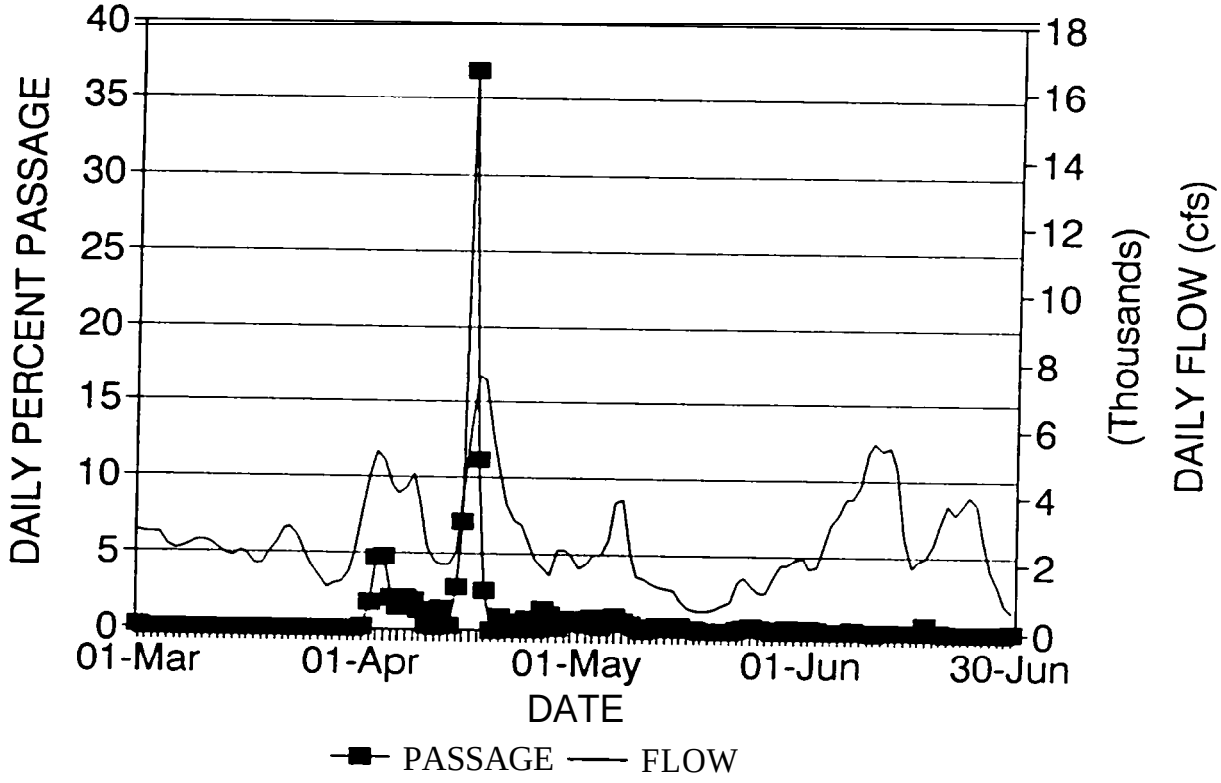


Figure 47a. Daily passage of wild spring chinook smolts at Prosser Dam and daily mean flows at Sunnyside Dam, 1990.

The importance of discharge to outmigration was illustrated in 1985 when the smolt run "stalled" during a prolonged period of low and declining river flows. Beginning April 16, discharge in the Yakima River at Prosser began a steady, nine-day decline, from approximately 1,800 cfs on April 16 to 1,000 cfs on April 24. During this period, daily estimates of outmigrating spring chinook fell precipitously, from a high of 4,041 fish on April 18 to a low of 120 fish on April 24. In response to a request from Yakima Indian Nation biologists, the Bureau of Reclamation released 1,350 cfs supplemental flow for three days (beginning April 25) and a reduced amount for two additional days. The spill reached Prosser on April 26 and crested on April 29. During the surge in discharge, the estimated number of wild chinook outmigrants increased nearly fivefold, from 998 fish on April 25 to 4,850 fish on April 28 (Figs. 48a and 48b). The number of hatchery chinook outmigrants during this time increased more than sixfold, from 440 to 2,834 fish.

As seen in Figures 40-47a, a number of "spikes" of passage can usually be observed each year. These spikes are normally the result of a sudden (although not necessarily large) increase in flow following a period of declining flow. An extreme spike occurred in 1988, when the river rose after an 18-day period of declining discharge. Discharge had dropped from 4,747 cfs on April 23 to 1,544 cfs on May 11. Flows remained relatively constant on hlay 12 and then increased to 2,518 cfs on May 14. Over the three-day period ending May 13, spring chinook passage averaged 1,613 fish per day. On May 14, however, passage increased suddenly and dramatically. On this single day, a total of 69,416 spring chinook smolts (25% of the entire outmigration), and 338,905 hatchery coho (*Oncorhynchus* kislcrch; 64.1% of the total outmigration) were estimated to have passed Prosser. Spikes of this magnitude occurring this late in the season indicate a stalled outmigration, and suggest that sudden and relatively modest increases in flow can remedy matters in spectacular fashion.

Characteristics of spring smolts: Wild Yakima spring chinook smolts are almost 100% age I+. To discriminate spring chinook smolts from fall chinook smolts, the Yakima Indian Nation has collected between 600 and 2,000 scale samples per year. Of the thousands of scales examined, no more than five were determined to be age II+. Similarly, in an analysis of scales from 268 spring chinook adults, Washington Department of Fisheries biologists (Knudsen, WDF, pers. commun., 1990) determined that all had smolted at age I + . It can therefore be accepted that all, but a negligible proportion of Yakima spring chinook smolts are age I+.

The mean monthly length, weight and condition factor of spring smolts as observed at Prosser in the years 1983-1990 are summarized in Table 31. As can be *seen,* there is a general trend for fork length to decrease through the season. In fact, the monthly mean length over all years is 138 mm, 130 mm, 125 mm and 129 mm in March, April, May and June, respectively. Major and Mighell (1969) observed a similar trend for the outmigrations of 1959 through 1963 (brood years 1957-1961), reporting mean lengths of 133 mm, 125mm and 122 mm in April, May and June, respectively (Major and Mighell did not monitor the old Prosser trap in March). A trend of decreasing length over time is consistent with larger fish smolting before smaller fish.

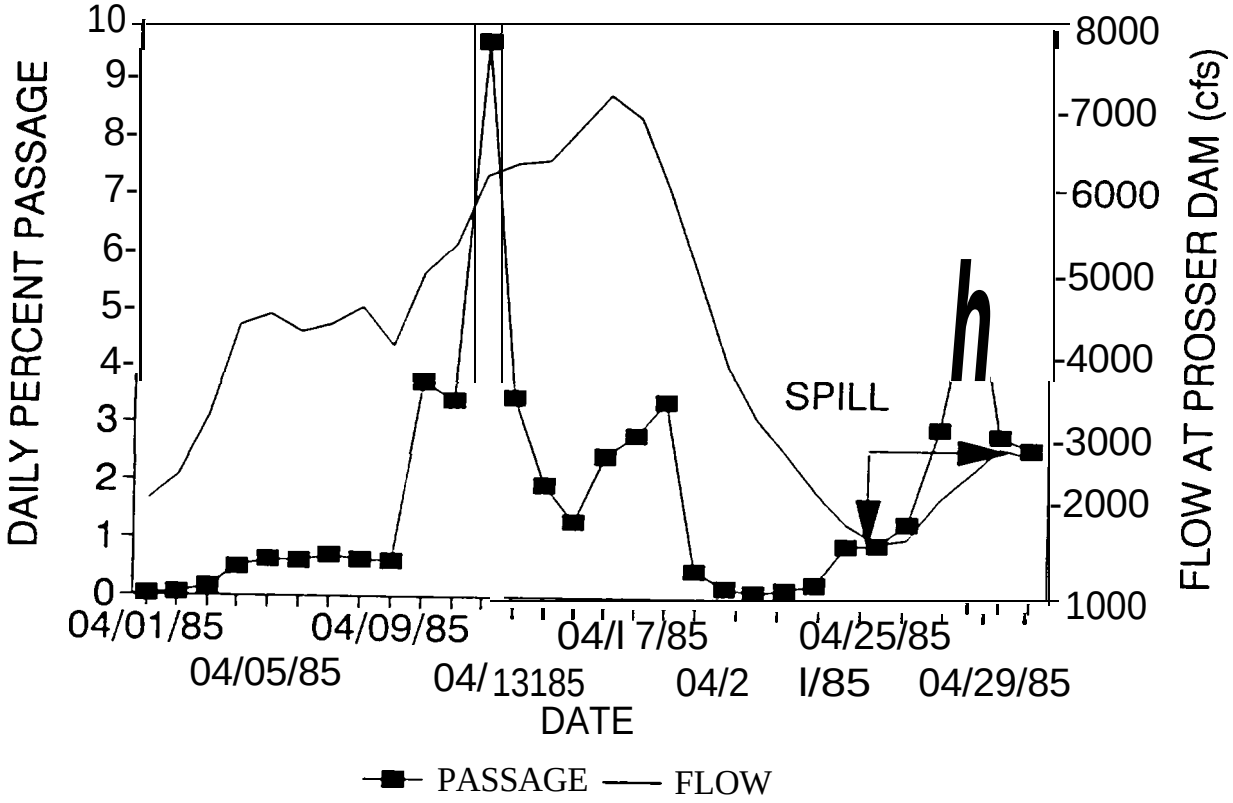


Figure 48a. Daily spring chinook passage and flow at Prosser Dam, April, 1985.

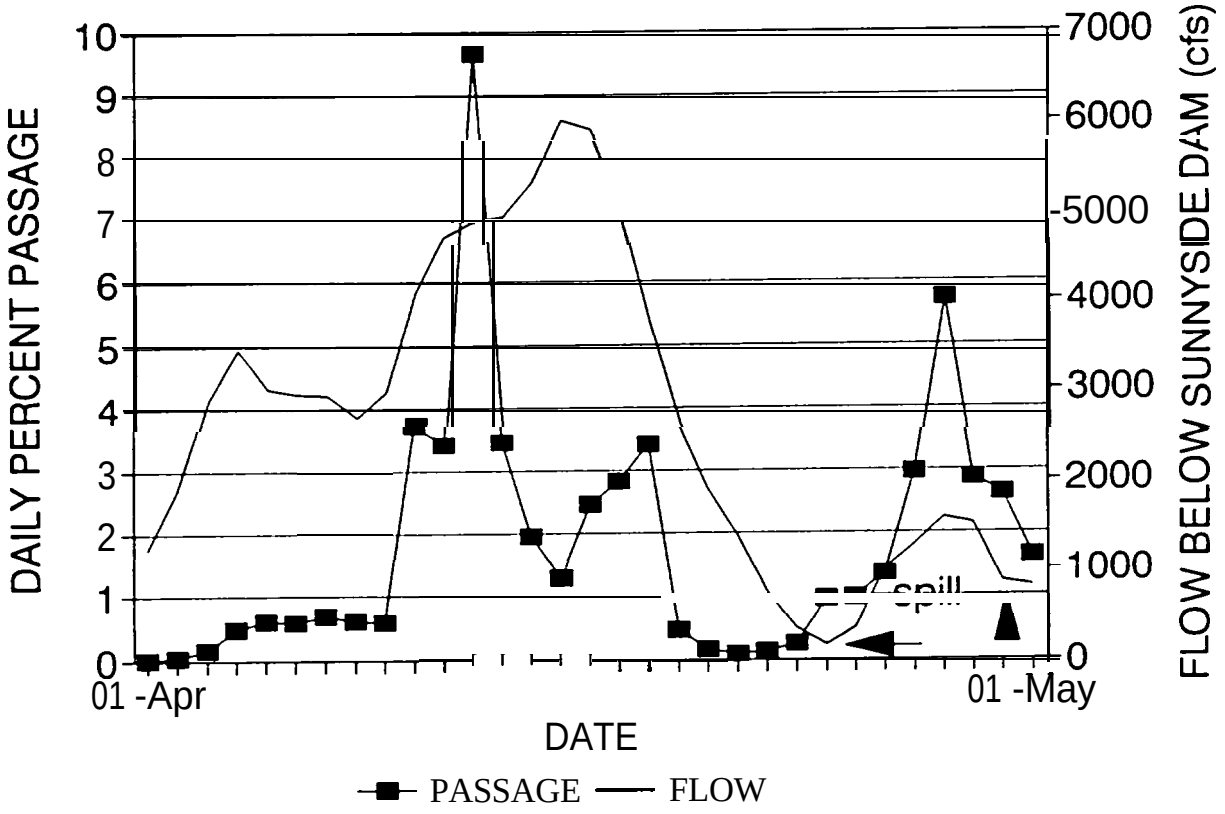


Figure 48b. Daily spring chinook passage and flow below Sunnyside Dam, April, 1985.

It should be noted that the larger smolts observed in March, which may be as large as 170 mm to 200 mm, are not older than later-migrating fish; analyses of scales from such fish have always shown them to be age I+.

Except for a slight decrease from March to April, no clear monthly trends in condition factor ("K") are apparent in the data. Mean K for the months of March through June are 11.2, 10.7, 10.8 and 10.9, respectively. (Note that condition factor is expressed as W/FL^3, where W is weight in grams and FL is fork length in mm.) On the other hand, Major and Mighell (1969) observed a clear tendency for condition factor to increase as the season progressed. Over the outmigrations of 1959 through 1963, the mean condition factor for smolts in April, May and June was 10.8, 11.0 and 11.5, respectively. An increase in condition factor from April to June may also be discemable in the data for 1983 to 1990. Condition factor would be expected to increase from April through June if food availability increased over the same period.

Table 31 also includes the estimated egg deposition, spring smolt production and egg-to-smolt survival for the outmigrations of 1983 through 1990. This was done to allow comparison of mean monthly length, weight and condition factor with indices of rearing density. Researchers have used the information in Table 31, as well as information on the outmigrations of 1959 through 1963 published by Major and Mighell (1969), to perform 24 one-variable regressions of length and condition factor on egg deposition, spring smolt production and egg-to-smolt survival. Table 32 summarizes the actual regressions performed.

The relationships in Table 32 are intriguing. First, all but one of the significant correlations between monthly mean length or condition factor and density indices occur in April; specifically, seven of eight significant correlations are for the month of April. Second, within the month of April, egg deposition and egg-to-smolt survival correlate with mean length and condition factor much more strongly than does spring smolt production. Figures 49-52 illustrate the nature of the relationships between egg deposition and egg-to-smolt survival, and mean April length and condition factor for the years covered by this study. These figures and Table 32 suggest that length and condition factor are, at least in the month of April, subject to a considerable degree of density-dependent regulation. In April, both length and condition factor are inversely related to brood year egg deposition and *directly* related to egg-to-smolt survival. However, the only evidence of density-dependent control of length or condition factor in May is the (significant) positive correlation between length and egg-to-smolt survival over 1959 through 1963 and 1983 through 1990.

The disparity between April and May suggests the possibility of two ecologically segregated spring chinook populations within the Yakima Subbasin. One might speculate that one of the independent populations rears in the upper Yakima, and passes by Prosser Dam slightly earlier than the other putative population, which might be assumed to rear in the Naches system.

Table 31. Mean monthly length, weight and condition factor of wild spring chinook emolts at Chandler in March, April, May and June, 1983-1990.

YEAR	EGGS ($X10^6$)	SMOLTS	EGG TO SMOLT SURV. (%)	MARCH			APRIL			MAY			JUNE		
				fork length (mm)	wt. (gms)	condit. factor	fork length (mm)	wt. (gme)	condit. factor	fork length (mm)	wt. (gme)	condit. factor	fork length (mm)	wt. (gme)	condit. factor
1983	1.889	167,077	8.84	N.D.	N.D.	N.D.	129	24.5	11.1	126	24.2	11.0	127	N.D.	N.D.
1984	2.265	143,331	6.33	134	26.3	10.8	133	25.8	10.8	135	25.9	10.3	140	32.4	10.7
1985	1.670	96,413	5.77	156	44.1	11.0	139	30.1	10.7	126	22.0	10.2	134	33.3	10.7
1986	3.003	180,789	6.02	135	33.0	12.3	129	22.8	10.6	126	22.2	10.6	127	23.0	10.8
1987	6.061	254,494	4.20	136	44.0	13.0	130	26.8	10.9	123	20.6	10.8	123	21.5	11.5
1988	15.073	282,968	1.88	142	38.4	10.7	126	20.5	10.1	127	21.1	10.0	123	21.1	10.7
1989	8.661	92,935	1.07	130	20.5	10.2	124	19.0	10.6	115	17.7	13.4	N.D.	N.D.	N.D.
1990	5.563	202,932	3.65	133	27.3	10.5	132	24.7	10.5	123	19.3	10.2	N.D.	N.D.	N.D.

Table 32. Regressions of egg deposition, spring smolt production and egg-to-smolt survival rate on mean length and condition factor of wild spring smolts in April and May. Note that monthly mean lengths and condition factors were calculated for the outmigrations of 1959-1963 (brood years 1957-1961) and 1983-1990 (brood years 1981-1988); or just for the outmigrations of 1983-1990 (the years covered by the current study). Note that * designates significance at 0.1, • * at 0.05.

INDEPENDENT VARIABLE	DEPENDENT VARIABLE			
	APRIL LENGTH (mm)	APRIL K	MAY LENGTH (mm)	MAY K
EGG DEPOSITION, OUTMIGRATIONS OF 1983-1990	L = -.65(EGGS) + 133.9 r^2 = .4202 .	K = -.051(EGGS) t 10.9 r^2 = .6164 . *	L = -.383(EGGS) t 127 2 r^2 = 0998	K = +.029(EGGS) t 10.8 r^2 = .0144
EGG DEPOSITION, OUTMIGRATIONS OF 1959-63 & 1993.90	L = -.78(EGGS) + 136.2 r' = .4244 **	K = -.034(EGGS) t 10.9 r' = .2365 *	L = -.462 t 127.6 r^2 = .1341	K = +.028(EGGS) t 10.7 r^2 = .0175
SPRING SMOLTS. OUTMIGRATIONS OF 1993.1990	L = -2.1X10 ^{5}(SMOLTS) + 134 r^2 = .0984	K = -1.6X10 ^{6}(SMOLTS) t 10.9 r^2 = .1356	L = t 1.29X10 ^{5}(SMOLTS) t 122.8 r^2 = 0253	K = -7.8X10 ^{6}(SMOLTS) t 12.2 r^2 = .2381
SPRING SMOLTS. OUTMIGRATIONS OF 1959-63 6 1993.90	L = -8.2X10 ^{6}(SMOLTS) + 133.1 r^2 = .0343	K = +5.4X10 ^{7}(SMOLTS) t 10.6 r^2 = 0433	L = -1.3X10 ^{6}(SMOLTS) t 125.6 r^2 = .0007	K = -9X10 ^{7}(SMOLTS) t 11.1 r^2 = 0126
EGG/SMOLT SURVIVAL. OUTMIGRATIONS OF 1993.1990	L = + 885(Se/s) t 126.1 r^2 = .2399	K = t .085(Se/s) + 10.2 r^2 = 5326 **	L = t 1 25(Se/s) t 119.2 r^2 = .3298	K = -.165(Se/s) t 11.6 r^2 = .1453
EGG/SMOLT SURVIVAL, OUTMIGRATIONS OF 1958-63 & 1983.90	L = + 1.24(Se/s) + 124.4 r^2 = 4468 **	K . + .056(Se/s) t 10 4 r^2 = .2635 . .	L = +1.21(Se/s) t 119.4 r^2 = .3800 .	K = -.088(Se/s) + 11 4 r^2 = .0692

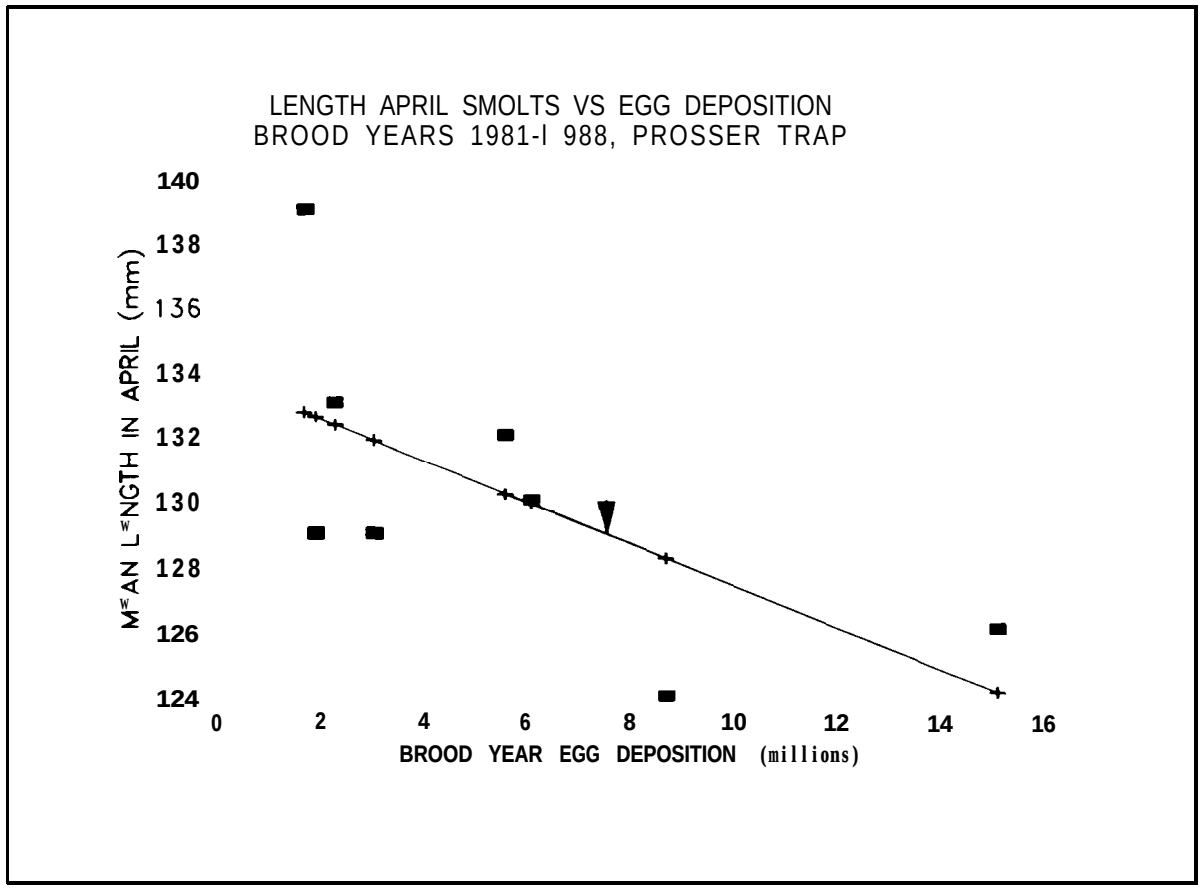


Figure 49. Relationship between mean April length and brood year egg deposition for wild Yakima spring chinook smolts at Prosser, 1983-1990.

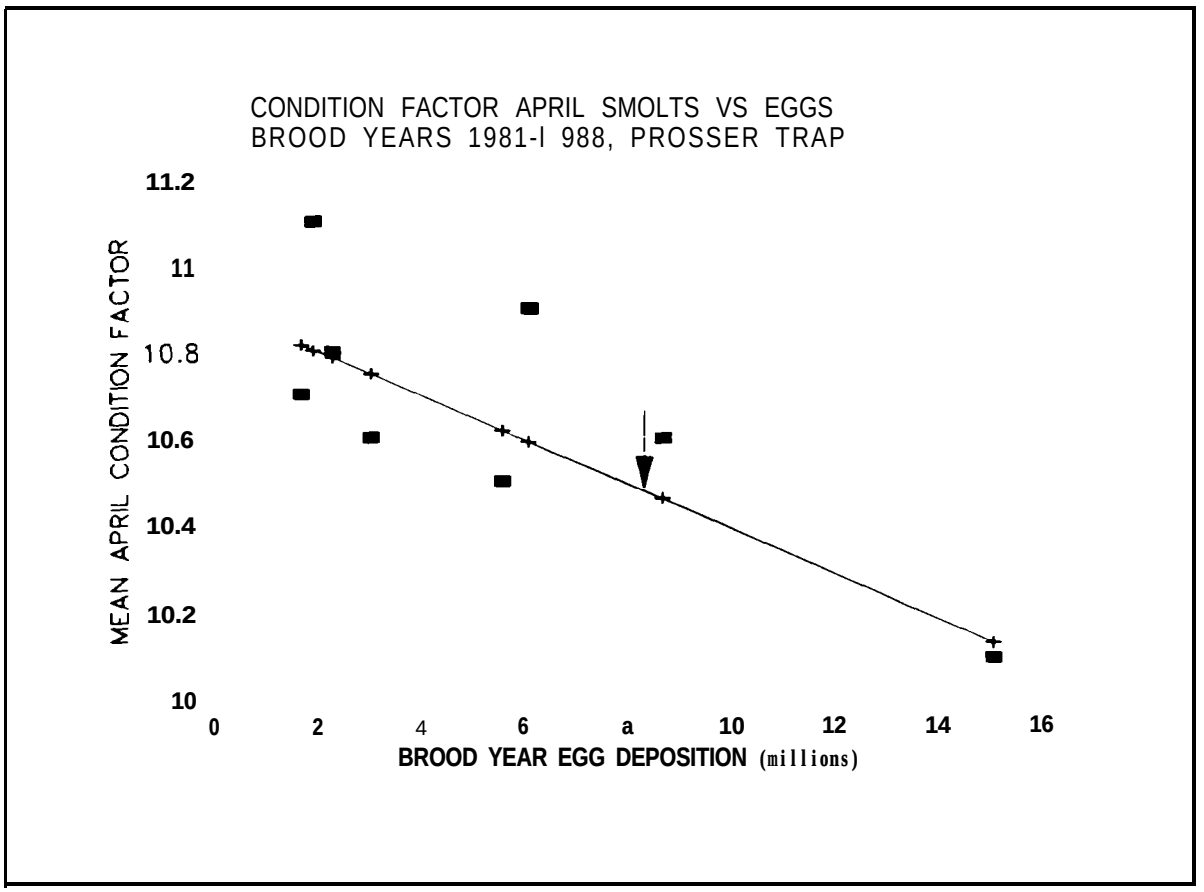


Figure 50. Relationship between mean April condition factor and brood year egg deposition for wild Yakima spring chinook smolts at Prosser over the years 1983-1990.

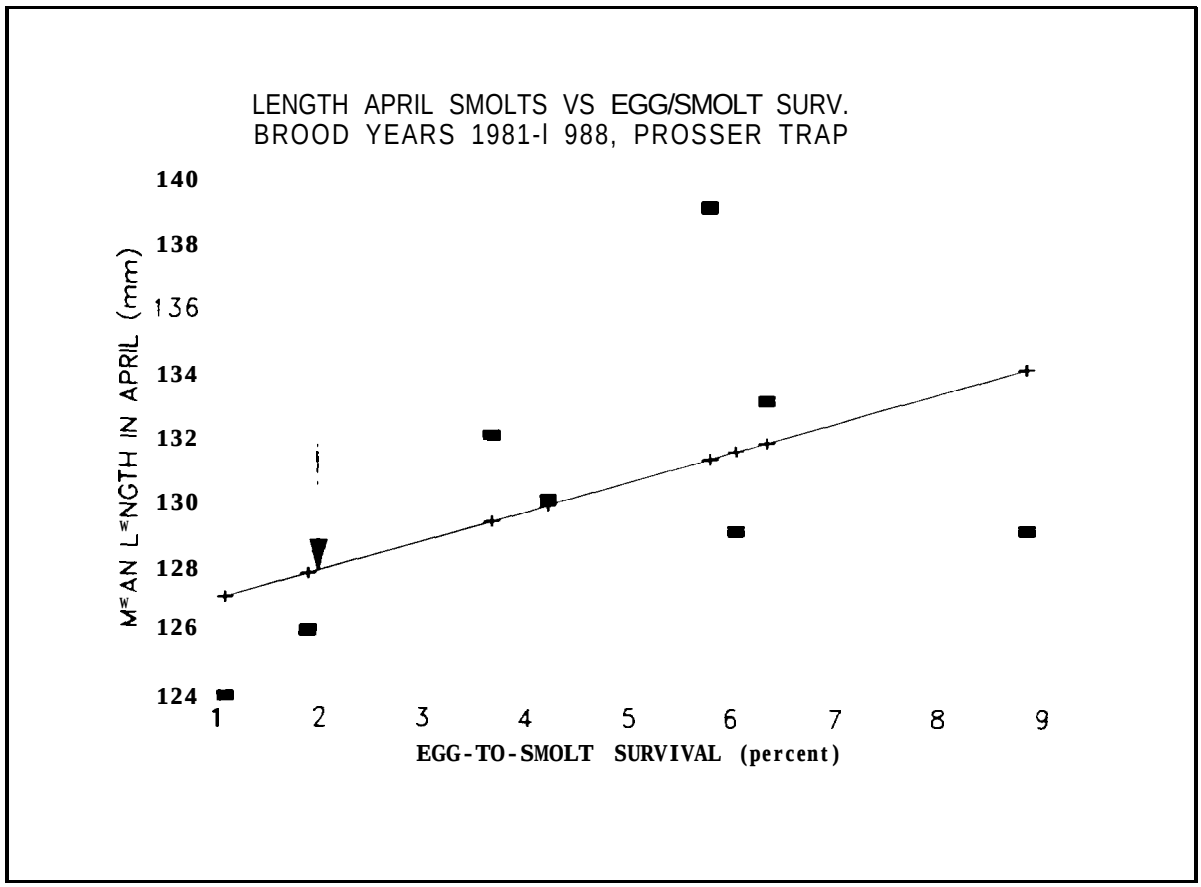


Figure 51. Relationship between mean April length of wild Yakima spring chinook smolts at Prosser and brood year egg-to-smolt survival over the years 1983-1990.

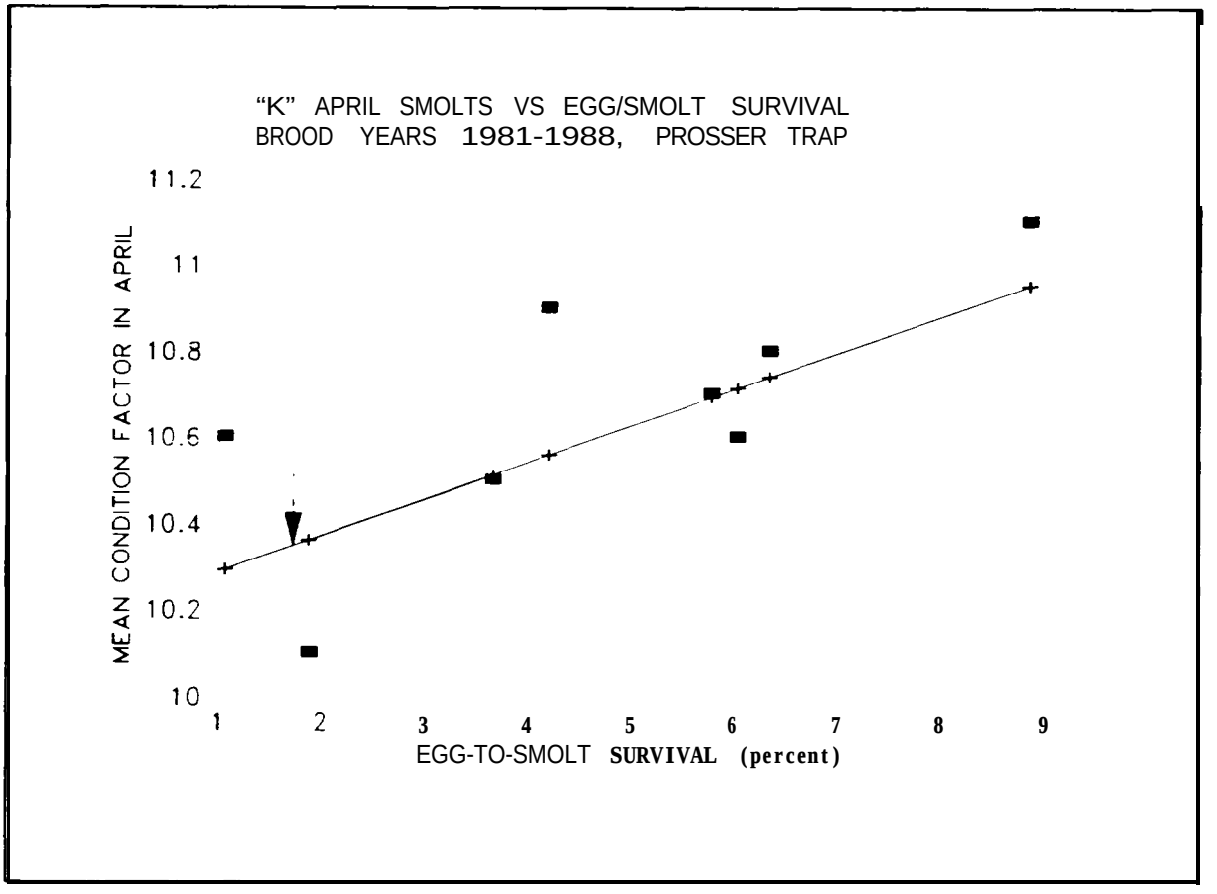


Figure 52. Relationship between mean April condition factor of wild Yakima spring chinook smolts at Prosser and brood year egg-to-smolt survival over the years 1983- 1990.

Impacts of flow on outmigration rate: Outmigration rate for wild smolts can be expressed in a number of ways. The most direct expression is the median migration rate in miles per day for a group of marked fish. This type of estimate for an entire population of wild fish is difficult to come by; fish would have to be marked and released over an entire season to estimate seasonal trends and fish would have to be released throughout the system, to integrate site-specific impacts.

There are, however, at least two alternative ways of describing the migration rate of a population of wild fish. An obvious option is the date of median passage. Another option is to describe the "compactness" of the outmigration, the concentration of the outmigration over time as monitored at a single counting station. Yakima Nation researchers examined the relationship between water velocity in the middle Yakima and the date of median passage. Researchers also examined the impact of flow on the number of days required for passage of the "middle 80%" of the outmigration -- the number of days separating the date of 10% and 90% cumulative passage. Researchers found a possible, but weak relationship between flow and "80% passage time," but no evidence of an impact of flow on the median passage date.

Table 33 summarizes the data examined. Researchers only examined flows below Sunnyside Dam and flows approaching Prosser Dam because flows at Prosser and (especially) below Sunnyside are usually lower than flows at any other point along the main migratory route. Researchers suspected a migration bottleneck might exist below Sunnyside because diversions into Wapato and Sunnyside canals frequently result in very low velocities in the reach.

It is appropriate at this point to digress a moment to discuss the manner in which flows are analyzed in this report. Discharge, per se', has little biological meaning. Hydraulic parameters with much more immediate relevance to rearing or migrating fish include velocity, depth, width and, perhaps, cross-sectional area.

Biologists in the Yakima Subbasin are blessed with a wealth of this type of data. The Bureau of Reclamation maintains a computerized data base of mean daily discharge covering more than 30 years in most reaches. Moreover, the U.S. Fish and Wildlife Service has conducted instream flow incremental method (IFIM) studies in many of these same reaches, and has estimated biologically critical parameters over a wide range of flows. Yakima Nation fisheries researchers have been allowed to use the raw IFIM hydraulic data to develop reach-specific regressions of various hydraulic parameters on discharge. Researchers have used these regressions to examine the impact of specific hydraulic parameters on biological response variables not currently addressed by IFIM analysis, such as migration rate, the survival of migrating smolts, and the survival of different juvenile life stages.

Table 34 summarizes the regressions researchers have developed. It is presented for reference and documentation of methodology.

Table 33. Relationship between discharge and water velocity below Sunnyside Dam and approaching Prosser Dam on wild spring chinook outmigration timing. Timing is expressed as date of median passage and days for passage of the middle 80% of the outmigration.

YEAR	DATE OF MEDIAN PASSAGE	DAYS FOR PASSAGE OF MIDDLE 80%	MEAN FLOW AT PROSSER APRIL-BAY (CfS)	MEAN FLOW AT PROSSER OVER PERIOD OF 10% TO 50% PASSAGE (CfS)	MEAN FLOW BELOW SUNNYSIDE APRIL-MAY (CfS)	MEAN FLOW BELOW SUNNYSIDE OVER PERIOD OF 10% TO 50% PASSAGE (CfS)	MEAN VELOCITY BELOW SUNNYSIDE APRIL-BAY (fps)	MEAN VELOCITY BELOW SUNNYSIDE OVER PERIOD OF 10% TO 50% PASSAGE (fps)
1983	April 23	38	6538	5361	4478	3736	3.98	3.54
1984	May 4	50	3935	3421	2561	1848	2.88	2.49
1985	April 29	46	**3394**	4241	2023	2812	2.44	2.85
1986	April 25	51	2913	3028	1292	1257	1.89	1.96
1987	April 23	33	3296	3000	1757	1326	2.23	2.06
1988	April 26	33	2566	3938	1423	2868	2.01	3.05
1989	April 23	39	4520	6883	3262	5846	3.10	4.49
1990	April 16	28	4012	4451	2610	3547	2.85	3.44

Table 34. Summary of reach-specific regressions of mean width, depth, cross-sectional area and velocity on discharge. Regressions are based on IFIM estimates of hydraulic parameters over a range of flows. N = number of IFIM data pairs, r^2 = coefficient of determination of regression.

REACH	MEAN WIDTH (ft)	MEAN DEPTH (ft)	MEAN CROSS-SECTIONAL AREA (ft^2)	MEAN VELOCITY (fps)
Yakima at Eaeton	$W = 21.89(Q^{.3040})$ $N = 18,\ r^2 = .9874$	$D = 1.001(Q^{.1722})$ $N = 18,\ r^2 = .9825$	$CSA = 21.87(Q^{.3766})$ $N = 18,\ r^2 = .9971$	$V = .0456(Q^{.6239})$ $N = 18,\ r^2 = .9991$
Yakima at Cle Elum	$W = 29.95\ln(Q) - 30.25$ $N = 26,\ r^2 = .9800$	$D = .1048(Q^{.4182})$ $N = 26,\ r^2 = .9854$	$CSA = 5.306(Q^{.5966})$ $N = 26,\ r^2 = .9995$	$V = .1883(Q^{.4035})$ $N = 26,\ r^2 = .9989$
Yakima at Ellensburg	$W = 40.32\ln(Q) - 102.5$ $N = 24,\ r^2 = .9867$	$D = .1678(Q^{.3614})$ $N = 24,\ r^2 = .9957$	$CSA = 7.348(Q^{.5631})$ $N = 24,\ r^2 = .9996$	$V = .1358(Q^{.4371})$ $N = 24,\ r^2 = .9998$
Yakima Canyon	$W = 20.07\ln(Q) + 46.15$ $N = 23,\ r^2 = .8341$	$D = .1391(Q^{.4067})$ $N = 23,\ r^2 = .9912$	$CSA = 10.88(Q^{.5245})$ $N = 23,\ r^2 = .9958$	$V = .0923(Q^{.4750})$ $N = 23,\ r^2 = .9947$
Yakima Below Sunnyside Dam	$W = 37.26\ln(Q) - 26.10$ $N = 29,\ r^2 = .9905$	$D = .2539(Q^{.3245})$ $N = 29,\ r^2 = .9935$	$CSA = 18.43(Q^{.4903})$ $N = 29,\ r^2 = .9997$	$V = .0544(Q^{.5092})$ $N = 29,\ r^2 = .9997$
Upper Naches (Sawmill Flats)	$W = 63.94(Q^{.1076})$ $N = 20,\ r^2 = .9864$	$D = .1422(Q^{.3766})$ $N = 20,\ r^2 = .9987$	$CSA = 9.106(Q^{.4838})$ $N = 20,\ r^2 = .9998$	$V = .1099(Q^{.5160})$ $N = 20,\ r^2 = .9998$
Lower Naches (below Wapatox)	$W = 22.05(Q^{.2690})$ $N = 25,\ r^2 = .9673$	$D = .3847(Q^{.2333})$ $N = 25,\ r^2 = .9985$	$CSA = 8.492(Q^{.5022})$ $N = 25,\ r^2 = .9882$	$V = .1182(Q^{.4972})$ $N = 25,\ r^2 = .9883$

As indicated in Table 33, there was no discemable relationship between any flow parameter and the date of median passage. There does, however, appear to be a relationship between 80% passage time and Sunnyside velocities. As Figure 53 indicates, there is a general downward trend in passage time (more compression of the run) as mean velocity below Sunnyside Dam increases. (Note that velocity was averaged over a period of time beginning with the date of 10% passage at Prosser and ending with the date of median passage. Velocities were averaged over this period because most of the fish making up the middle 80% of the run would probably have been affected by them; the fish were either above Sunnyside, or below it, in the region of impact.) If one accepts the outlying points of 1987 and 1989, the regression of 80% migration time (T) on Sunnyside velocity is:

$T = 51.2 - 3.85(V_{sunnyside})$, with an R^2 of 0.14 (not significant).

If, however, 1987 and 1989 are dropped, the regression is:

$T = 79.2 - 13.2(V_{sunnyside})$, with an R^2 of 0.69 (significant at p=.O5).

The importance of such a relationship is that substantial flows are required if the outmigration is to be compressed. Using the regression for all years, an 80% passage time of 30 days requires a mean below-Sunnyside velocity of 5.51 feet per second (fps). This velocity converts (using the regression based on IFIM data for the Sunnyside reach) to a discharge of 8,682 cfs. Using the regression that omits 1987 and 1989, a discharge of 4,029 cfs would be necessary for a passage time of a month. If true, these predictions are important, because a highly compressed run, as it passes through a series of aggregations of resident predators, may simply overwhelm the foraging capacity of the predators at any given site.

Unfortunately, mean flows in excess of 4,000 cfs below Sunnyside are not common in April, and mean flows in excess of 8,000 cfs are extremely infrequent.

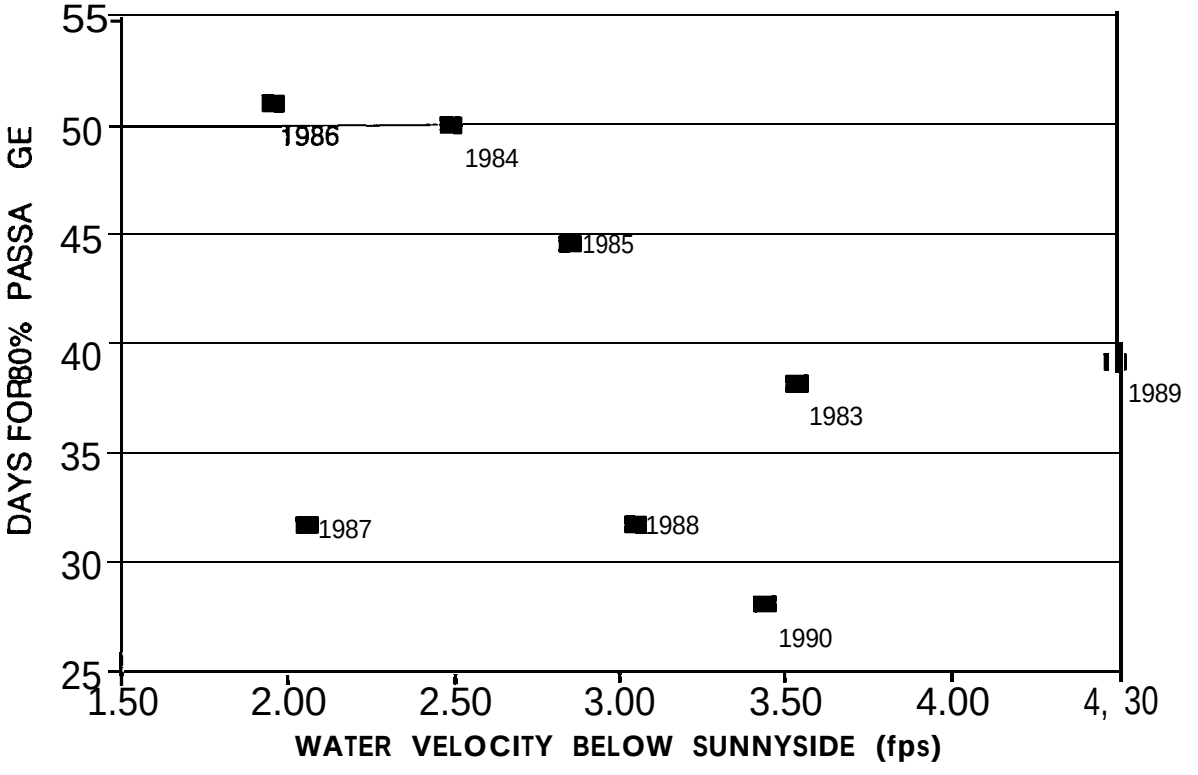


Figure 53. Days for passage of the "middle 80%" of wild spring chinook smolts vs mean water velocity below Sunnyside Dam during outmigration.

NOTE: Velocities were averaged over the period circumscribed by the passage of 10% to 50% of the total outmigration.

LIFE STAGE SURVIVAL

Overview

Egg-to-Fry Survival

Point estimates of egg-to-fry survival were obtained by "capping" redds in the upper Yakima in 1985 and 1986. Nylon mesh nets, which funneled into a removable livebox at the cod end, were dug into the gravel entirely around redds. Newly emergent fry were removed from the livebox on a daily basis. Egg deposition for individual redds was estimated by substituting the mid-eye to hypural (MEHP) length from the spent female (which was snagged from the redd by hook and line) into a length-fecundity relationship for wild Yakima spring chinook. The mean egg-to-fry survival rate for redds capped in 1985 was 62.5%) and the mean in 1986 was 56.7%. The mean over both years, 59.6%, was assumed characteristic of the basin.

Basinwide fry production was estimated as the product of the total estimated egg deposition and the assumed egg-to-fry survival rate (59.6%). Total egg deposition was estimated as the sum of the product of the number of redds deposited in each spawning area and the mean egg complement of the redds in each area. Mean egg complements by area were estimated by substituting the mean MEHP length of female carcasses collected on the spawning grounds into the length-fecundity relationship. Total fry production from 1983 through 1990 ranged from 995,428 fish in 1983 to 8,983,692 in 1986.

Smolt-Related Survival Estimates

Statistical confidence intervals could not be described for estimates of smolt passage or survival at Prosser Dam. This is because satisfactory confidence intervals could not be described for the logistic diversion/entrainment relationship employed at Prosser (passage is estimated by dividing raw catches corrected for subsampling by the estimated entrainment fraction). Readers should refer to Appendix D for a detailed discussion of this issue.

As a result of the inability to specify statistical precision of smolt passage and survival estimates, readers should regard reported survival figures as indices of survival only. Accordingly, a great deal of emphasis should not be placed on absolute estimates. However, because the same (possibly biased) estimator was used on all groups monitored, relative passage and survival estimates across groups should be reasonably accurate.

Indices of survival to McNary Dam are also reported. These estimates were calculated as the ratio of the cumulative passage index (as reported by the Fish Passage Center) to the release number. These "McNary survival rates" should be interpreted in exactly the same way as Prosser "survival rates" -- as possibly biased indices that should, nevertheless, reflect relative survival among groups reasonably well.

Overwinter Survival

Overwinter survival has been estimated for "winter migrants" (pre-smolts that emigrate from their natal areas the fall and winter preceding the spring of smoltitication), but never for the fraction of the population that remains in natal areas until spring. Survival of Naches system winter migrants (to Prosser Dam) has ranged from 22.2% (winter of 1986-87) to 49% (winter of 1989-90). The survival of winter migrants branded at Roza in the winter of 198990 was 44.9%. As mentioned in the previous section, the majority of both Naches system (Wapatox) and upper Yakima (Roza) winter migrants that survive to Prosser actually pass Prosser in the spring.

Smolt-to-Smolt Survival

There is evidence to suggest that virtually all of the mortality incurred by wild, actively outmigrating smolts occurs between Sunnyside and Prosser dams. The evidence supporting this contention is provided by four releases of branded wild spring chinook smolts in April of 1988. Releases occurred at four sites: above Roza Dam, above Sunnyside Dam, below Sunnyside Dam and below Wapatox Dam. All fish for the Yakima releases were collected at Roza Dam (upper Yakima stock), and all fish for the Naches release were collected at Wapatox Dam (Naches system stock). Each release consisted of four, distinctively branded sub-lots. The survival to Prosser of the four sub-lots released above Roza, above Sunnyside and below Sunnyside was 56%, 61% and 54%, respectively, while the mean survival of the sub-lots released at Wapatox was 40%. If sub-lots are treated as replicates and an analysis of variance (ANOVA) is performed, none of the survival estimates are significantly different. Because survival was equivalent for all Yakima releases, researchers concluded that essentially all of the mortality was incurred below Sunnyside Dam. Although the Wapatox release was not significantly different, the 15% to 20% difference in survival was regarded as "real," as representative of Naches smolts. This interpretation was justified by the smaller size and greater predatory vulnerability of Naches smolts, and by the fact past Wapatox releases have resulted in substantially lower survival rates than were observed for upper Yakima fish in 1988.

The mean survival to McNary of all upper Yakima sub-lots was 40%, while the mean survival to McNary for all Naches system sub-lots was only 12%.

Survival of Wild Fish from Prosser to McNary

McNary passage indices of branded wild spring chinook used to estimate entrainment at Prosser were examined in an attempt to index survival from Prosser to McNary. Survival was indexed by dividing the McNary passage index by the number of fish released at Prosser The mean survival estimates for wild smolts released in 1984, 1985, 1986 and 1988 were 53%) 50%) 42% and 71% , respectively, although individual estimates ranged from 10% to 100%.

Surprisingly, no relationship between flows below Prosser and migration rate (to McNary) was observed. Even more surprising was the lack of a relationship between migration rate and survival. Failure to demonstrate these intuitive relationships was interpreted as a probable artifact of small samples sizes and imprecise estimators.

Survival of Hatchery Fish to Prosser and McNary

The migration and survival rates of hatchery-reared smolts from upriver release points to Prosser and McNary dams were related to flow. Specifically, migration rate and survival were positively correlated with water velocity in two reaches, the Yakima River bordering the city of Yakima, and the Yakima River below Sunnyside Dam. The correlation between migration rate and water velocity was significant for both reaches, as was the correlation between water velocity below Sunnyside and survival to both Prosser and McNary

The importance of the relationship between flows below Sunnyside and smolt survival is that mean flows must be much greater than are commonly observed if survival is to be substantially improved by flow augmentation alone. For example, flows below Sunnyside would have to average -4,300 cfs through April and May to achieve a McNary survival rate of 50%) while a survival rate of 75 % entails mean flows of – 7,200 cfs. Mean flows below Sunnyside from 1982 through 1987 for April and May have been 2,295 and 3,000 cfs, respectively.

Potential Causes of Poor In-basin Survival

Six potential causes of poor survival were identified. They are:

1) Entrainment or trauma associated with entrainment/bypass at irrigation diversions.

2) Physical stranding in braided areas and side channels.

3) Disease.

4) Poor water quality.

5) Residualization.

6) Predation exacerbated by low flows below irrigation diversions.

Available data indicates that all possibilities but the last (flow-mediated predation) are unlikely to play a major role in the Yakima.

A plausible argument can be made that all in-basin smolt losses are attributable to predation by northern squawfish. If squawfish feed at the rate of one smolt every three days

for an outmigration of 68 days (April 1 through June 7), a population of only -9,000 squawfish would be required to cause losses as large as those estimated in the Yakima. Consumption rates of one smolt per day require a population of only – 3,000 squawfish. The densities of squawfish that would be required between Sunnyside and Prosser to give a total population of 3,000 to 9,000 fish are not unusual, and have been documented in a number of northwestern rivers and reservoirs.

Three areas besides the reach between Sunnyside and Prosser have been identified as potential "hot spots" for squawfish predation. They are the forebay and bypass outfall area of Roza Dam; the forebay and bypass outfall area of Wapato Dam; and the Naches River between Wapatox Dam and the Wapatox Power-plant outfall.

Egg-to-Smolt Survival

Expressed as spring smolts (outmigrants observed between March 1 and June 30), egg-to-smol! survival has ranged from 1.1% (1989 outmigration) to 8.8% (1983 outmigration). If winter migrants are classed as smolts the range is 1.3% to 10.6%. Survival has generally declined since the 1983 outmigration, reaching a low point in 1989, and rebounding to 3.6% in 1990.

Yakima Indian Nation biologists performed a number of regressions to attempt to elucidate the cause(s) of the observed decline in egg-to-smolt survival. The analysis included two biotic variables (egg deposition and total smolt production) and 24 abiotic variables that consisted of hydraulic parameters for specific reaches at specific times. Among the hydraulic variables were such items as:

1) The number of days flows were low enough in the Easton reach of the Yakima to risk stranding fry in side channels and braids during the early post-emergent period (April through July).

2) The mean width, depth and cross-sectional area through the winter (October through February) in a number of reaches where overwintering might occur.

3) The probability of avoiding entrainment in major irrigation diversions.

4) The mean velocity, depth, width and cross-sectional area of the reach below Sunnyside Dam during outmigration.

The only significant one-variable correlations were between egg-to-smolt survival and: egg deposition; the number of days Easton flows threatened fry stranding; the mean width, depth and cross-sectional area of the Yakima Canyon during the winter before outmigration; and the mean overwinter cross-sectional area in the lower Naches the winter before outmigration. None of the irrigation dam "avoidance probabilities" were significant, nor

were any of the hydraulic parameters describing conditions below Sunnyside Dam during outmigration.

In stepwise regressions covering brood years 1981 through 1988 that used all "independent variables," biotic as well as abiotic, the first variable entered was egg deposition and the second was total smolt production. The coefficient of the egg deposition term was negative, suggesting density-dependent mortality, and the coefficient of the smolt production term was positive, suggesting depensatory smolt mortality. The third variable entered was avoidance probability at Wapato Dam and the fourth was the combined avoidance probability at Roza, Wapato and Sunnyside dams. It should, however, be noted that the two-variable regression, which included no hydraulic variables, had an R^2 of .93. Addition of the two hydraulic variables increased R^2 only 6% to .99.

A second stepwise regression was performed omitting any variable relating to egg deposition to highlight important variables related to flow. For the years covered by the study (brood years 1981 through 1988), the first variable entered was the number of days flows were critically low in the Easton reach during the early post-emergent period. Subsequent variables either related to avoidance probabilities at irrigation diversions, or to widths and depths in suspected overwintering areas. The R^2 for the best four-variable regression excluding egg deposition was .98 for the data relating only to the years of the study.

The preceding regression analysis led Yakima tribal biologists to draw five major conclusions:

1) Biotic density-dependent or depensatory factors (egg deposition and total smolt production) appear to explain more annual variability in egg-to-smolt survival than do the particular flow-related variables examined.

2) Nevertheless, good fits can be obtained with flow-related variables alone at the three- and four-variable level.

3) The most significant flow-related variables are avoidance probability at Wapatox and Wapato dams, and the frequency of critically low flows in the Easton reach during the early post-emergent period.

4) The decline in egg-to-smolt survival from the 1981 brood through the 1987 brood was primarily attributable to increasing egg deposition, increasing frequencies of low flow days at Easton during the post-emergent period, and decreasing avoidance probabilities at several irrigation dams.

5) Perhaps most significantly, even if egg deposition and total smolt production are the best predictors of egg-to-smolt survival under the current conditions, it does not follow that flows are unimportant nor, indeed, that they are not the primary factor limiting production. To see the truth of this assertion, one need only consider the Yakima Canyon, which is probably the single, most important habitat for summer rearing in the basin. Instream flows in the Yakima Canyon through the irrigation season (roughly late June or July through mid October) are so high that weighted usable area for juvenile spring chinook rearing is only about 20 percent of optimal. Thus, because they are regulated and are very similar from year to year (at least during the irrigation season), flows may be limiting although not particularly useful as predictors.

Smolt-to-Adult Survival

Estimates of smolt-to-adult survival for wild spring chinook salmon in the Yakima system were based on the estimated outmigration of smolts at Prosser Dam from 1983 through 1987. Adult returns corresponding to each year's smolt outmigration were calculated as the sum of the jacks (3-year-old fish) returning one year after the outmigration, and the 4-, 5-, and 6-year-old adults returning two, three and four years after the outmigration. Jack return was determined directly from counts at viewing windows on fish ladders at Prosser Dam. The contribution of 4-, 5- and 6-year-old adults entailed an age-class analysis based on scales collected from carcasses on the spawning grounds.

Three distinct substocks of spring chinook (American River, Naches River and upper Yakima River) occur in the Yakima Subbasin (Busack 1990). The age-class composition of each substock was determined separately. The proportion of total returns attributed to each substock in a given year was estimated by the proportion of all redds counted in the basin deposited in each of the three, distinct spawning areas. The age-class composition of each substock was then applied to the appropriate proportion of the total adult return (exclusive of jacks) to the Yakima Subbasin. Total adult return was estimated by the sum of Prosser Dam counts and the tribal ceremonial and subsistence harvest below Prosser.

Smolt-to-adult survival estimates begin with the 1983 outmigration **and** end with the outmigration of 1987. Smolt outmigrations were also estimated in 1988, 1989 and 1990, but adult returns for those outmigrations are not yet complete.

The total number of adults (3-year-old through 6-year-old fish) returning from the smolt outmigrations of 1983 through 1987 has ranged from 4,209 to 8,596 fish. The average adult return for these five years was 5,655 fish. Thus, smolt-to-adult survival has averaged 3.7%, and has ranged from 1.7% to 6%. It should **be** noted that these figures are influenced by the location of the smolt trap and the extent of smolt mortality incurred before smolts were counted at Prosser. Experimental releases of marked wild smolts indicate that this pre-counting mortality may be on the order of 50%. Thus, smolt-to-adult survival based on the

number of smolts *at the beginning of the ourmigration* might be about half of the preceding figures.

Because of a lack of identifying marks (such as coded-wire tags), the factors affecting smolt-to-adult survival of wild spring chinook in the mainstem Columbia, the estuary, and on the high seas are very difficult to identify. It is believed that passage at mainstem dams, especially in drought years, has had a very negative impact on smolt survival. Some studies (Park 1985) have also indicated that the smolt transportation program on the mainstem Snake and Columbia have had at best a marginal impact on survival of spring chinook smolts. Ocean survival depends on many factors (such as food supply, water temperature and fishing effort, especially from the new high-seas drift net fishery) that are uncontrollable and very difficult to assess for individual stocks. Adult returns are diminished by mortalities associated with ladders on mainstem dams as well as by Columbia River fisheries. These fisheries include lower Columbia commercial gillnetters, state test fisheries, sport fishing and tribal ceremonial and subsistence fishing. As discussed in the section on adult returns of hatchery-reared fish, the average Columbia River harvest rate of hatchery-reared Yakima spring chinook has been about 25 percent. It is at least possible that wild fish are subject to comparable harvest rates.

Egg-to-Fry Survival

Annual egg deposition in the subbasin was calculated with the following expression:

$$E_{tot} = \sum_{i=1}^{3} \sum_{j=3}^{5} (R_i)(f_{ij})(F_{ij})$$

where

E_{tot} is total subbasin egg deposition in the year at issue;
R_i is the number of redds in subarea i in the year at issue. (Note: the Yakima Subbasin supports three distinct substocks of spring chinook in three geographically distinct "subareas:" substocks differ in age and length composition, and therefore in fecundity); f_{ij} is the fraction of females in subarea i that are age-j in the year at issue; and
F_{ij} is the mean fecundity of age-j females in subarea i in the year at issue.

The total number of fry produced annually (N,) was calculated as:

$$N_{fry} = (E_{tot})(\hat{S}_{egg/fry})$$

where

E_{tot} is total subbasin egg deposition; and

$\hat{S}_{egg/fry}$ is the estimated mean egg-to-fry survival rate.

Survival from egg to fry was investigated in 1985 and 1986 by capping a number of redds in the upper Yakima with tine-meshed nets equipped with liveboxes on their downstream ends. An estimate of the number of eggs deposited in these redds was obtained by snagging (with hook and line) spent females off the redd and substituting their length into the length-fecundity relationship. The fry were counted out of the liveboxes on a daily basis from early March through June. Survival from egg to emergent fry was estimated as the total number of fry removed divided by the estimated egg deposition. Mean survival was estimated at 62.5% in 1985 and 56.7% in 1986. Researchers have assumed that the mean of these estimates, 59.6%, is characteristic of the system.

As summarized in Table 35, total egg deposition was estimated as the sum of three distinct subareas -- the upper Yakima River, the American River, and the Naches system exclusive of the American River because of the different age and size distributions of females spawning in each subarea. The age distribution of females spawning in a given subarea and year was estimated from the length (mid-eye hypural) distributions of recovered carcasses and an age-length relationship developed for female Yakima River spring chinook.

The age-length relationship was based on over 1,000 fish of known length (mid-eye to hypural) and age (by scale analysis) collected from the subsistence fishery and from spawning grounds. This relationship assigned a probability of age to each 2.5-cm increment of length (the probability of being age IV for a fish with a mid-eye to hypural length of 60 cm to 62.5 cm is equal to the number of 60 cm to 62.5 cm age-IV fish in the data set divided by the total number of aged fish that had a length of 60 cm to 62.5 cm.) Researchers developed a spreadsheet to determine age distributions by multiplying the number of carcasses in each length interval by the length-specific probability of being age III, IV or V, and then summing the estimated number of fish at each age over all length intervals. This spreadsheet also calculated age-specific mean fecundity by substituting age-specific mean length into the length-fecundity relationship.

The egg complement of the redds in a given subarea and year was assumed to reflect the age distribution of the spawners. If x, y and z percent of the female spawners were 3-, 4-, and 5-year-olds, then x, y, and z percent of the redds were assumed to contain the egg complement of the average 3-, 4- and 5-year-old female for the subarea and year under consideration. Thus, total egg deposition was estimated as the product of age-specific fecundity and “age-specific redd number” summed over all ages and subareas.

Table 35. Spring chinook egg deposition in the Yakima Subbasin, brood years 1980-1990.

YEAR	SUBSTOCK	AGE	FRACTION FEMALES AT AGE	MEAN LENGTH(a)	AGE-SPECIFIC MEAN FECUNDITY	NUMBER OF REDDS	REDDS FROM FEMALES AT AGE	EGGS DEPOSITED SUBSTOCK	EGGS DEPOSITED BASIN
1980	AMERICAN	III	0.002	56.8	3353	38	0.076	255	
(SMOLT	AMERICAN	IV	0.430	62.6	4486	38	16.34	73297	
YEAR 1982)	AMERICAN	V	0.568	71.3	6184	38	21.584	133484	
							subtotal	207036	
	NACHES	III	0.002	54.4	2885	52	0.104	300	
	NACHES	IV	0.716	61.6	4290	52	37.232	159744	
	NACHES	V	0.282	70.1	5950	52	14.664	87252	
							subtotal	247296	
	U. YAKIMA	III	0.014	52.8	2572	312	4.368	11236	
	U. YAKIMA	IV	0.937	57.0	3392	312	292.344	991735	
	U. YAKIMA	V	0.049	66.7	5286	312	15.288	80816	
							subtotal	1083787	1538119
1981	AMERICAN	III	0.002	56.8	3353	72	0.144	483	
(SMOLT	AMERICAN	IV	0.430	62.6	4486	72	30.96	138879	
YEAR 1983)	AMERICAN	V	0.568	71.3	6184	72	40.896	252917	
							subtotal	392279	
	NACHES	III	0.002	54.4	2885	100	0.2	577	
	NACHES	IV	0.716	61.6	4290	100	71.6	307200	
	NACHES	V	0.282	70.1	5950	100	28.2	167793	
							subtotal	475569	
	U. YAKIMA	III	0.014	52.8	2572	294	4.116	10588	
	U. YAKIMA	IV	0.937	57.0	3392	294	275.478	934519	
	U. YAKIMA	V	0.049	66.7	5286	294	14.406	76154	
							subtotal	1021261	1889109
1982	AMERICAN	III	0.002	56.8	3353	11	0.022	74	
(SMOLT	AMERICAN	IV	0.430	62.6	4486	11	4.73	21218	
YEAR 1984)	AMERICAN	V	0.568	71.3	6184	11	6.248	38640	
							subtotal	59931	
	NACHES	III	0.002	54.4	2885	43	0.086	248	
	NACHES	IV	0.716	61.6	4290	43	30.788	132096	
	NACHES	V	0.282	70.1	5950	43	12.126	72151	
							subtotal	204495	

Table 35. Spring chinook egg deposition in the Yakima Subbasin, brood years 1980-1990.

YEAR	SUBSTOCK	AGE	FRACTION FEMALES AT AGE	MEAN LENGTH(a)	AGE-SPECIFIC MEAN FECUNDITY	NUMBER OF REDDS	REDDS FROM FEMALES AT AGE	EGGS DEPOSITED	
								SUBSTOCK	BASIN
	U. YAKIMA	III	0.014	52.8	2572	576	8.064	20743	
	U. YAKIMA	IV	0.937	57.0	3392	576	539.712	1830895	
	U. YAKIMA	V	0.049	66.7	5286	576	28.224	149199	
							subtotal	2000838	2265264
1983	AMERICAN	III	0.002	56.8	3353	36	0.072	241	
(SMOLT	AMERICAN	IV	0.430	62.6	4486	36	15.48	69439	
YEAR 1985)	AMERICAN	V	0.568	71.3	6184	36	20.448	126459	
							subtotal	196139	
	NACHES	III	0.002	54.4	2885	47	0.094	271	
	NACHES	IV	0.716	61.6	4290	47	33.652	144384	
	NACHES	V	0.282	70.1	5950	47	13.254	78863	
							subtotal	223518	
	U. YAKIMA	III	0.014	52.8	2572	360	5.04	12964	
	U. YAKIMA	IV	0.937	57.0	3392	360	337.32	1144310	
	U. YAKIMA	V	0.049	66.7	5286	360	17.64	93250	
							subtotal	1250524	1670181
1984	AMERICAN	III	0	0	0	72	0	0	
(SMOLT	AMERICAN	IV	0.305	66.6	5267	72	21.96	115658	
YEAR 1986)	AMERICAN	V	0.695	73.2	6555	72	50.04	328031	
							subtotal	443688	
	NACHES	III	0.009	54.2	2846	148	1.332	3790	
	NACHES	IV	0.788	57.5	3490	148	116.624	407015	
	NACHES	V	0.203	71.7	6263	148	30.044	188151	
							subtotal	598956	
	U. YAKIMA	III	0.036	45.4	1127	634	22.824	25734	
	U. YAKIMA	IV	0.956	55.8	3158	634	606.104	1914112	
	U. YAKIMA	V	0.008	60.7	4115	634	5.072	20870	
							subtotal	1960716	3003360
1985	AMERICAN	III	0.003	54.4	2885	141	0.423	1220	
(SMOLT	AMERICAN	IV	0.514	61.3	4232	141	72.474	306704	
YEAR 1987)	AMERICAN	V	0.484	73.5	6614	141	68.244	451362	
							subtotal	759287	

Table 35. Spring chinook egg deposition in the Yakima Subbasin, brood years 1980-1990.

YEAR	SUBSTOCK	AGE	FRACTION FEMALES AT AGE	MEAN LENGTH(a)	AGE-SPECIFIC MEAN FECUNDITY	NUMBER OF REDDS	REDDS FROM FEMALES AT AGE	EGGS DEPOSITED	
								SUBSTOCK	BASIN
	NACHES	III	0.009	48.3	1694	286	2.574	4360	
	NACHES	IV	0.621	60.8	4134	286	177.606	734276	
	NACHES	V	0.370	71.1	6145	286	105.82	650301	
							subtotal	1388937	
	U. YAKIMA	III	0.004	55.8	3158	951	3.804	12013	
	U. YAKIMA	IV	0.898	60.0	3978	951	853.998	3397289	
	U. YAKIMA	V	0.098	67.3	5403	951	93.198	503587	
							subtotal	3912890	6061114
1986	AMERICAN	III	0.000	56.8	3353	464	0	0	
(SMOLT	AMERICAN	IV	0.174	69.7	5872	464	80.736	474082	
YEAR 1988)	AMERICAN	V	0.826	75.8	7063	464	383.264	2707001	
							subtotal	3181083	
								0	
	NACHES	IV	0.390	64.8	4798	849	331.11	1588713	
	NACHES	V	0.610	74.3	6770	849	517.89	3506191	
							subtotal	5094904	
	U. YAKIMA	III	0.011	49.6	1948	1793	19.723	38411	
	U. YAKIMA	IV	0.937	58.7	3724	1793	1680.041	6256939	
	U. YAKIMA	V	0.052	67.2	5384	1793	93.236	501972	
							subtotal	6797322	15073309
1987	AMERICAN	III	0.002	54.4	2885	222	0.444	1281	
(SMOLT	AMERICAN	IV	0.388	62.8	4525	222	86.136	389748	
YEAR 1989)	AMERICAN	V	0.610	76.7	7239	222	135.42	980270	
							subtotal	1371299	
	NACHES	III	0.001	56.8	3353	455	0.455	1526	
	NACHES	IV	0.350	64.2	4798	455	159.25	764104	
	NACHES	V	0.649	74.7	6848	455	295.295	2022253	
							subtotal	2787882	
	U. YAKIMA	III	0.005	55.4	3080	1043	5.215	16062	
	U. YAKIMA	IV	0.792	59.5	3880	1043	826.056	3205490	
	U. YAKIMA	V	0.203	70.6	6048	1043	211.729	1280480	
							subtotal	4502032	8661213

Table 35. Spring chinook egg deposition in the Yakima Subbasin, brood years 1980-1990.

YEAR	SUBSTOCK	AGE	FRACTION FEMALES AT AGE	MEAN LENGTH(a)	AGE-SPECIFIC MEAN FECUNDITY	NUMBER OF REDDS	REDDS FROM FEMALES AT AGE	EGGS DEPOSITED SUBSTOCK	EGGS DEPOSITED BASIN
1988	AMERICAN	III	0.001	54.4	2885	239	0.239	689	
(SMOLT	AMERICAN	IV	0.324	64.2	4798	239	77.436	371549	
YEAR 1990)	AMERICAN	V	0.675	75.6	7024	239	161.325	1133142	
							subtotal	1505380	
	NACHES	III	0.003	46.8	1401	247	0.741	1038	
	NACHES	IV	0.305	65.5	5052	247	75.335	380590	
	NACHES	V	0.692	74.9	6887	247	170.924	1177204	
							subtotal	1558832	
	U. YAKIMA	III	0.017	46.1	1264	566	9.622	12164	
	U. YAKIMA	IV	0.773	60.4	4056	566	437.518	1774660	
	U. YAKIMA	V	0.210	70.3	5989	566	118.86	711871	
							subtotal	2498695	5562907
1989	AMERICAN	III	0.000	0	0	187	0	0	
(SMOLT	AMERICAN	IV	0.260	66.1	5169	187	48.62	251322	
YEAR 1991)	AMERICAN	V	0.740	74.6	6829	187	138.38	944958	
							subtotal	1196281	
	NACHES	III	0.001	55.8	3158	347	0.347	1096	
	NACHES	IV	0.443	63.7	4701	347	153.721	722568	
	NACHES	V	0.557	73.3	6575	347	193.279	1270790	
							subtotal	1994454	
	U. YAKIMA	III	0.012	49.1	1850	937	11.244	20800	
	U. YAKIMA	IV	0.929	58.4	3666	937	870.473	3190896	
	U. YAKIMA	V	0.058	66.6	5267	937	54.346	286226	
							subtotal	3497922	6688657
1990	AMERICAN	III	0.000	54.3	2865	143	0	0	
(SMOLT	AMERICAN	IV	0.280	66.6	5267	143	40.04	210880	
YEAR 1992)	AMERICAN	V	0.720	74.9	6887	143	102.96	709116	
							subtotal	919996	
	NACHES	III	0.003	53.7	2748	321	0.963	2646	
	NACHES	IV	0.629	61.5	4271	321	201.909	862348	
	NACHES	V	0.368	73.8	6673	321	118.128	788212	
							subtotal	1653206	

Table 35. Spring chinook egg deposition in the Yakima Subbasin, brood years 1980-1990.

YEAR	SUBSTOCK	AGE	FRACTION FEMALES AT AGE	MEAN LENGTH(a)	AGE-SPECIFIC MEAN FECUNDITY	NUMBER OF REDDS	REDDS FROM FEMALES AT AGE	EGGS DEPOSITED	
								SUBSTOCK	BASIN
	U. YAKIMA	III	0.004	55.4	3080	735	2.94	9055	
	U. YAKIMA	IV	0.839	60.2	4017	735	616.665	2477236	
	U. YAKIMA	V	0.158	69.8	5892	735	116.13	684183	
							subtotal	3170474	5743676

a. The length-fecundity expression used is: 195.248 (MEHP length) - 7736.78. Note that the lack of sex-specific data for the American and Naches substocks in the years 1980-83 necessitated the use of 1980-83 mean figures for age distribution and length.

The estimated number of fry produced from the eggs deposited in the brood years 1981 through 1990 is summarized in Table 36. Again, these figures are based on an estimated 59.6% egg-to-emergent-fry survival rate.

Table 36. Estimated fry production from eggs deposited in the Yakima Basin from 1981 through 1990.

BROOD YEAR	TOTAL EGG DEPOSITION	% SURVIVAL	TOTAL FRY
1981	1,889,109	59.6	1,125,909
1982	2,265,264	59.6	1,350,097
1983	1,670,181	59.6	995,428
1984	3,003,360	59.6	1,790,002
1985	6,061,114	59.6	3,612,424
1986	15,073,309	59.6	8,983,692
1987	8,661,213	59.6	5,162,083
1988	5,562,907	59.6	3,315,492
1989	6,688,657	59.6	3,986,440
1990	5,743,676	59.6	3,423,231

Smolt-Related Survival Estimates

The assessment of the smolt survival rates listed in this report should be conditioned by several factors:

1) In-basin smolt survival was estimated only at the Chandler trap. This trap straddles a pipe that returns fish from Chandler canal to the river (Prosser Dam diverts water into Chandler canal). Chandler canal is equipped with a fish-tight screen that shunts entrained fish into the return pipe and into the trap. The number of smolts passing

Prosser Dam per day is estimated by dividing raw catches at the trap by an estimated entrainment fraction, which is a function of the daily canal diversion rate. In-basin survival is, in turn, estimated as the ratio of seasonal outmigration estimates to release number.

It must be understood that the flow/entrainment estimator Yakima Nation fisheries researchers employ has never been independently validated. Moreover, this estimator describes entrainment as a logistic function of diversion, a fact that makes the computation of confidence intervals non-trivial. In fact, it has not been possible to develop satisfactory confidence intervals for the entrainment estimator. Consequently, it has not been possible to assess the statistical significance of observed survival rate differences. (For more details on the development and application of the diversion/entrainment estimator, see Appendix D.).

The survival rates estimated within the basin should be viewed as indices that are probably biased in some manner. Thus, a great deal of significance should not be attached to absolute survival estimates. However, as the same relationship was applied to all observations, the bias should be equal among groups, and relative estimates between groups should still be accurate. Thus, the survival rates reported are most useful in indicating relative performance among experimental groups, or as evidence of localized regions of smolt mortality.

2) Indices of survival at McNary Dam are also reported. The McNary "survival rate" is calculated as the ratio of the cumulative "passage index" to the release number. McNary's passage index bears approximately the same relationship to true outmigration as the expanded Chandler counts; it is an index of passage number, which may be biased. It is, however, also like expanded Chandler counts in preserving the accuracy of relative passage among groups, especially for the same species per run in the same year.

3) With varying degrees of completeness, overwinter survival of Naches system winter migrants has been estimated five times (the winters of 1985-86, 1986-87, 1987-88, 1988-89 and 1989-90). Overwinter survival of upper Yakima winter migrants has been estimated only for the winter of 1989-90. All of these survival rates were estimated by branding winter migrants (at Wapatox or Roza) and then dividing the estimated total seasonal outmigration at Chandler by the number released. It should be noted that the length of the season varies between estimates. In particular, the Naches figure for 1985-86 is based only on spring recoveries (Chandler trap was not operated in the winter of 1985). The results of these studies are summarized in Table 37.

The survival (to Prosser of Naches winter migrants marked at Wapatox in the winters of 1986-87 and 1989-90 was 22.2% and 49%, respectively. The survival of Naches winter migrants marked at Wapatox the winter of 1985-86 was only 15.6%, but this

figure does not include winter passage (Chandler smolt trap was not operated the winter of 1985-86). If only about 60% of 1985-86 Naches system winter migrants passed Prosser during the spring monitoring period, as was the case for 1986-87 winter migrants, then the true overwinter survival would have been (15.7)/.6 or about 26%. If, on the other hand, the proportion of 1985-86 winter migrants passing Prosser in the spring was similar to 1989-90 fish, 83% of which passed Prosser in the spring, the true survival rate for 1985-86 would be (15.7)/.83 or 18.9%. The survival of the only group of winter migrants marked at Roza Dam was 44.9%. These fish were marked between November 15, 1989 and January 16, 1990. As was the case with Naches winter migrants, most (75%) of these upper Yakima winter migrants passed Prosser in the spring.

It should not be inferred that these rates are characteristic of all overwintering fish in the Naches or upper Yakima. It is probable that non-migrant fish (fish that "hole up" in quality cover in the upper watershed) fare much better, at least until spring. Such fish may, however, incur higher smolt-to-smolt mortality in outmigration, as they will begin their outmigration higher in the drainage and have a longer "gauntlet" to run.

It is interesting to contrast the overwinter survival of marked hatchery fish with wild fish survival rates. As will be described in detail in a subsequent section, about 10,000 branded pre-smolts of Leavenworth stock were released in the upper Yakima in September and November of 1984 and 1985. These hatchery fish might be considered "winter migrants," at least in the sense that they were introduced into unfamiliar waters in the fall, and may not have found and utilized appropriate winter habitat. The estimated survival to Chandler the following spring (March - June) of the September '84, September '85, November '84 and November '85 groups was ll.O%, 0.896, 3.7% and 9.4%, respectively. Note that these rates are based on spring passage only; Chandler was not operated in the winters of 1984-85 or 1985-86. Allowing for the -40% winter movement characteristic of wild fish, these figures would be 18.3%, 1.3%, 6.2% and 15.7% (mean = 10.4%), respectively. Even with this adjustment, the mean hatchery overwinter survival rate is still less than half the rate of wild winter migrants.

Table 37. Estimated overwinter survival rates (marking point to Chandler) for wild winter migrant spring chinook branded at Wapatox trap on the Naches or Roza trap on the Yakima.

MARKING SITE	MARKING PERIOD	NUMBER MARKED	ESTIMATED PASSAGE AT CHANDLER	MONITORING PERIOD AT CHANDLER	ESTIMATED SURVIVAL (%)
WAPATOX	OCTOBER-NOVEMBER 1985	1,274	200	FEBRUARY 23, 1986 through JUNE 30, 1986	15.7
WAPATOX	OCTOBER-NOVEMBER 1986	19,867	4,406	NOVEMBER 1, 1986 through JUNE 30, 1987	22.2
WAPATOX	NOVEMBER-DECEMBER 1989	3,916	1,931	DECEMBER 1, 1989 through JULY 5, 1990	49.3
ROZA	DECEMBER-FEBRUARY 1989-1990	4,570	3,573	DECEMBER 1, 1989 through JULY 5, 1990	78.2

Smolt-to-Smolt Survival

It is difficult to estimate a meaningful egg-to-smolt survival rate at the Chandler smolt trap. Although egg deposition can be estimated and smolt passage at Chandler can at least be indexed with reasonable accuracy, it is known that a substantial number of fish are lost before reaching Prosser Dam and the Chandler counting station. If expressed simply as a ratio of Prosser outmigrants to brood-year egg deposition, egg-to-smolt survival will be underestimated by a factor equal to the "pre-Chandler" losses.

The mortality smolts incur in moving from upstream "staging areas" to Prosser may be large. This in-basin smolt loss been termed "smolt-to-smelt" mortality or, inversely, "smolt-to-smolt" survival. If survival from egg to smolt is not to be confounded with it. the smolt-to-smelt survival rate must be determined. Moreover, smolt-to-smolt survival is important in its own right; it probably represents a distinct and significant limiting factor on production.

Smolt-to-Smolt Survival for Wild Fish

Releases of freeze-branded wild spring chinook smolts trapped at Roza and Wapatox dams in 1988 allowed the estimation of wild smolt-to-smolt survival rates through two and possibly four major portions of the migratory route -- Sunnyside Dam to Prosser Dam; Prosser Dam to McNary Dam; possibly Wapatox Dam to Prosser Dam; and Prosser Dam to the Columbia confluence.

Four distinctively marked groups of wild Naches spring chinook smolts were released immediately below Wapatox Dam, and 12 groups of upper Yakima smolts were released from the upstream face of Roza Dam (four groups), above Sunnyside Dam (four groups), and several hundred yards below Sunnyside Dam (four groups). The mean surival of the "above Roza, " "above Sunnyside" and "below Sunnyside" groups to Prosser was 56%) 61% and 54%, respectively (mean = 57%; see Tables 38 and 39). As there was no significant difference among survival rates for upper Yakima smolts released at these locations (nor for Naches smolts released at Wapatox; l-way ANOVA, p= .05), researchers concluded that essentially all losses of upper Yakima fish occurred between Sunnyside Dam and Prosser Dam, and that survival through this reach was on the order of 57%.

The mean survival of Naches smolts from Wapatox to Prosser was 40%. Although this value was not significantly different from the upper Yakima values, it has nonetheless been treated as a real difference (the survival from Wapatox to Prosser is assumed to be on the order of 40%). This interpretation was made because the 1988 study involved only four replicates per treatment and might have shown significant differences with more replicates, and because survival rates from Wapatox to Prosser have in the past been considerably lower than the 54% to 61% values estimated for upper Yakima fish in 1988 (Table 40). Moreover, the lower Naches supports a high concentration of irrigation diversions fitted with antiquated

screens, and Naches smolts. by virtue of their small size (20 mm - 40 mm shorter than upper Yakima fish), are more vulnerable to predators.

Parenthetically, it should be noted that the Yakima Subbasin supports three genetically distinct substocks (Craig Busack, WDF. pers. commun. 199G). Two, the American River and Naches proper. spawn in the Naches system, and the other spauns in the upper Yakima (from just below Roza Dam to Easton Dam). The Naches system smolt-to-smolt survival rate might be regarded as a substock-specific trait.

The interpretation of these results bears some discussion. Researchers estimated that the survival of upper Yakima smolts in April of 1988 was about 57% from Sunnyside to Prosser and that the survival of Naches smolts from Wapatox to Prosser was about 40% in the same period. The runoff in 1988 was about average. As well over half the spring chinook outmigration occurs in April, it is not inappropriate to use these April 1988 estimates as typical or benchmark figures. Doing so does not. however, imply that researchers feel survival rates are always similar to 1988. On the contrary, Yakima fisheries researchers believe survival was almost certainly substantially less in the very low-flow years of 1985, 1986 and 1987. and probably somewhat greater in the above-average years of 1983 and 1990. Moreover it is quite likely that smolt-to-smolt surival varies seasonally, declining from March through June as flows in the Yakima fall and water temperatures increase.

Table 38. Survival of wild upper Yakima spring chinook smolts released at various points in the Yakima River on April 13, 1988 (survival calculated from release point to Prosser smolt trap).

	ESTIMATED PASSAGE																			
	Above Roza				Above Sunnyside				Below Sunnyside				Below Wapatox				River Flows			
DATE	# 1	# 2	# 3	# 4	# 1	# 2	# 3	# 4	# 1	# 2	# 3	# 4	# 1	# 2	# 3	# 4	Qwptx	Qpark	Qgrndvw	Qpros
4/13	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	1633	1196	1663	247
4/14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2505	2347	2164	557
4/15	5	0	0	0	37	38	21	0	32	27	37		0	0	0	0	3281	3937	3414	1791
4/16	56	0	101	11	78	67	22	56	34	45	89	60	0	0	0	0	3681	4923	4560	3195
4/17	70	35	70	0	0	52	17	35	17	70	52	17	0	0	17	0	3500	4958	5496	4321
4/18	12	24	24	0	12	24	0	24	24	12	0	12	0	0	0	0	2908	4284	5742	4513
4/19	9	28	0	0	37	46	0	18	18	37	0	0	9	0	9	0	2575	3292	5122	3770
4/20	7	20	10	10	0	10	20	27	0	0	20		0		0	0	2237	2588	4444	2987
4/21	3	8	11	0	11	5	0	3	3	5	3	0	0	0	0	0	2352	2430	4054	2540
4/22	22	5	19	5	8	3	19	14	24	11	19	3	0	0	3	0	2745	3136	4114	2552
4/23	16	4	4	8	4	0	4	0	4	4	4	12	0	0	0	4	2548	3294	4855	3335
4/24	0	8	8	4	0	4	0	0	4	0	4	8	0	0	0	4	2190	2627	4770	3293
4/25	18	6	9	3	12	3	0	12	0		0	6	0	3		0	1896	1980	4248	2758
4/26	9	7	0	0	2	2	4	0	2	7	0	0	0	0	0	0	1689	1436	3692	2163
4/27	10	12	7	8		8	7	8	7	5	7	5	0	0	2	3	1550	1148	3227	1661
4/28	22	13	0	9	4	13	9	13	13	22	0	0	4	0	0	9	1398	854	2957	1383
4/29	4	0	4	0	0	4	0	8	0	0	0	0		0		0	1557	1065	2740	1196
4/30	0	5	3	0	0	0	8	0	3	0	0	0	0	0	5	3	1490	1253	2845	1249
5/01	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	6	1339	1031	2942	1360
5/02	0	0	0	0	0	0	0	0	0	0	0		5	0	3	5	1311	811	2766	1207
5/03		0	0	0	0	2	2	0	0	2	0	2	0	0	7	0	1202	545	2590	1060
5/04	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	5	1140	302	2368	845
5/05	0	4	2	0	0	0	0	2	0	4	0	0	4	11	13	2	1266	482	2222	712
5/06	7	0	0	0	0	0	0	0	0	0	0	0	4	0	4	2	1119	224	2188	652
5/07	0	0	0	0	0	0	0	0	0	0	0	0	8	2	8	6	1270	193	2010	506
5/08	0	0	2	0	0	0	4	0	0	0	0	0	10	0	8	10	1297	85	1944	420
5/09	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	10	1470	445	1845	355
5/10	0	0	0	0	0	0	0	0	0	0	0	0	6	0	3	4	1516	380	1782	280
	0	0	0	0	0	0	0	0	0	0	0		9	0	0	6	1882	794	1688	242
5/12	0	0	0	0	0	0	0	0	0	0	0	0	6	6	4	8	2514	1221	1830	254

(continued)

Table 38 cont. Survival of wild upper Yakima spring chinook smolts released at various points in the Yakima River on April 13, 1988 (survival calculated from release point to Prosser smolt trap).

	ESTIMATED PASSAGE																			
	Above Roza				Above Sunnyside				Below Sunnyside				Below Wapatox				River flows			
DATE	# 1	# 2	# 3	# 4	# 1	# 2	# 3	# 4	# 1	# 2	# 3	# 4	# 1	# 2	# 3	# 4	Qwptx	Qpark	Qgrndvw	Qpros
5/13	0	0	0	0	0	0	0	0	0	0	0	0	2	2 0	7	2	4108	3437	2549	888
5/14	0	0	0	0	0	0	0	0	0	0	0	0	0			0	3513	3984	4362	2670
5/15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	2705	2460	4284	2761
5/16	0	0	0	0	0	0	0	0	0	0	0	0	5	0	10	0	2586	1662	3269	1698
5/17	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	2516	1550	2824	1187
5/18	0	0	0	0	0	0	0	0	0	0	0	0	5	0	2	2	2473	1371	2810	1130
5/19	0	0	0	0	0	0	0	0	0	0	0	0	4	0	7	0	2233	872	2622	993
5/20	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	2181	658	2229	668
5/21	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	1924	476	2021	453
5/22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	2306	753	1868	353
5/23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2592	1265	1967	370
5/24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2272	1081	2323	793
5/25	0	0	0	0	0	0	0	0	0	0	0	0	7	0	11	0	2433	946	2112	688
5/26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	2130	254	1820	302
5/27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2062	138	1469	151
5/28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2228	523	1412	153
5/29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	2482	1168	1687	203
5/30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	2376	1153	2275	593
5/31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1977	249	2232	642
6/01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0				
TOT	268	180	273	59	215	283	141	221	185	253	236	135	99	29	152	95				
SURV/	0.76	0.51	0.79	0.17	0.61	0.79	0.42	0.62	0.54	0.62	0.66	0.33	0.40	0.12	0.64	0.39				
MEAN GROUP SURV			0.56				0.61				0.54				0.39					

Qwptx=Wapatox Dam
Qpark=Parker Dam
Qgrndvw=Grandview Dam
Qp=Prosser Dam

Table 39. Survival of wild Yakima River spring chinook smolts released at various points in the Yakima River on April 13, 1988. (Survival calculated from release point to McNary Dam). Survival estimated by (McNary Passage Index)/(Release number).

	Above Roza				Above Sunnyside				Below Sunnyside				Below Wapatox			
DATE	# 1	# 2	# 3	# 4	# 1	# 2	# 3	# 4	# 1	# 2	# 3	# 4	# 1	# 2	# 3	# 4
4/21	0	0	10	0	0	0	0	10	10	10	0	0	0	0	0	0
4/22	10	0	0	0	10	10	0	0	0	10	10	0	0	0	0	0
4/23	20	10	0	10	0	10	0	10	20	10	20	10	0			0
4/24	10	10	0	10	0	0	0	10	10	40	20	30	0	0	0	0
4/25	0	10	0	0	0	20	20	0	20	0	10	20	0	0	0	0
4/26	30	10	10	0	20	10	0	0	10	10	10	30	0	0	0	0
4/27	0	0	10	10	10	20	20	10	0	10	10	0	0	0	0	0
4/28	0	10	10	0	20	0	0	10	0	10	0	0	0		0	0
4/29	10	10	0	0	10	10	0	10	0	0	0	0	0	0	0	0
4/30	10	0	0	10	0	0	0	10	0	0	0	0	0	0	0	0
5/1	0	10	0	0	10	0	0	10	0	20	10	20	0	0	0	0
5/2	10	10	0	20	0	20	10	0	10	30	10	10	0	0	0	0
														0		
5/3	20	10	10	20	10	0	0	0	10	10	0	10	0	0	0	0
5/4	30	0	0	10	30	30	10	0	10	0	0	20	0			0
5/5	0	10	0	10	0	0	0	20	0	20	10	0	10	0	10	0
5/6	0	0	20	10	10	20	10	10	0	0	0	0	0	0	0	0
5/7	10	10	20	10	0	0	10	0	20	0	0	10	0	0	0	0
5/8	0	20	0	0	0	10	0	0	10	0	0	10	10	0	0	0
5/9	0	0	0	14	14	0	0	14	0	14	0	0	0	0	0	0
5/10	0	0	10	0	0	0	0	10	10	0	0	0	0		0	0
5/11	11	0	0	0	0	0	0	11	11	0	0	0	0	0	0	0
5/12	0	0	0	0	0	0	14	0	0	0	0	14	14	0	0	0
5/13	0	0	0	0	0	0	0	0	0	0	0	13	0	0	0	0
5/14	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5/15	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
5/16	0	0	0	14	0	0	14	0	0	0	0	0	0	0	0	0
5/17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5/18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5/19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5/20	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0
5/21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	0
5/22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5/23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0
5/24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
5/25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10
5/26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5/27	0	0	0	0	0	0	0	0	0	0	0	0	7	0		0
5/28	0	0	0	0	0	0	0	0	0	0	0	0	13	0	0	0
5/29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5/30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5/31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6/1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
TOT	171	143	100	148	144	160	108	145	151	194	110	197	64	0	38	17
SURV	0.49	0.41	0.29	0.42	0.41	0.44	0.32	0.40	0.44	0.47	0.31	0.48	0.26	0.00	0.17	0.07
MEAN GROUP SURV			0.40				0.39				0.42				0.12	

RELEASE VARIABLES:
Above Roza: #1 = RAA(1), N=352; #2 = RAA(2), N=349; #3 = RAA(3), N=347; #4 = RAA(4), N=352.
Above Sunnyside: #1 = RAB(1), N=351; #2 = RAB(2), N=360; #3 = LAB(1), N=335; #4 = LAB(2), N=358.
Below Sunnyside:#1 = RA9T(1), N=345; #2 = RA9T(2), N=409; #3 = RA9T(3), N=357; #4 = RA9T(4), N=409.
Below Wapatox: #1 = RA+F(1), N=245; #2 = RA+F(2), N=245; #3 = RA+F(3), N=238; #4 = RA+F(4), N=245.

Table 40. Survival to Chandler smolt trap of wild spring chinook smolts branded at Wapatox in 1985 through 1988.

RELEASE DATE	NUMBER RELEASED	ESTIMATED SURVIVAL TO CHANDLER (%)
April 8, 1985	200	22.8
April 12, 1985	198	40.0
April 17, 1985	196	11.6
April 20, 1985	149	24.3
April 25, 1985	99	41.8
April 29, 1985	151	43.7
May 7, 1985	117	19.1
April 23, 1986	274	25.9
May 29, 1986	149	38.9
April 13, 1988	245	40.0
April 13, 1988	245	12.0
April 13, 1988	238	64.0
April 13, 1988	245	39.0

Partitioning Smolt-to-Smolt Survival

The mean index of survival to McNary Dam for all upper Yakima smolts was about 40%. Granting the accuracy of this figure, survival from Prosser to McNary would be about 70% (.57 X .7 = – .40). Assuming equal survival over the nearly equal distances from Prosser to the Columbia confluence, and from the confluence to McNary Dam, survival through each of these reaches would be on the order of 83% (.83 X .83 = – .68). With the latter figure, one can estimate the "typical" cumulative survival from two mid-Yakima points to the Columbia; the survival (of upper Yakima smolts) from any point between Sunnyside and Roza Dam to the Columbia is (0.57)(0.83) = -0.47, and the survival (of Naches system smolts) from Wapatox to the Columbia is (0.40)(0.83) = -0.33.

The partitioning of Naches smolt survival into a "Wapatox to Sunnyside reach" and a "Sunnyside to Prosser reach" is also possible, but only if one assumes smaller Naches smolts survive the Sunnyside to Prosser reach as well as upper Yakima fish. If this is true, then the product of the survival from Wapatox to Sunnyside and Sunnyside to Prosser should be 0.40, and:

$$(S_{\text{Wapatox to Sunnyside}})(0.57_{,\ \text{Sunnyside to Prosser}}) = 0.40;$$
$$(S_{\text{Wapatox to Sunnyside}}) = (0.40)/(0.57) = \sim 0.70.$$

In 1988, there was no way of determining whether ~ 60% of the Naches smolts were lost between Sunnyside and Prosser (with no losses in the lower Naches), or whether ~ 30% was lost in the lower Naches and another -40% between Sunnyside and Prosser. It does, however, seem most probable that much of the Naches smolts were lost between Sunnyside and Prosser, as flows in the lower Naches at the time of release were excellent (see Tables 38 and 39).

Survival From Prosser to McNary and Impact of Flow

Survival from Chandler to McNary has been estimated (indexed) with recovery data from 21 groups of wild, branded smolts released in the river immediately above Prosser Dam (Table 41). These fish, released in 1984 through 1986, were initially used to estimate the Chandler flow-entrainment relationship. Survival for these fish was estimated as the ratio of the McNary passage index to the release number. This data was combined with data from the 1988 survival study. Prosser-to-McNary survival was indexed for the 1988 group and calculated from the ratio of the Chandler outmigration estimate to the McNary passage index.

One of the striking things about Table 41 is the variability of the data. Survival of wild fish from Prosser to McNary ranged from 10% to 100%. (Note that "100 percent" estimates merely indicate the relative inaccuracy of available estimators; they should be interpreted as high figures approaching lOO%.) Mean survival values for 1984, 1985, 1986 and 1988 releases are 53 %, 50%) 42 % and 7 1% , respectively.

Table 41 also includes columns for Prosser-to-McNary migration rate, and mean discharge below Prosser Dam the week of release. These variables were expected to have a discemable impact on survival. Below-Prosser flows were investigated instead of Columbia flows, or some combination of the two, because Yakima flows are of course much less, and because water velocities in the Yakima are also lower. Initially researchers felt that flows below Prosser, a reach impacted by Chandler canal diversions, might be the bottleneck in a chain of flows influencing migration rate and survival.

As seen in Figures 54 and 55, no relationship between Below-Prosser flow and the migration rate of these marked wild smolts is discernable. Even more surprising is the absence of a relationship between migration rate and survival. Observed travel times range

from six to 30 days, a fivefold span -- easily enough variation for a time-dependent source of mortality, such as predation, to make itself evident.

The lack of effect may be attributable to small release groups and imprecise estimators. This conjecture is supported somewhat by the fact flow and migration rate do seem to have an effect on the survival of the larger experimental hatchery groups monitored.

Smolt-to-Smelt Survival for Hatchery Fish

The survival of hatchery smolts (spring chinook, fall chinook, steelhead and coho) from release points ranging from 57 miles to 145 miles above Prosser has been poor since monitoring began in 1983. As summarized in Table 42, the mean survival of hatchery spring chinook smolts from release point to Chandler has been only 33.5% during 1983 through 1987 (releases of pre-smolts and fry excluded, as well as one set of acclimated releases in which egress from the acclimation pond was restricted by low water). The survival of hatchery steelhead, fall chinook and coho has also been poor, averaging 25%, 27% and 48%, respectively. (Note that coho were generally released much lower in the river and closer to Prosser Dam than the other species.)

Table 41. Estimated survival from Prosser Dam to McNary Dam for wild spring chinook branded and released at Chandler or several upstream points in 1984, 1985, 1986 and 1988.

GROUP	RELEASE DATE OR MEDIAN ARRIVAL DATE AT PROSSER	NUMBER RELEASED	CUMULATIVE PASSAGE INDEX AT MCNARY DAM	SURVIVAL TO MCNARY 1%)	DAYS TO MEDIAN PASSAGE AT MCNARY	MIGRATION RATE (mil es day)	MEAN FLCW BELOW PROSSER 7 DAYS AFTER RELEASE
PROSSER EFFICIENCY	4/15/84	322	123	38	28	3.22	4202
PROSSER EFFICIENCY	4/15/84	495	370	75	22	4.10	4202
PROSSER EFFICIENCY	4/17/84	270	80	30	25	3.61	4365
PROSSER EFFICIENCY	4/20/84	233	198	85	30	3.01	3090
PROSSER EFFICIENCY	4/27/84	281	37	13	11	8.21	2683
PROSSER EFFICIENCY	4/29/84	162	93	57	16	5.64	2727
PROSSER EFFICIENCY	4/29/84	197	115	58	15	6.02	2727
PROSSER EFFICIENCY	5/3/84	197	142	72	16	5.64	2736
			MEAN	53	20.4	4.93	3342
PROSSER EFFICIENCY	4/20/85	193	74	38	15	6.02	1278
PROSSER EFFICIENCY	4/26/85	133	71	53	9	10.03	995
PROSSER EFFICIENCY	5/2/85	204	79	39	9	10.03	970
PROSSER EFFICIENCY	5/9/85	224	158	70	11	8.21	605
			MEAN	50	11	8.57	962
PROSSER EFFICIENCY	4/12/86	207	65	31	14	6.45	1729
PROSSER EFFICIENCY	4/15/86	321	175	54	18	5.02	1023
PROSSER EFFICIENCY	4/18/86	193	68	35	15	6.02	945
CROSSER EFFICIENCY	4/23/86	209	134	64	12	7.52	816
PROSSER EFFICIENCY	4/30/86	218	23	10	11	8.21	548
PROSSER EFFICIENCY	5/3/86	223	193	86	12	7.52	877
PROSSER EFFICIENCY	5/7/86	205	55	27	10	9.03	971
PROSSER EFFICIENCY	5/19/86	123	57	46	7	12.9	692
PROSSER EFFICIENCY	5/27/86	124	32	26	6	15.05	2369
			MEAN	42	11.7	8.64	1108
'88 SURVIVAL STUDY	4/13/88	352	174	64	12	7.52	3284
'88 SURVIVAL STUDY	4/13/88	349	143	79	12	7.52	2804
'88 SURVIVAL STUQY	4/13/88	347	100	37	16	5.64	3431
'88 SURVIVAL STUDY	4/13/88	352	148	100	10	9.03	2256

Table 41. Estimated survival from Prosser Dam to McNary Dam for wild spring chinook branded and released at Chandler or several upstream points in 1984, 1985, 1986 and 1988.

GROUP	RELEASE DATE OR MEDIAN ARRIVAL DATE AT PROSSER	NUMBER RELEASED	CUMULATIVE PASSAGE INDEX AT MCNARY DAM	SURVIVAL TO MCNARY (%)	DAYS TO MEDIAN PPSSAGE AT MCNARY	MIGRATION RATE (miles/day)	MEAN FLOW BELOW PROSSER 7 DAYS AFTER RELEASE
'88 SURVIVAL STUDY	4/13/88	351	144	67	15	6.02	3411
'88 SURVIVAL STUDY	4/13/88	360	160	56	12	7.52	3431
'88 SURVIVAL TUDY	4/13/88	335	108	76	14	6.45	2804
'88 SURVIVAL STUDY	4/13/88	358	145	65	13	6.95	3284
'88 SURVIVAL STUDY	4/13/88	345	151	82	14	6.45	3284
'88 SURVIVAL STUDY	4/13/88	409	194	77	11	8.21	3431
'88 SURVIVAL STUDY	4/13/88	357	110	47	9	10.03	3411
'88 SURVIVAL STUDY	4/13/88	409	197	100'	14	6.45	3431
			MEAN	71	12.7	7.31	3188

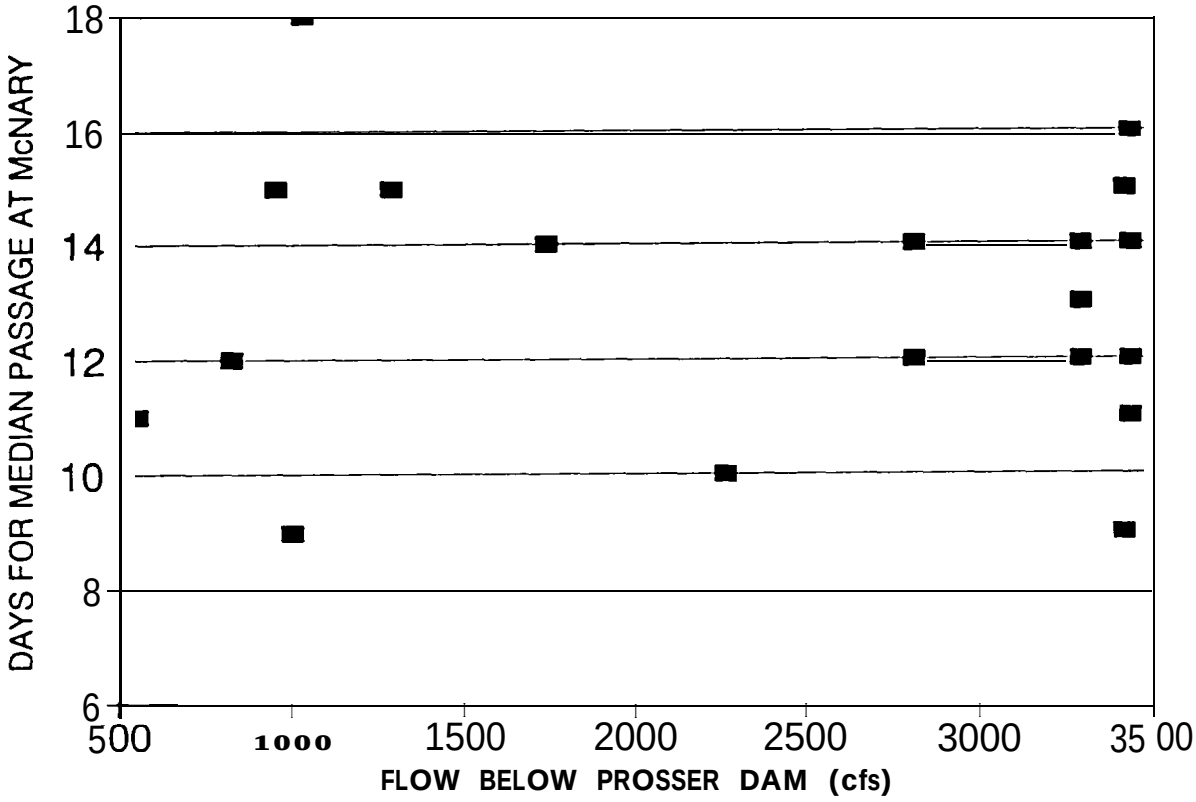


Figure 54. Median travel time from Prosser to McNary Dam vs mean flow below Prosser Dam for branded wild spring chinook smolts released at Prosser. April releases only.

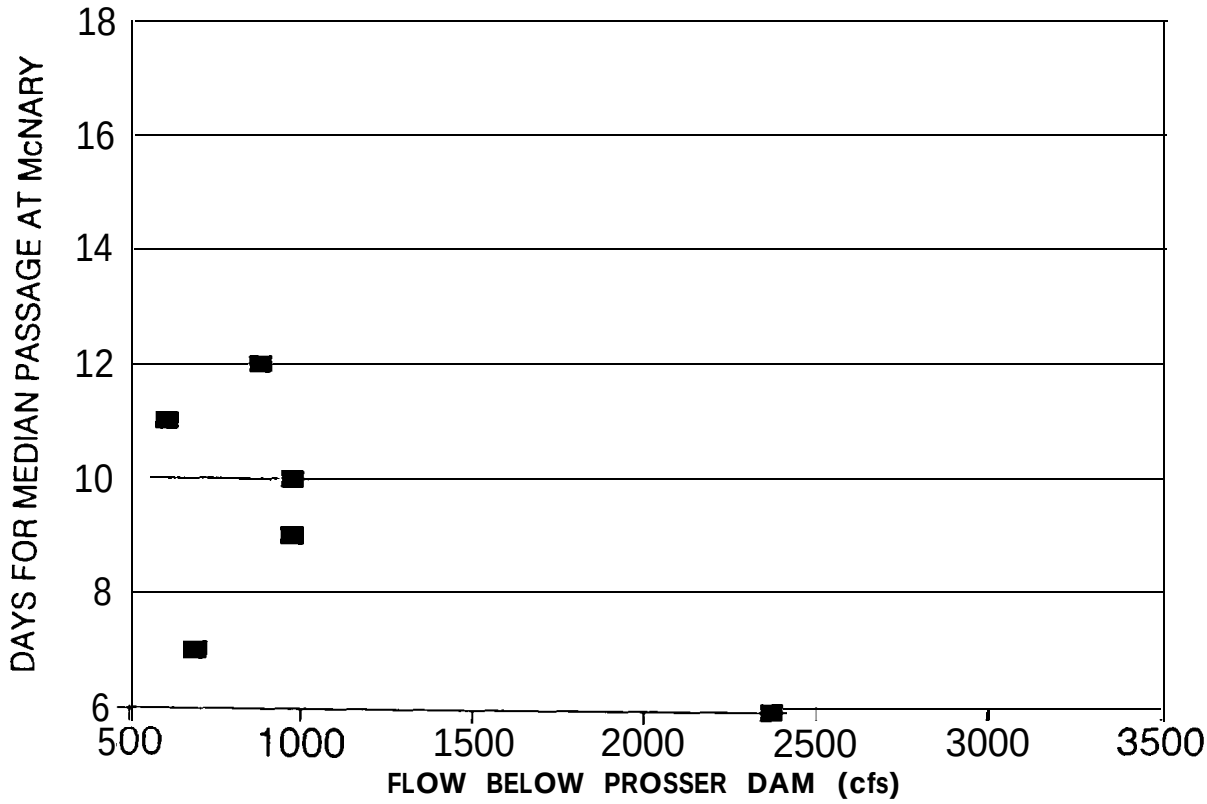


Figure 55. Median travel time from Prosser to McNary Dam vs mean flow below Prosser Dam for branded wild spring chinook smolts released at Prosser. May releases only.

Table 42. Estimated survival to Chandler of marked, hatchery-reared spring chinook smolts, pre-smolts and fry released between 1983 and 1987.

RELEASE TYPE	RELEASE DATE	RELEASE POINT	DISTANCE TO CHANDLER	ESTIMATED SURVIVAL (%)
Direct-release, smolts, Leavenworth stock.	April 1983	Upper Yakima (scatter-plant)	118 miles (median)	24.1
Pond-acclimated, smolts, Leavenworth stock.	April 1983	Nile Pond (Naches, RM 29)	98.6 miles	89.0*
Direct-release, smolts, Leavenworth stock.	April 1984	Upper Yakima (scatter-plant)	118 miles (median)	40.4
Pond-acclimated, smolts, Leavenworth stock.	April 1984	Nile Pond (Naches, RM 29)	98.6 miles	64.9
Direct-release, June fry, Leavenworth stock.	June 1984	Upper Yakima (scatter-plant)	118 miles (median)	11.4
Direct-release, smolts, Leavenworth stock.	April 1985	Upper Yakima (scatter-plant)	118 miles (median)	25.5
Pond-acclimated, smolts, Leavenworth stock.	April 1985	Mary's Pond (Yakima, RM 192)	144.9 miles	21.6
Direct-release, September pre-smolts, Leavenworth stock.	September 1984	Upper Yakima (scatter-plant)	118 miles (median)	11.0
Direct-release, November pre-smolts, Leavenworth stock.	November 1984	Upper Yakima (scatter plant)	118 miles (median)	3.7
Direct-release, smolts, Leavenworth stock.	April 1986	Upper Yakima (scatter-plant)	118 miles (median)	8.2
Pond-acclimated, smolts, Leavenworth stock.	April 1986	Mary's Pond (Yakima, RM 192)	144.9 miles	17.8
Pond-acclimated, smolts, hatchery-reared native Yakima stock.	April 1986	Mary's Pond (Yakima, RM 192)	144.9 miles	20.2
Pond-acclimated, smolts, hatchery-reared Leavenworth/Yakima hybrid stock.	April 1986	Mary's Pond (Yakima, RM 192)	144.9 miles	18.7
Direct-release, September pre-smolts, Leavenworth stock.	September 1985	Upper Yakima (scatter-plant)	118 miles (median)	0.8
Direct-release, November pre-smolts, Leavenworth stock.	November 1985	Upper Yakima (scatter-plant)	118 miles (median)	9.4
Direct-release, June fry, Leavenworth stock.	June 1985	Upper Yakima (scatter-plant)	118 miles (median)	0.3

Table 42. Estimated survival to Chandler of marked, hatchery-reared spring chinook smolts pre-smolts and fry released between 1983 and 1987.

RELEASE TYPE	RELEASE DATE	RELEASE POINT	DISTANCE TO CHANDLER	ESTIMATED SURVIVAL (%)
Direct-release, smolts, Leaavenworth stock.	April 1987	Upper Yakima (scatter-plant)	118 miles (median)	38.5
Pond-acclimated, smolts, Leavenworth stock.	April 1987	Mary's Pond (Yakima, RM 192)	144.9 miles	3.7[b]
Pond-acclimated, smolts, hatchery-reared native Yakima stock.	April 1987	Mary's Pond (Yakima, RM 192)	144.9 miles	10.6[b]
Pond-acclimated, smolts, hatchery-reared native Yakin/Leavenuorth hybrid stock.	April 1987	Mary's Pond (Yakima, RM 192)	144.9 miles	2.8[b]

' Losses of acclimating pre-smolts to bird predation uas very high in Nile Pond in 1983 and 1984. A multiple mark-recapture census of the pond's population just before the 1984 release indicated about half of the fish initially stocked had been lost. Unfortunately, no pre-release census was performed in 1983. The figure presented in this table assumes 50% of the initial stocking number had been lost prior to release. If no adjustment to the initial stocking number had been made, estimated survival uould have been half as large as the figure listed (44.5% instead of 89%).

' Acclimated survival rates reflect the fact the river flows dropped to the point that the outlet from the acclimation pond to the river was nearly dewatered; an unknown proportion of the acclimated groups therefore never left the pond.

Survival to Prosser and McNary: Effect of Flow

Unlike with wild smolts, there is some evidence that the migration rate and survival of hatchery smolts from upriver release points to Prosser or McNary are affected by flow. Table 43 summarizes migration and survival rates for all of the experimental hatchery fish released as smolts. (Fall-released pre-smolts and spring-released fry cannot be analyzed in terms of migration rate or the effect of flows on outmigrant survival because the fish cannot be located at the beginning of outmigration). The table also includes the mean water velocity through the migratory route leading to Prosser. Water velocity was used instead of discharge, because velocity is the parameter most directly related to migration rate and survival. Velocity was averaged over a period extending from the day of release through the day the median fish passed Prosser. [A number of different approaches of estimating velocities through a series of reaches could have been used. This approach was taken because some fish were probably in all reaches except for the very beginning (downstream reaches) or end (upstream reaches) of the period.]

Water velocity in two reaches of the Yakima River correlated significantly (p=.O5) with the migration rate of the 14 experimental releases of hatchery smolts summarized in Table 43. These reaches were on the Yakima near the city of Yakima (Fig. 56), and the Yakima below Sunnyside Dam (Fig. 57). Migration rate correlated positively with water velocity in the Yakima Canyon and Cle Elum reaches also, but the correlation was slight (r = 0.12 and 0.04, respectively) and insignificant.

Perhaps more importantly, significant correlations also exist between survival to McNary and migration rate, and between survival (to Prosser and McNary) and water velocity below Sunnyside Dam. Figure 58 plots survival to Prosser as a function of migration rate, and Figure 59 plots survival to McNary as a function of migration rate. In both cases, survival correlates positively with migration rate, but only in the case of survival to McNary is the correlation significant (p= . 1). Figures 60 and 61 plot survival to Prosser and McNary, respectively, as a function of water velocity below Sunnyside Dam. In both cases, the positive correlation between survival and water velocity is significant (p = .l for Prosser ; p = .05 for McNary).

Table 43. Migration rate and survival rate of hatchery spring chinook and associated water velocities through reaches traversed.

GROUP	MIGRATION RATE (to Prosser, miles/day)	SURVIVAL TO PROSSER (%)	SURVIVAL TO McNARY (%)	MEAN VELDCI TY CLE ELIM (fps)	MEAN VELOCITY CANYON (fps)	MEAN VELOCITY YAKIMA (fps)	MEAN VELOCITY SUNNYSIDE (fps)	MEAN VELOCITY LOWER NACHES (fps)
TRUCK '83	6.94	24.2	44.6	4.41	5.10	6.20	4.36	N.A.
POND '83	7.58	89.0[a]	89.6[a]	N.A.	N.A.	6.06	4.33	6.41
TRUCK '84	3.37	40.4	27.6	3.40	3.81	3.23	2.48	N.A.
POND '84	3.52	65.0	32.8	N.A.	N.A.	3.03	2.40	3.79
TRUCK '85	3.25	25.5	11.3	3.91	4.16	3.89	2.24	N.A.
POND '85	5.57	21.65	27.6[a]	3.78	4.13	3.87	2.49	N.A.
TRUCK '86	3.19	8.2	4.8	2.61	3.06	2.90	1.50	N.A.
HATCHERY POND '86	5.37	17.8	8.8	2.81	3.50	3.03	2.68	N.A.
WILD POND '86	5.37	20.2	6.9	2.81	3.50	3.03	2.68	N.A.
HYBRID POND '86	5.37	18.7	7.9	2.81	3.50	3.03	2.68	N.A.
TRUCK '87	7.87	38.5	21.0	2.86	3.21	3.16	1.82	N.A.
HATCHERY POND '87	4.53	3.69	5.34	2.73	3.26	2.94	2.01	N.A.
WILD POND '87	3.72	10.6	10.2	2.76	3.36	3.40	2.26	N.A.
HYBRID POND '87	3.92	2.81	0.55	2.77	3.34	3.25	2.17	N.A.

[a] This survival rate assumes half of the experimental fish originally stocked in the acclimation pond were lost to bird predation. Fifty percent losses of spring chinook pre-smolts uere docunented in this pond in 1984 (by a pre-release census using multiple mark/recapture techniques); and 50% losses of coho pre-smolts uere documented in 1986 (fish were monitored by a photoelectric fish cou7ter as they left the pond). Thus, it uas assuned that the effective number of fish released from the acclimation pond in 1983 was half the original stocking number.

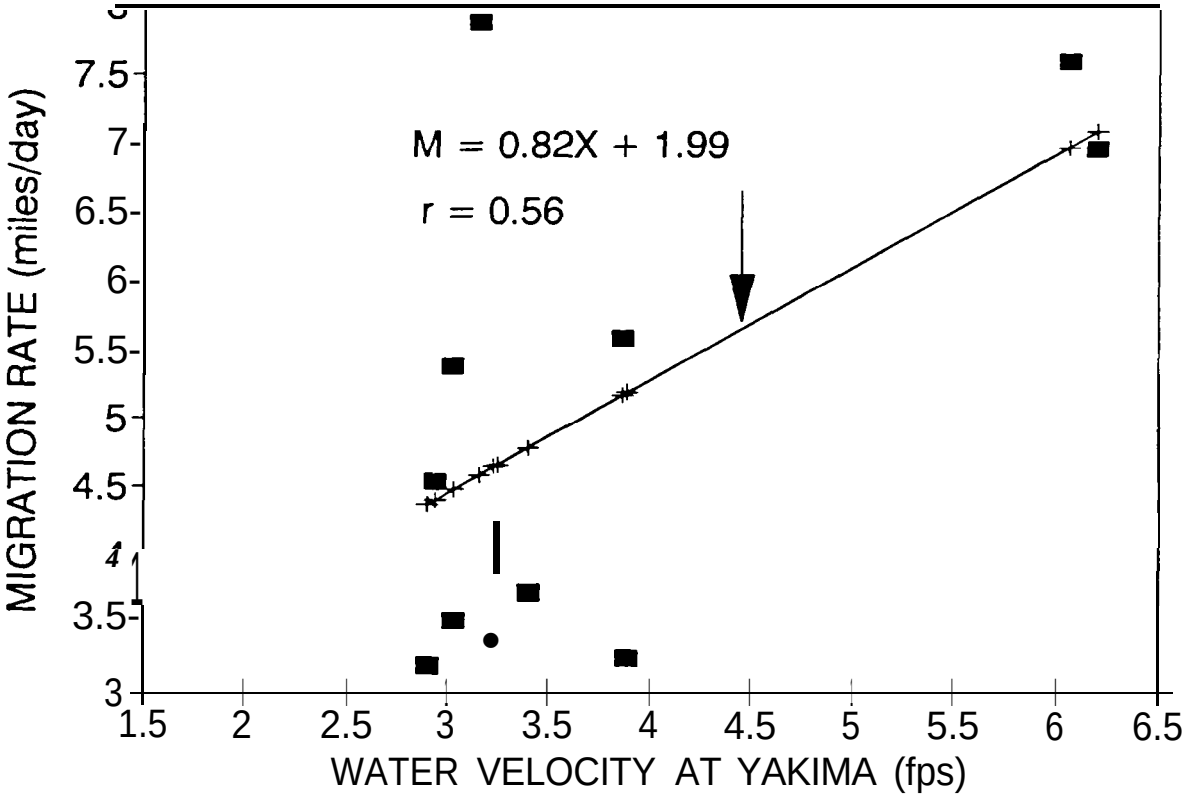


Figure 56. Migration rate (release point to Prosser Dam) vs water velocity at Yakima city gauge, experimental hatchery smolts, 1983 - 1987.

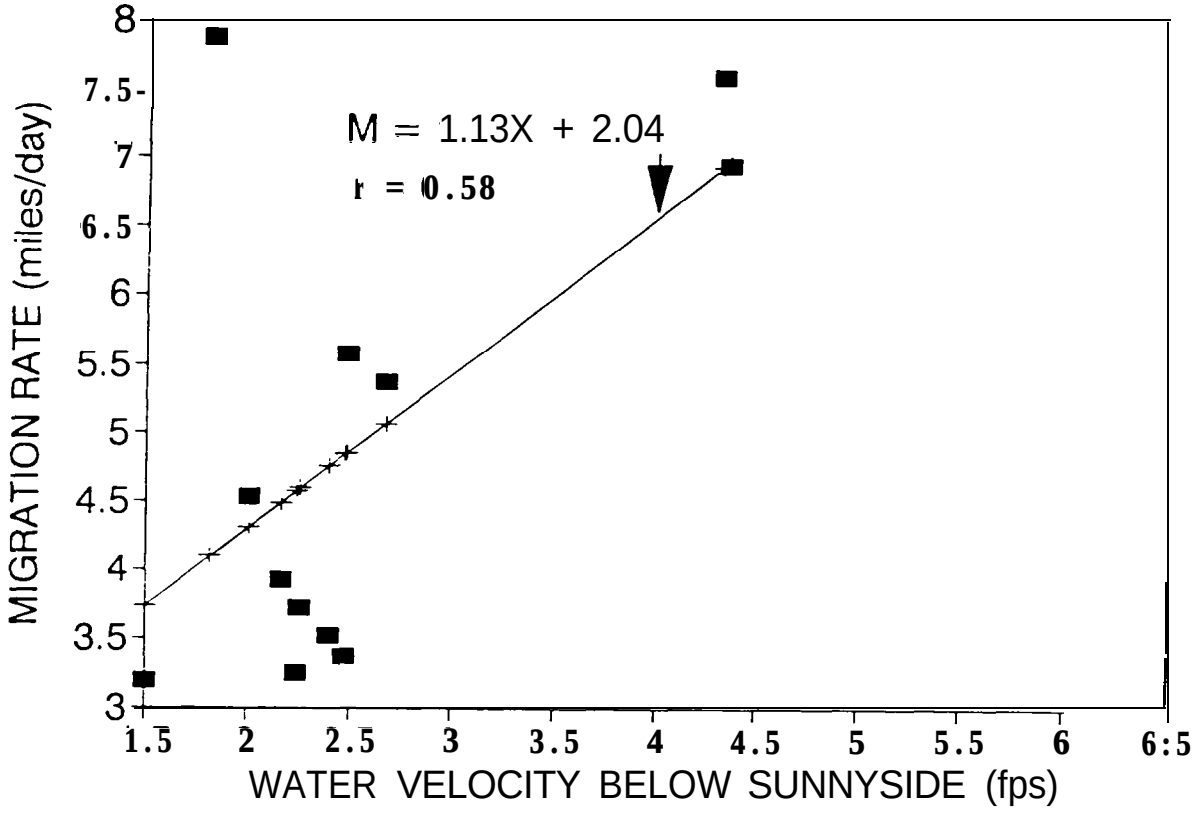


Figure 57. Migration rate (release point to Prosser Dam) vs water velocity below Sunnyside Dam, experimental hatchery smolts, 1983-I 987.

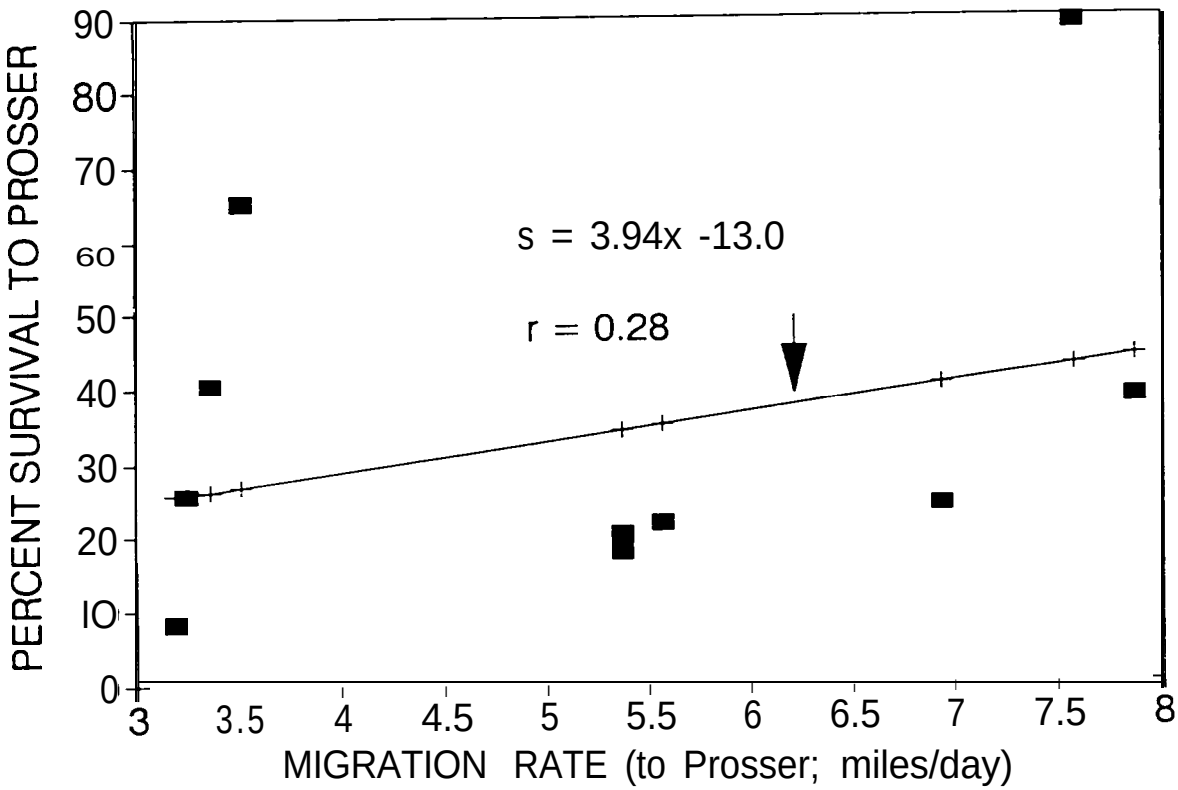


Figure 58. Survival to Prosser vs migration rate, experimental smolts, 1983 through 1987.

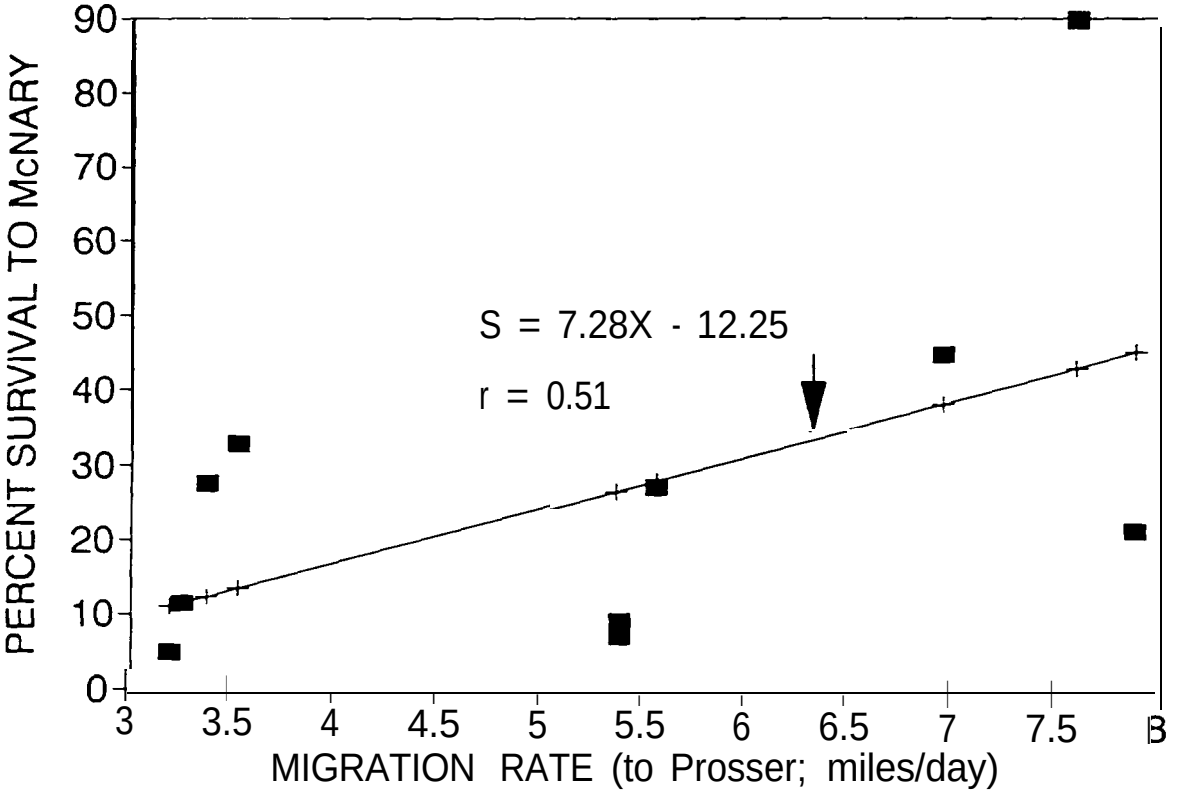


Figure 59. Survival to McNary vs migration rate, experimental smolts, 1983 through 1987.

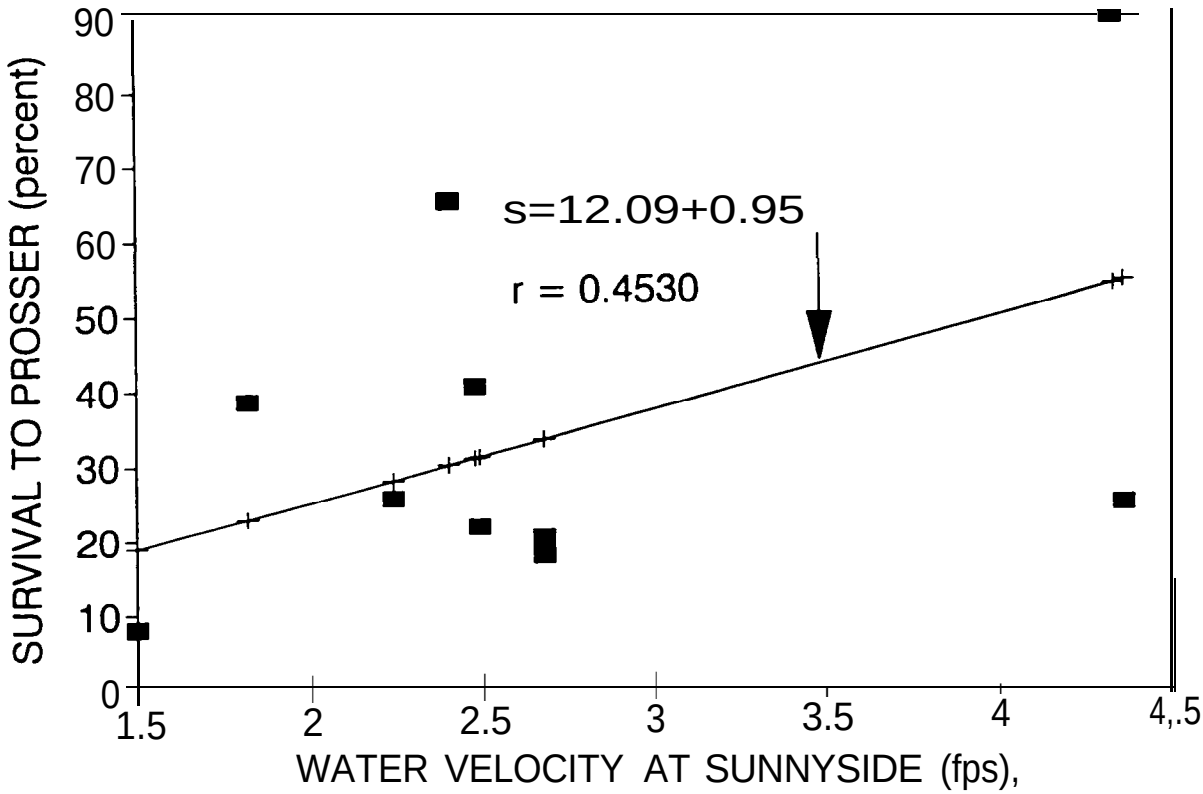


Figure 60. Prosser survival vs water velocity below Sunnyside Dam, experimental smolts, 1983 through 1987.

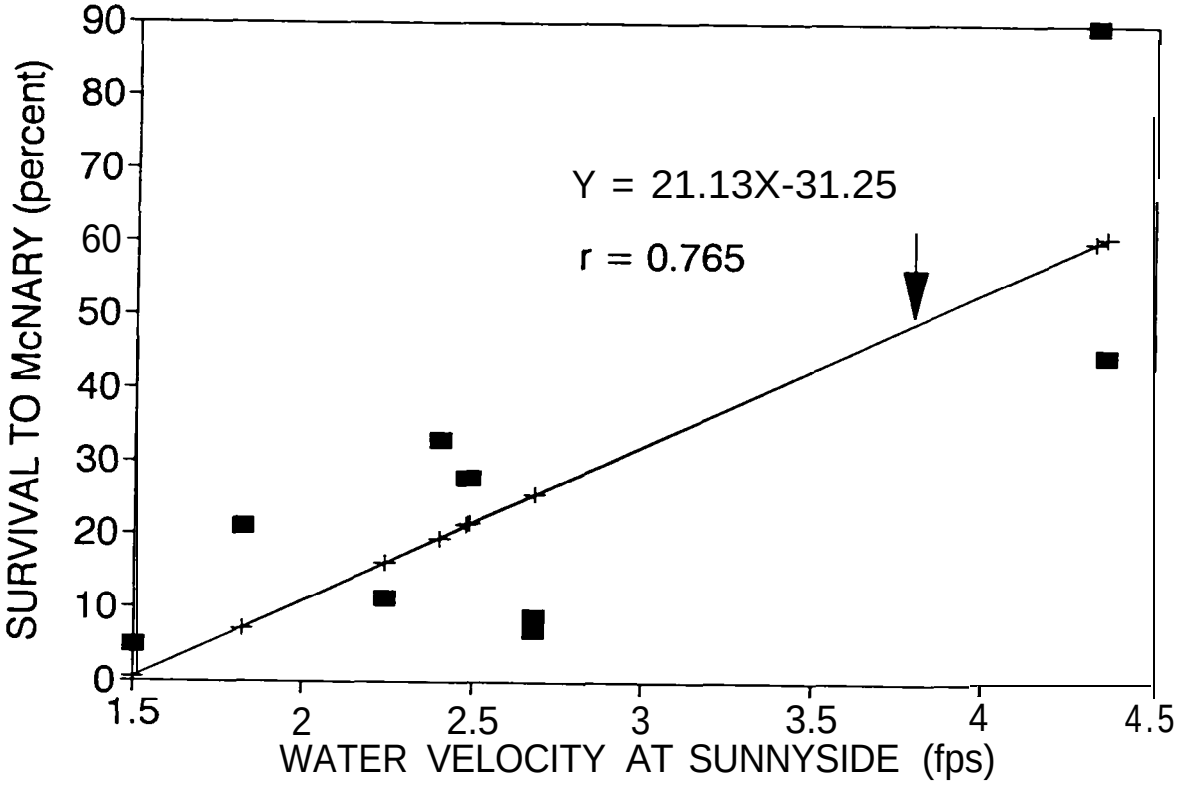


Figure 61. McNaty survival vs water velocity below Sunnyside Dam, experimental smolts, 1983 through 1987.

As has been mentioned, flows are only one of a large number of factors affecting the survival of outmigrating smolts. Nevertheless, it would appear that flows in one critical reach of the lower Yakima -- the reach from Sunnyside to Prosser -- have an impact on survival that is discernable even through the variability accompanying different groups of fish released at different places over five different years. The importance of the relationship between flows below Sunnyside and smolt survival is that mean flows during the outmigration must be increased substantially if survival is to be improved significantly by flow augmentation alone. Assuming the relationship between McNary survival and mean Sunnyside velocity is valid, a 50% McNary survival would entail a mean Sunnyside water velocity of 3.845 fps, which translates to a mean discharge of 4,276 cfs. Similarly, if survival to McNary were to be increased to 75%) the mean discharge below Sunnyside would have to be 7,241 cfs.

Cause of Poor Smolt-to-Smolt Survival

Six basic types of factors might be responsible for the poor in-basin survival observed in the Yakima. These potential causes are:

1) Entrainment in irrigation canals, or mortalities attributable to physical trauma associated with bypass systems on irrigation canals.

2) Poor water quality, specifically inadequate dissolved oxygen concentrations, excessive water temperatures, and injurious concentrations of toxic substances, especially pesticides and herbicides.

3) Physical stranding of smolts, especially in braided areas subject to sudden and wide flow fluctuations associated with delivery of stored water for irrigation.

4) Disease, especially bacterial kidney disease, and especially BKD in hatchery fish.

5) Residualization.

6) Predation, especially intense predation by piscivorous fish concentrated in mainstem areas heavily impacted by irrigation diversions.

The primary cause or causes of the poor in-basin survival cannot yet be conclusively identified. There is, however, some data suggesting that the sixth possibility, localized predation exacerbated by low flows, is the single most dominant factor.

It is highly unlikely that the screens and bypass systems in the larger mainstem Yakima irrigation canals are directly responsible for the degree of mortality researchers have observed. State-of-the-art angled, rotating drum screens and bypass systems were installed at all major diversions on the middle and lower Yakima before the outmigration of 1987. Each

of the new bypass systems were thoroughly evaluated immediately after construction, and all were found to pass very high proportions of marked smolts placed inside the canal, and to pass them quickly and with negligible descaling or physical injury (Fish Management Consultants 1990). Nevertheless, the highest survival of a group of hatchery smolts released in 1987 was 38% (see "Hatchery Operations"). In addition, the -5,000 wild spring chinook smolts released in the 1988 survival study also suffered heavy mortality in the middle Yakima. If substantial mortalities remain after screens and bypass systems have been replaced and favorably evaluated, the screens and bypass systems were most likely not directly responsible.

It is conceivable that most of the loss could be attributable to the roughly 60 "Phase-II screens" clustered primarily in the lower Naches and the upper Yakima upstream of Ellensburg. The Phase-II screens are located on small to medium-sized canals, and are both obsolete and badly deteriorated. Collectively, these screens probably do have a significant impact on the net production of smolts and, especially, fry. The Phase-II screens could not, however, have played any part in the losses of three of the four 1988 test groups, which were released in the Yakima below all but a few Phase-II screens.

Water quality, at least during the spring outmigration, is another unlikely candidate. The U.S. Geological Survey has maintained water quality gauging stations at Union Gap and Kiona for many years; inspection of their records indicates that neither temperature nor dissolved oxygen approaches physiologically limiting values through May Temperature rarely exceeds 16°C through this period, which includes well over 90% of the spring chinook outmigration; dissolved oxygen concentrations range from 8.6 mg/l to 12 mg/I. Nor are the most suspect toxic substances, pesticides and herbicides, likely to be a problem. In 1985 the Washington Department of Ecology's water quality investigations division evaluated the hazards to human health and aquatic life presented by toxic chemicals (DDT and metabolites, 15 additional organochlorine pesticides, PCBs and mercury) in water, sediments and fish tissue (Johnson et al. 1986). Compounds detected in fish included DDT, DDE, dieldrin and PCB-1260. Fish in the lower river had higher concentrations than fish in the upper river, and resident fish had higher concentrations than juvenile anadromous salmonids. Concentrations of all substances were, however, well below federal Food and Drug Administration "action levels," and were not high enough to suggest the possibility of impaired reproduction. DDT, DDE, DDD, dieldrin and endosulfan, evidently of historic origin, were detected in a number of irrigation drains, but only in one instance from the Yakima River (lower river at Kiona). All of these substances were present in concentrations well below those known to be toxic to aquatic life.

Physical stranding is a realistic possibility, at least in heavily braided reaches such as the lower Naches and the Easton reach of the upper Yakima. Once again, however, stranding could not have played a part in the 1988 survival study, in which fish were either released below braided areas (Yakima releases) or above them, but during a period of excellent flow (Naches releases).

The impact of disease on smolt survival, particularly the survival of wild fish, is almost totally unknown. However, it is believed to be minor for wild fish, as visibly ill wild fish have never been observed at Chandler. In particular, there have been no observations of the "bug-eye syndrome" characteristic of advanced BKD.

Thus, on the basis of tribal observations over the years, Yakima fisheries researchers believe that it is most probable that the ultimate cause of poor smolt survival is low flows, especially low flows downstream of irrigation diversions; but that the proximate cause of mortality is predation, especially predation by northern squawfish.

It is possible that poor smolt survival is attributable to predation in reaches below major diversions, and especially within and just downstream of the bypass outfall. Such reaches can be severely dewatered during a dry spring. The predator under greatest suspicion is the northern squawfish, although gulls are known to feed heavily on smolts in a few locations. The specific mechanism proposed is as follows. River flows, water velocities and mean depths in the middle and lower reaches of the river drop substantially during the course of the outmigration as irrigation demands rise. In a dry spring, these drops are earlier and more pronounced. Accordingly, the in-basin residence time and predatory vulnerability of outmigrants is increased. As the river shrinks and fewer near-shore refuges are accessible, smolts and predators are concentrated in smaller areas, and the consumption rates of predators (the functional response) increases. Smolts in the end of the outmigration, in mid to late May, are especially vulnerable, as increasing water temperatures further accelerate predator consumption rates.

Available data from the literature indicates smolt losses of the magnitude observed in the Yakima could be mainly or entirely attributable to squawfish predation. The total outmigration in the spring (March through June) of 1987 was 254,494 smolts. Assuming a 57% loss between Sunnyside and Prosser Dam, the total number that entered the reach was 254,494/.57, or 446,481 fish. The loss was therefore 191,987 smolts. If a squawfish consumes a smolt only once every three days over a 68-day period (April through the first week of lune), it would take 191,987/(68 X 0.33) or about 8,556 squawfish to consume – 192,000 smolts. If the mean feeding rate were one smolt per day, the necessary population would be only 2,823 squawfish.

Squawfish populations as large as 3,000 to 9,000 fish could reside in the Yakima River between Wapato Dam and Prosser Dam. The distance from Wapato Dam to Prosser Dam is 59.5 miles; the mean width of the river at normal spring flows (– 2,000 cfs) is about 250 feet. The total area of this reach is thus 78,540,OOO square feet, or about 730 hectares. If the total squawfish population in this area was 9,000 fish, a density of 12.3 fish per hectare would be required, or 3.8 fish per hectare for a total population of 2,800 squawfish. Squawfish densities of 12 fish per hectare have been observed in Lake Washington (Bar-too 1977), and 18.5 to 37 fish per hectare in Idaho's Cascade Reservoir (Lindland 1973). The lowest density reported in the literature for this species is 4.4 fish per hectare for the John Day Reservoir (Vigg 1988). It is worth noting that in a two-year survey of the Yakima

River in 1953 and 1954 (Patton 1957), the third most abundant species (both by numbers and biomass) was the northern squawfish.

Other Regions of Smolt Loss

Unfortunately, Yakima fisheries researchers have no concrete data to indicate any region other than the Sunnyside to Prosser reach is associated with significant smolt loss. They do, however, suspect that three other areas might be "hot spots," at least some of the time.

The forebay and, especially, the outfall area of Wapato Dam is almost certainly another hot spot. Unfortunately, a lack of experimental subjects precluded a examination of losses in the immediate area of Wapato Dam in 1988. However, schools of squawfish are known to congregate below the Wapato outfall from late March through July. Tribal biologists have observed squawfish chasing chinook smolts in this area on numerous occasions. At such times, anglers can catch large (12- to 15-inch) squawfish with a silver. smolt-like lure on virtually every cast.

Roza pool and the Yakima River below Roza Dam support large populations of squawfish. Indeed, very large squawfish are frequently videotaped in the Roza ladder. Tribal researchers suspect that predatory smolt mortality may be significant in Roza pool and in the Roza bypass outfall at low flows. The 1988 Roza release is not regarded as disproving this conjecture because, due to a misunderstanding, the Roza fish were released immediately in front of the screens and the bypass intake, and not at the head of the pool as had been planned.

The lower Naches River, between the Wapatox canal intake and the Wapatox powerplant outfall, is another region where smolt losses might be serious. This reach is over 60% braided, and is very heavily diverted during low flows; three quarters or more of the instream flow approaching Wapatox Dam may be diverted during low flows. Because of the potential stranding hazard, as well as the exacerbation of predation, this reach is a suspected "hot spot" at low flows.

Egg-to-Smolt Survival

Egg-to-smolt survival for wild Yakima spring chinook was estimated at Chandler as the ratio of the sum of the expanded catches to the total egg deposition in the subbasin. This rate was expressed both in terms of spring smolts and in terms of the "total brood year production," the sum of winter migrants and spring smolts. Again, "winter migrants" were defined as all spring chinook juveniles observed at Chandler between November 1 and February 28; "spring smolts" were defined as juveniles observed between March 1 and June 30.

Winter migrants and spring smolts have been separated primarily because the mortality winter migrants experience between observation at Chandler and the beginning of the spring outmigration is unknown. If, for example, this mortality was 50%, each winter migrant would be "worth" half a spring smolt.

Egg-to-smolt survival for the brood years 1981 through 1988 (outmigrations of 1983-1990) is summarized in Table 44. Note that these figures are expressed in terms of smolts surviving to Prosser; no correction for upstream losses has been made.

Expressed as spring smolts, egg-to-smolt survival has ranged from about 1.1% to 8.8%, and from 1.3% to 10.6% if winter migrants are included. (Note that the contribution of winter migrants for brood years 1981 through 1984 was not directly estimated. Rather, it was assumed to equal the observed mean for brood years 1985 through 1988, ~ 20% of total brood year production.) The 1981 brood (1983 outmigration) had the highest survival rate, 8.84% and 10.61% for spring smolts and total production, respectively. After 1983, survival rates generally dropped for each successive brood year. The low point was reached with the 1987 brood (1989 outmigration), for which egg-to-smolt survival was only 1.07% and 1.27% for spring smolts and total production, respectively. Egg-to-smolt survival for the 1988 brood year, the last year monitored, rebounded considerably, to 3.65% and 4.69% for spring smolts and total production, respectively.

It should be noted that the observed rates would almost certainly be substantially greater if the counting station had been farther up the drainage. If the counting station had been above Wapato Dam, and if smolt mortality between Wapato and Prosser dams was about 50%, the survival rates would have ranged from 2.2% to 17.6% as spring smolts, or from 2.6% to 2 1.2 % as total brood year production.

The egg-to-smolt survival rates tribal biologists have estimated on the Yakima compare reasonably well with rates reported for spring chinook on other Columbia Basin tributaries. On the Lemhi River in Idaho, Bjomn (1978) reported that egg-to-smolt survival ranged from 4% to 15.9% for brood years 1962 through 1975. Lindsay et al. (1982) reported spring chinook survival in the Deschutes River ranged from 2.3% to 10% for brood years 1975 through 1980. Survival rates in the John Day River for brood years 1978 through 1982 ranged from 3.6% to 8.6% (Lindsay et al. 1985). The principal difference between these other systems and the Yakima would seem to be the greater variability of Yakima estimates. High variability might be expected in a system like the Yakima, which experiences extreme variability in flow from year to year.

Table 44. Estimated egg-to-smolt survival rates for wild spring chinook, brood years 1981-1988.

BROOD YEAR	NUMBER OF SPRING SMOLTS	EGG-TO-SMOLT SURVIVAL BASED SOLELY ON SPRING SMOLTS	NUMBER OF WINTER-MIGRANT PRE-SMOLTS	EGG-TO-SMOLT SURVIVAL BASED ON BOTH SPRING SMOLTS AND WINTER MIGRANTS (R)
1981	167,077	8.84	33,415'	10.61
1982	143.33 1	6.33	28.666'	7.59
1983	96,413	5.77	19,282	6.93
1984	180,789	6.02	36,157[a]	7.22
1985	254,494	4.20	75,983	5.45
1986	282,968	1.87	7 1,336	2.35
1987	92,935	1.07	16,721	1.27
1988	202,932	3.65	58,128	4.69

[a] Estimated as 20% of spring smolt production; winter migrants not actually monitored.

The reasons for the decline and rebound of egg-to-smolt survival over the brood years 1981 through 1988 can be determined only to a limited degree. It must be borne in mind that egg-to-smolt survival integrates all survival rates impacting the population from the time of egg deposition through observation of migrating smolts at the counting station. Mathematically, egg-to-smolt survival is simply the product of all life-stage-specific survival rates preceding the outmigrant smolt at a counting station -- survival to emergence, early fry survival, spring/summer parr survival, overwinter survival of pre-smolts, and smolt-to-smelt survival of outmigrants. The magnitude of egg-to-smelt survival is therefore dependent on its smallest component.

Researchers have very little data bearing on the biotic factors affecting survival of the life stages leading up to outmigrant smolts. The number of eggs deposited and the number of smolts passing Prosser are the most significant biotic data available. Total egg deposition is significant because it largely determines the degree of density-dependent mortality to be expected. Smolt production will impact smolt-to-smelt survival by its effect on predation, which can generally be expected to be depensatory.

Researchers do, however, have a wealth of data bearing on important abiotic factors. The combination of the Bureau of Reclamation's discharge records and the IFIM data base developed by the U.S. Fish and Wildlife Service allows researchers to examine the hydraulic conditions impacting fish of a given brood at each life stage from egg to downriver smolt. However, the utility of this data base is significantly compromised by the fact it refers primarily to the upper Yakima. Moreover, and perhaps more importantly, tribal researchers do not know the proportion of Naches system and upper Yakima fish in the outmigration observed at Chandler. Thus, it is impossible to associate hydraulic events in the upper Yakima with a known number of upper Yakima smolts at Chandler several months to a year later.

Nevertheless, tribal researchers have examined the correlation between hydraulic events in the upper and middle Yakima and egg-to-smolt survival for all Yakima smolts. Researchers did so with the understanding that hydraulic-survival relationships specific to upper Yakima fish will be confounded with the survival of Naches fish subject to other influences. Researchers are, however, also aware that the Chandler outmigration should reflect upper Yakima survival fairly well, since the majority of fish at Chandler are upper Yakima fish; most of the egg deposition for brood years 1981 through 1988 occurred in the upper Yakima (mean = 61%). The utility of this investigation is further bolstered by the fact that many of the more important areas to be investigated are in the Yakima River below the Naches confluence, and therefore affect all stocks.

Tribal researchers examined relationships between hydraulic events and basinwide egg-to-smolt survival by regression techniques, specifically by stepwise multiple regression. The dependent variable was egg-to-smolt survival, expressed as spring smolts (March 1 through June 30); the independent variables were egg deposition, number of spring outmigrants, and a number of hydraulic parameters that might plausibly impact survival of specific life stages. Researchers used data from the eight years of study (1983-1990), as well as the five years (1959-1963) egg-to-smolt survival was monitored by Major and Mighell (1969). Fortunately, Major and Mighell estimated outmigration at the same site used in the present study (Chandler canal), ensuring the fundamental comparability of outmigration estimates then and now.

Major and Mighell's (1969) outmigration and egg deposition estimates have, however, been reworked to increase comparability with tribal data. Specifically, tribal researchers re-estimated basinwide egg deposition by the procedures outlined in under "Egg-to-Fry Survival" in this document, and recalculated outmigration by expanding Major and Mighell's record of daily raw catches with the tribe's new diversion/entrainment estimator (See Appendix D).

Probably the most significant revision tribal biologists made to Major and Mighell's (1969) data was the recalculation of the number of redds in the upper Yakima used in estimating egg deposition. Major and Mighell estimated upper Yakima redds directly; one or

two men waded or floated sections of the river as frequently as once a week, updating a cumulative count of redds and live fish. It is, however, probable that Major and Mighell (1969) lacked sufficient manpower to survey the upper Yakima thoroughly (the Yakima Indian Nation typically assigns four men per reach, two per raft, one raft for each side of the river). When compared with Washington Department of Fisheries counts of adult spring chinook passage at Roza Dam from 1957 through 1961 (the brood years Major and Mighell studied), Major and Mighell's redd counts indicate the spawner-per-redd ratio in these years varied from 3.3 to 6.5 (mean = 4.4). The mean "spawners-per-redd ratio" tribal biologists have observed for brood years 1981 through 1990 has been -2.3. Accordingly, the tribe has concluded that Major and Mighell (1969) were unable to locate all redds in the upper Yakima; tribal researchers have revised upper Yakima redd counts for 1957 through 1961 by dividing the Roza adult count by 2.3. (Tribal researchers have assumed the redd counts for the much smaller Naches system were accurate).

Tribal biologists made one other significant revision to Major and Mighell's data. Major and Mighell mention that in 1957, "30 to 50 percent of the eggs deposited in the upper Yakima River succumbed to exposure when, in October and November, the water level was artificially lowered and maintained 2 feet below what it had been when the fish spawned in late September." Tribal researchers used this information to calculate an "effective egg deposition" for the upper Yakima, by multiplying the tribe's revised egg estimate by 0.6.

Tribal researchers have analyzed the following hydraulic events for impact on egg-to-smolt survival as observed at Chandler:

1) The earliest life stage investigated is the early post-emergent stage. (Tribal biologists will not investigate survival to emergence because, except for 1957, all years examined have been characterized by good incubation flows in the upper Yakima. Researchers have therefore assumed that survival to emergent fry did not vary appreciably between years except in 1957. As mentioned, egg deposition figures for 1957 were adjusted to reflect poor incubation conditions.) Specifically, tribal researchers have indexed the probability of newly emergent fry becoming stranded (or exposed to severe predation risk) in one of the numerous side channels of the Easton reach. Observations and IFIM data indicate that some side channels begin to dewater at total flows (across all channels) of about 200 cfs, and that most are dewatered or isolated at flows of 100 cfs. Tribal researchers have therefore assumed that stranding risk becomes significant when total flow in the Easton reach falls below 150 cfs. The tribe tracked both the number of days total flows were 150 cfs or less in the early post-emergent period (April through July), as well as the number of "recruitment/stranding" cycles that occurred in the period -- the number of occasions from April 1 through July 31 that flows equalled or exceeded 200 cfs and then fell to 150 cfs or less.

2) Tribal researchers did not investigate hydraulic impacts on the quantity of summer rearing habitat available to parr in the upper Yakima. Although summer rearing habitat may well limit overall production, the annual variability of rearing habitat, due to the careful control of flows for irrigation, is very small.

3) Researchers indexed the impact of flows on the availability of winter habitat for pre-smolts. Specifically, tribal biologists indexed the degree to which winter flows permitted access to shoreline structures (such as large organic debris, undercut banks, and submerged vegetation) that spring chinook use for overwintering by tracking mean channel width from October through February in four areas in which overwintering is thought to occur: the Easton, Cle Elum and Yakima Canyon reaches in the Yakima River, and the lower Naches River (below the Tieton confluence). Tribal biologists also tracked mean depth and cross-sectional area in these reaches over the winter months.

4) Finally, the tribe investigated the impact of flow on smolt-to-smolt survival in two ways. First, researchers examined the probability of entrainment (and bypass) in Roza, Wapato, Wapatox and Sunnyside canals. Assuming that entrainment is roughly proportional to percent diversion at all of these dams, researchers estimated the "probability of entrainment" by site and year as the mean percent diversion over a criterial period. The criterial period began on the day cumulative passage at Prosser reached 10%) and ended when Prosser passage reached 90%. If E,, E_{wo}, E_{wx} and E, are the seasonal probabilities of entrainment/bypass at Roza, Wapato, Wapatox and Sunnyside, respectively, then (1 - E,) is the probability of avoiding entrainment. Moreover, the product of the "avoidance probabilities" at Wapatox, Wapato and Sunnyside, and at Roza, Wapato and Sunnyside, represents an index of the probability of avoiding entrainment at any dam above Prosser along both major migration routes.

The second relationship to be investigated is the impact of flow in the "bottleneck reach" between Sunnyside Dam and Prosser Dam on the survival of migrating smolts. Tribal biologists used IFIM data and flow records to estimate the mean velocity, depth, width and cross-sectional area in this reach through a criterial time period. Again, the criterial time period was bounded by the dates of 10% and 90% cumulative passage at Chandler. Researchers also tracked the number of days in the criterial period flows fell below 1,000 cfs in the Sunnyside-to-Prosser reach, as flows of this magnitude have seemed to characterize "stalled" outmigrations.

Egg-to-smolt survival rates for 1959 through 1963 and 1983 through 1990, as well as the various parameters assumed to impact egg-to-smelt survival, are summarized in Table 45. Note that this table also lists correlation coefficients between each putative independent variable and egg-to-smolt survival.

The results of one variable linear regression are summarized in Table 45. Tribal researchers found the coefficients of determination in the table somewhat surprising. The

only significant correlations were between egg-to-smolt survival and: egg deposition; ln(egg-deposition); the number of days Easton flows were less than 150 cfs in the early post-emergent period (April-July); the mean over-winter width, depth and cross-sectional area in the Yakima Canyon the winter before outmigration; and the mean overwinter cross-sectional area in the lower Naches the winter before outmigration. None of the "avoidance probabilities" at individual dams were significant by themselves (although Wapatox approaches significance at the 0.1 level), and none of the hydraulic variables characterizing conditions between Sunnyside and Prosser during the outmigration approached significance.

Table 45. Estimated Yekima River spring chtnook egg-to-smolt survival for brood years 1957-1963 end 1981-1988, and biotrc and hydreulrc parameters assuned to have an jmpact on egg-to-smolt survival. Note that the r^2 values associated with hydraulic parameters indicate the coefficient of determination for a one-variable regressjon of survival on the independent variable (over aLL years). Note also that *, * , ** , and **** indicate the correlation coefficient was significant at the -1, .05, .025 and -01 Levels, respectively.

PARAMETER	BROOD YEAR (ADD 2 FOR YEAR OF SMOLT UJTMIGRATION)												
	1957	1958	1959	1960	1961	1981	1982	1983	1964	1985	1986	1987	1988
EGG-TO-SMOLT SURVIVAL (%)	5.36	5.71	6.70	7.12	10.33	8.84	6.33	5.77	6.02	4.20	1.88	1.07	3.65
EGG DEPOSITION ($X 10^6$) r^2 = .5566****	9.054	4.586	3.351	1.482	2.653	1.889	2.265	1.670	3.003	6.061	15.073	8.661	5.563
ln (# EGGS) r^2 = .5714****	2.203	1.523	1.209	0.393	0.976	0.636	0.818	0.513	1.100	1.802	2.713	2.159	1.716
TOTAL SMOLT OUTMIGRATION (spring smolts) r^2 = .0008	485,318	261,977	224,438	105,455	274,157	167,077	143,331	96,413	180,789	254,494	282,968	92,935	202,932
ln(# SMOLTS) r^2 = .0077	13.092	12.476	12.321	11.566	12.521	12.026	11.873	11.476	12.105	12.447	12.553	11.440	12.221
# EASTON RECRUITMENT/ STRANDING EPISODES r^2 = .0574	3	1	4	2	3	1	1	0	3	3	2	5	1
# DAYS EASTON FLOWS <150 cfs APRIL - JULY r^2 = .4247****	41	17	27	14	24	5	3	0	19	15	43	64	38

Table 45. Estimated Yakima River spring chinook egg-to-smolt survival for brood years 1957-1963 and 1981-1988, and biotic and hydraulic parameters assumed to have an impact on egg-to-smolt survival. Note that the r^2 values associated with hydraulic parameters indicate the coefficient of determination for a one-variable regression of survival on the independent variable (over all years). Note also that *, **, ● **, and • *** indicate the correlation coefficient was significant at the .1, .05, .025 and .01 levels, respectively.

PARAMETER	BROOD YEAR (ADD 2 FOR YEAR OF SMOLT OUTMIGRATION)												
	1957	1958	1959	1960	1961	1981	1982	1983	1984	1985	1986	1987	1988
MEAN WIDTH OCT - FEB EASTON REACH (ft) r^2 = .1058	80.96	87.83	68.72	71.48	70.59	72.28	75.55	63.42	67.41	64.65	58.34	67.46	69.54
MEAN DEPTH OCT - FEB EASTON REACH (ft) r^2 = .1050	3.01	3.22	2.62	2.71	2.68	2.74	2.84	2.46	2.58	2.5	2.29	2.59	2.65
MEAN CROSS SECT. AREA OCT - FEB EASTON REACH (ft_2) r^2 = .0936	250.61	292.87	185.79	200.07	195.2	199.41	217.71	156.1	175.67	162.86	134.59	175.72	187.68
MEAN WIDTH OCT - FEB CLE ELUM REACH (ft) r^2 = .0806	177.38	190.54	154.96	159.81	159.7	162.17	166.64	150.75	156.99	151.5	139.33	156.21	158.74
MEAN DEPTH OCT - FEB CLE ELUM REACH (ft) r^2 = .0624	1.98	2.46	1.46	1.58	1.56	1.58	1.71	1.32	1.46	1.36	1.13	1.44	1.51
MEAN CROSS SECT. AREA OCT - FEB CLE ELUM REACH (ft_2) r^2 = .0500	360.24	500.73	234.93	261.90	255.00	258.25	292.21	197.29	230.92	208.27	159.91	224.39	244.46

Table 45. Estimated Yakima River spring chinook egg-to-smolt survival for brood years 1957-1963 and 1981-1988, and biotic and hydraulic parameters assumed to have an impact on egg-to-smolt survival. Note that the r^2 values associated with hydraulic parameters indicate the coefficient of determination for a one-variable regression of survival on the independent variable (over all years). Note also that• ,• *,• **, and • *** indicate the correlation coefficient was significant at the .1, .05, .025 and .01 levels, respectively.

PARAMETER	BROOD YEAR (ADD 2 FOR YEAR OF SMOLT OUTMIGRATION)												
	1957	1958	1959	1960	1961	1981	1982	1983	1984	1985	1986	1987	1988
MEAN WIDTH OCT - FEB YAKIMA CANYON (ft) r^2 = .1917*	198.22	202.48	185.36	186.87	190.83	190.15	191.91	181.72	183.68	181.32	172.69	184.06	186.59
MEAN DEPTH OCT - FEB YAKIMA CANYON (ft) r^2 = .1624*	3.10	3.44	2.41	2.49	2.68	2.62	2.75	2.18	2.30	2.18	1.82	2.30	2.43
MEAN CROSS SECT. AREA OCT - FEB YAKIMA CANYON (ft_2) r^2 = .1520*	600.83	693.12	437.48	455.24	498.69	483.14	515.91	380.04	408.42	379.62	302.24	407.22	437.76
MEAN WIDTH OCT - FEB LOWER NACHES (ft) r^2 = .1159	135.62	124.50	99.90	84.20	125.1	122.00	134.50	89.53	95.52	86.35	101.8	97.28	108.25
MEAN DEPTH OCT - FEB LOWER NACHES (ft) r^2 = .1092	1.85	1.72	1.42	1.22	1.72	1.69	1.84	1.30	1.36	1.25	1.45	1.39	1.52
MEAN CROSS SECT. AREA OCT - FEB LOWER NACHES (ft_2) r^2 = .1381*	268.29	225.16	151.54	114.4	230.14	216.71	257.23	118.54	140.24	112.61	151.56	140.95	173.65

Table 45. Estimated Yakima River spring chinook egg-to-smolt survival for brood years 1957-1963 and 1981-1988, and biotic and hydraulic parameters assumed to have an impact on egg-to-smolt survival. Note that the r^2 values associated with hydraulic parameters indicate the coefficient of determination for a one-variable regression of survival on the independent variable (over all years). Note also that ● ,● *,***,and . *** indicate the correlation coefficient was significant at the .1, .05, .025 and .01 levels, respectively.

	BROOD YEAR (ADD 2 FOR YEAR OF SMOLT OUTMIGRATION)												
PARAMETER	1957	1958	1959	1960	1961	1981	1982	1983	1984	1985	1986	1987	1988
MEAN VELOCITY BELOW SUNNYSIDE (fps) r^2 = .0201	3.38	1.83	1.79	1.94	2.83	3.83	2.78	2.36	1.60	2.40	2.30	3.88	3.39
MEAN DEPTH BELOW SUNNYSIDE (ft) r^2 = .0148	3.49	2.39	2.35	2.48	3.13	3.81	3.1	2.74	2.15	2.80	2.68	3.84	3.51
MEAN CROSS SECT. AREA BELOW SUNNYSIDE (ft^2) r^2 = .0193	980.8	545.4	532.5	576.0	828.2	1108.1	814.4	694.2	478.0	706.1	674.1	1122.6	983.7
MEAN WIDTH BELOW SUNNYSIDE (ft) r^2 = .0070	272.8	231.0	229.3	235.3	261.3	284.2	259.6	242.4	214.9	247.1	238.8	284.9	274.3
AVOIDANCE PROBABILITY ROZA CANAL r^2 = .0538	51.3	40.9	59.9	27.6	33.2	49.9	43.2	49.0	26.3	46.3	45.0	49.7	37.6
AVOIDANCE PROBABILITY WAPATOX CANAL r^2 = .1246	82.6	87.4	87.3	83.2	88.0	91.3	77.9	81.7	80.1	80.6	80.0	86.3	86.8
AVOIDANCE PROBABILITY WAPATO CANAL r^2 = .0193	74.0	70.1	79.6	60.3	73.1	81.4	68.8	62.3	58.8	66.2	61.6	79.1	71.4

Table 45. Estimated Yakima River spring chinook egg-to-smolt survival for brood years 1957-1963 and 1981-1988, and biotic and hydraulic parameters assumed to have an impact on egg-to-smolt survival. Note that the r^2 values associated with hydraulic parameters indicate the coefficient of determination for a one-variable regression of survival on the independent variable (over all years). Note also that ● ,● *,***,and • *** indicate the correlation coefficient was significant at the .1, .05, .025 and .01 levels, respectively.

PARAMETER	BROOD YEAR (ADD 2 FOR YEAR OF SMOLT OUTMIGRATION)												
	1957	1958	1959	1960	1961	1981	1982	1983	1984	1985	1986	1987	1988
AVOIDANCE PROBABILITY SUNNYSIDE CANAL r^2 = .0023	73.3	69.9	82.6	52.7	73.5	83.9	72.0	55.2	39.8	64.4	58.2	82.3	76.0
AVOIDANCE PROBABILITY WAPATOX-WAPATO-SUNNYSIDE r^2 = .0171	45.0	43.4	57.7	29.3	48.3	62.6	39.3	31.1	20.6	35.7	31.9	56.7	47.8
AVOIDANCE PROBABILITY ROZA-WAPATO-SUNNYSIDE r^2 = .0014	29.9	22.3	40.1	11.7	18.7	34.4	22.6	21.1	6.6	21.9	17.9	32.1	22.3

Researchers performed four stepwise multiple regressions. Two included all years' data, or only the years 1983 through 1990; and two included all putative independent variables, or all variables save estimated egg deposition (only density-independent variables). Note that all regressions were performed on standardized data; dependent and independent variables were transformed into standard normal deviates by subtracting the mean from each observation and dividing the difference by the standard deviation of all years' observations. Data were transformed in this way to put all observations "on the same scale." The cases examined may be summarized as follows.

CASE 1 ALL years' data; all independent variables	CASE 3 Only data from broods 1981-1988; all independent variables
CASE 2 All years' data; all independent variables except those related to egg deposition	CASE 4 Only data from broods 1981-1988; all independent variables except those related to egg deposition

The regressions that utilized all independent variables (Cases 1 and 3) were somewhat similar. For the "all years" (1959-63 and 1983-90) and "recent years" (1983-90) regressions, the first variable to be entered was the natural log of egg deposition; the second variable was the natural log of smolt production. (Note that egg deposition and smolt production are still the first and second variables entered if they are not expressed as logs, but the coefficient of determination is slightly smaller.) The coefficient of determination for survival as a function of In(eggs) is .57 and .79 for all years and recent years, respectively. When smolt production is added, these R^2s increase to .90 (all years) and .93 (recent years). The third variable to be entered in the "all years" regression is the number of days flows were less than 150 cfs at Easton in the post-emergent period (Eas_{150}); the third variable to be entered in the "recent years" regression is the avoidance probability at Wapato (A_{wap}). Addition of these variables increases the R^2 but slightly -- to .93 for the "all years" regression, and to .96 for the "recent years" regression. Variables were reshuffled somewhat in the best four-variable model, which increased the R^2 to .95 and included In(eggs), In(smoIts), avoidance probability at Wapato (A_{wap}), and combined avoidance probability at Roza/Wapato/Sunnyside (A_{RWS}) in the "all years" regression; and which increased the R^2 to .99 in the "recent years" regression and involved In(eggs), ln(smoIts), combined avoidance probability at Wapatox/Wapato/Sunnyside (A_{WWS}) and channel width below Sunnyside during the outmigration period (W_{SS}). The best one- through four-variable regressions are summarized below.

All Years:

$$S = -.76\ln(eggs) + -16;$$
$$r^2 = .57 \quad (p = -0028)$$

$$S = -1.1\ln(eggs) + .67\ln(smolts) + .24;$$
$$R^2 = -90 \quad (p = .0001)$$

$$S = -1.42\ln(eggs) + .76Ln(smlts) + .33Eas_{150} + -31;$$
$$R^2 = .93, \quad (p = -0001)$$

$$s = -1.07\ln(eggs) + .62\ln(smolts) + .50A_{wsp} - .37A_{nws} + -23;$$
$$R^2 = -95 \quad (p = .0001)$$

Recent Years:

$$s = - .81\ln(eggs) - .1;$$
$$r^2 = .79 \quad (p = .0032)$$

$$S = -.99\ln(eggs) + .5\ln(smolts) + .1;$$
$$R^2 = .93 \quad (p = .0012)$$

$$S = -1.01\ln(eggs) + .59\ln(smolts) + .18A_{wsp} + .16;$$
$$R^2 = .96 \quad (p = -0023)$$

$$S = -.96\ln(eggs) + .48Ln(smolts) + .84A_{wws} - .74W_{SS} + .32;$$
$$R^2 = .99 \quad (p = .0022)$$

The preceding analysis indicates that density-dependent factors account for much more annual variability in egg-to-smolt survival than the flow-related, density-independent factors used in this analysis. This conclusion is somewhat surprising in light of the range of flow fluctuations over the years analyzed.

The Case 2 and 4 regressions eliminated egg deposition and the natural log of egg deposition from the analysis. This was done to examine flow-related, density-independent factors in isolation. When eggs are excluded from the "all years" regression, the first variable to be entered is the number of days flows were less than 150 cfs at Easton during the early post-emergent period (Eas,,,). This one-variable regression has an r^2 of .42. The second variable to enter is the avoidance probability at Wapatox (A_{wptx}); the R^2 increases to .62. The third variable entered, the number of recruitment/stranding episodes at Easton during the early post-emergent period ($Eas_{r/s}$), is closely related to the first, Eas_{150}, and increases the R^2 to .69. The coefficient of determination increases to .80 when the fourth variable, mean overwinter depth in the lower Naches (D_{Nach}), is entered. As was the case with the analyses involving all independent variables, researchers will discuss no models more complex than the four-variable model because the regression is based on only 13 observations.

The regression using only recent years' data with eggs excluded begins much like the "all years" regression. The first variable entered is Eas_{150} (r^2 = .76), and the second variable entered is A,, (R^2 = .89). However, the "recent years" regression diverges from the "all years" regression when the third and fourth variables are entered. The best three-

variable regression involves a reshuffling of variables; the avoidance probability at Wapatox is dropped, and the avoidance probability at Wapato (A_{wap}) is added, along with the combined avoidance probability at Roza/Wapato/Sunnyside (A_{RWS}), giving an R^2 of .95. The fourth variable entered, overwinter width at Cle Elum (W_{Cle}), results in an R^2 of .98. The best one-through four-variable regressions with eggs excluded are summarized below.

<u>All Years (eggs excluded)</u>:

$$S = -.65Eas_{150} + .0013;$$
$$r^2 = .42 \ (p = .0158)$$

$$S = -.71Eas_{150} + .45A_{wptx} + .0014;$$
$$R^2 = .62 \ (p = .0077)$$

$$S = .36Eas_{1/8} - .95Eas_{150} + .45A_{wptx} + .0012;$$
$$R^2 = .69 \ (p = .0110)$$

$$S = .33D_{Nach} + .44Eas_{1/8} - .99Eas_{150} + .38A_{wptx} + .0011;$$
$$R^2 = .80 \ (p = .0072)$$

<u>Recent Years Onlv (eggs excluded)</u>:

$$S = -.71Eas_{150} - .37;$$
$$r^2 = .76 \ (p = .0046)$$

$$S = -.77Eas_{150} + .32A_{wptx} - .288;$$
$$R^2 = .89 \ (p = .0037)$$

$$S = -.82Eas_{150} + .99A_{wap} - .86A_{RWS} - .314;$$
$$R^2 = .95 \ (p = .0046)$$

$$S = -.98Eas_{150} + 1.59A_{wap} - 1.37A_{RWS} - .51W_{Cle} - .487;$$
$$R^2 = .98 \ (p = .0091)$$

This "exploratory" regression analysis must be interpreted cautiously. Rearing in mind that correlation does not establish causation, it nonetheless appears that biotic, density-dependent factors are associated with annual variability in egg-to-smolt survival more than a particular set of density-independent factors related to flow. It is also clear that the particular flow-related variables researchers have investigated are also correlated with survival, and that fairly tight tits can be obtained with flow-related factors alone at the three- and four-variable level. The estimates of egg-to-smolt survival for 1983 through 1990 generated by the four-variable models containing or excluding eggs may be compared with the actual values in Table 46.

Considering only flow-related factors, it is apparent some are much more related to survival than others. The probability of avoiding entrainment in mainstem dams, especially Wapatox and Wapato, is a recurring element in these regressions, as is the frequency of low flows in the Easton reach during the early post-emergent period. Variables presumed to be related to overwinter survival occur but twice and, surprisingly, variables related to the survival of outmigrating smolts in the Sunnyside to Prosser reach occur only once (in regressions containing up to four variables).

From the perspective of both the density-dependent and density-independent regressions discussed above, it is clear that the decline of egg-to-smolt survival from the 1981 brood through the 1387 brood is attributable primarily to increasing egg deposition, increasing numbers of days of low flow at Easton during the early post-emergent period, and decreasing avoidance probabilities at mainstem dams.

Table 46. Comparison of egg-to-smolt survival for Yakima spring chinook as estimated by four-variable multiple regressions including or excluding egg deposition.

YEAR	"ACTUAL" EGG-TO-SMOLT SURVIVAL	EGG-TO-SMOLT SURVIVAL AS ESTIMATED BY FOUR-VARIABLE REGRESSION CONTAINING A TERM FOR EGG DEPOSITION	EGG-TO-SMOLT SURVIVAL AS ESTIMATED BY FOUR-VARIABLE REGRESSION EXCLUDING A TERM FOR EGG DEPOSITION
1983	8.84%	8.80%	8.65%
1984	6.33%	5.88%	6.27%
1985	5.77%	5.95%	5.43%
1986	6.02%	6.07%	5.87%
1987	4.20%	4.43%	5.10%
1988	1.88%	1.65%	1.66%
1989	1.07%	1.08%	0.96%
1990	3.65%	3.93%	3.85%

The relative importance of the density-dependent and flow-related factors analyzed here may be spurious. It is quite probable that flow variables could have been expressed better, by casting them in terms of a more relevant parameter or by averaging them over a more appropriate time interval. It is also possible that, under current conditions, egg deposition and the number of outmigrants really are the best predictors of egg-to-smolt survival. The truth of this hypothesis does not, however, imply that flows are not important nor, indeed, that they are not the primary factor limiting production.

The current carrying capacity of the system is largely determined by the amount of habitat in which depth and velocity fall within the preferred range of juvenile spring chinook. As depth and velocity are inescapably tied to flow, it follows that flow patterns are very important determinants of carrying capacity. There is abundant evidence that existing, highly regulated flow patterns restrict carrying capacity to such a degree that egg-to-smolt survival may well be significantly impacted by density-dependent factors, even with the modest

escapements seen in recent years. One need only consider a plot of the weighted useable area in the Yakima Canyon to appreciate the truth of this assertion. The Yakima Canyon is probably the most important summer rearing area in the subbasin. Figure 62 plots weighted useable area for spring chinook parr in the Yakima Canyon as a function of discharge. It is evident from this figure that optimal flows for juvenile rearing are very much less than typical summer flows as regulated for irrigation delivery. Flows are in fact so high that the useable habitat available to spring chinook is only about 20% of that potentially available. This type of situation is characteristic of the entire upper Yakima from the city of Yakima to Easton Dam. Because summer flows are regulated, and are quite similar from year to year. flows may be limiting although not especially useful as predictors.

Smolt-to-Adult Survival

Methods

The smolt-to-adult survival (S,) of wild spring chinook salmon in the Yakima system uas based on the estimated outmigration of smolts at Prosser from 1983 through 1987. The adult returns that correspond to each year's smolt outmigration was calculated as the sum of the jacks (3-year-old fish) returning one year after the smolt outmigration, and the 4, 5- and 6-year-old adults returning two three and four years after the outmigration. The jack return is determined directly from adult counts made at the Prosser counting window (visual or videotape counts). The 4-. 5- and 6-year-old fish returning in any given year are separated by age class analysis of scales collected from carcasses on the spawning grounds.

Three distinct substocks (American River, Naches River and upper Yakima River) occur in the Yakima Subbasin (Busack 1990). Each substock was age-classed separately. The number of fish returning from each substock was calculated by determining what proportion of the total redds counted in the entire basin in a given year were deposited in each of the three spawning areas. The age class structure of each substock was then applied to the appropriate proportion of the entire adult return (minus jacks) to the Yakima Subbasin. The total adult return is calculated as the counts from the windows at Prosser plus the tribal ceremonial and subsistence harvest below Prosser. Thus, if the American River had 15% of the total redds in the subbasin, the age class structure of the American River substock was applied to 15% of the total adult return to Prosser (minus jacks) plus the tribal harvest below Prosser.

These estimations of smolt-to-adult survival begin with the smolt outmigration in 1983 (the first year of smolt trapping in the subbasin) and end with the 1987 smolt outmigration. Smolt outmigrations were also estimated in 1988, 1989, and 1990, but obviously the adult returns are incomplete for those years.

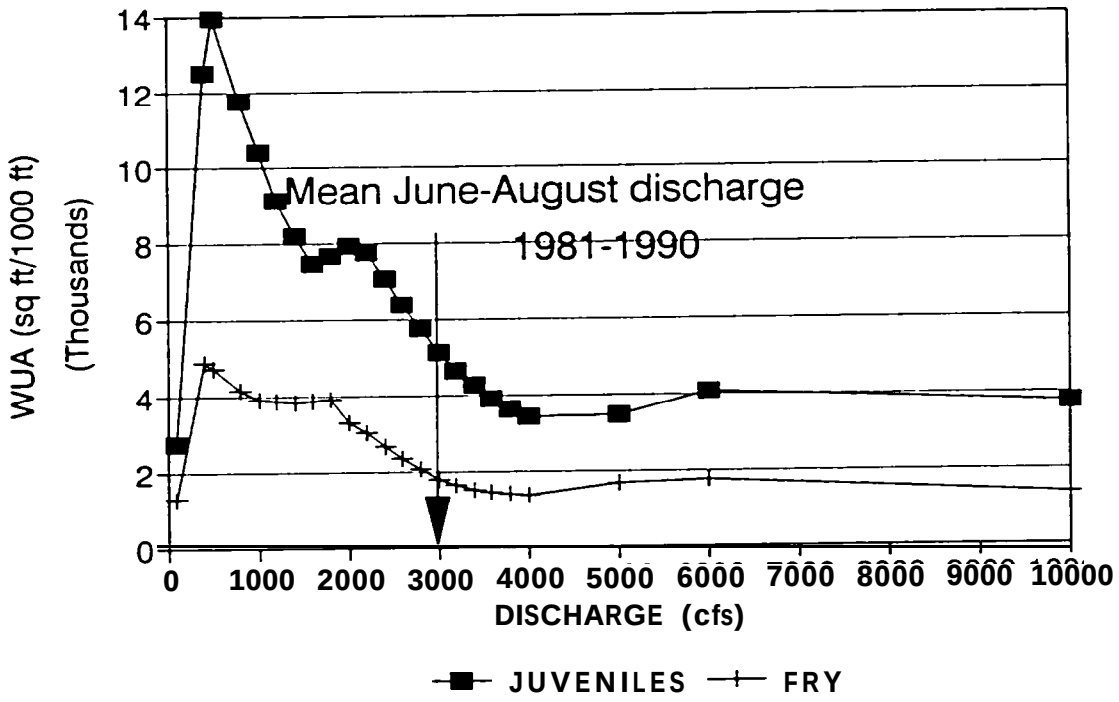


Figure 62. Weighted usable area vs discharge, spring chinook juveniles and fry, Yakima Canyon.

Results

The smelt-to-adult (S_{sa}) survival based on the 1983 smolt outmigration estimated at Prosser and the 1984 return of jacks (3-year-old fish) and the 1985, 1986 and 1987 return of 4-, 5 and 6-year-old adults to the Yakima River is reported in Table 47. The age class structure of the 1985 adult returns was calculated based on the lengths of carcasses collected on the spawning ground rather than scales because of the low number of readable scales collected that year. Although length analysis is somewhat less accurate than scale analysis, it is believed that the greater number of lengths used in the analysis gives a fair representation of the actual age class structure. It was estimated that 6,257 wild 3-, 4-, 5- and 6-year-old fish returned from an estimated smolt outmigration of 167,077 wild fish in 1983. This gives a smolt-to-adult survival for wild Yakima Subbasin spring chinook of 3.74% for the 1983 smol t outmigration.

The factors affecting wild smolt-to-adult survival are very difficult to evaluate in the mainstem Columbia, the estuary and on the high seas due to a lack of identifying marks, such as coded-wire tags. It is believed that passage at mainstem dams, especially in drought years, has had a very negative affect on smolt outmigration survival from Prosser to the Columbia River below Bonneville Dam. Studies have also indicated that smolt transportation also has negative, or at best, no net benefits for transported spring chinook smolts. Ocean survival is dependent on many uncontrollable, and in many instances, inestimable factors such as food supply, ocean temperature, and fishing effort, especially recently from high seas squid driftnet fisheries. Adult returns through the Columbia are affected by passage at mainstem dam adult ladders and by fishing effort in the mainstem lower river. This combined fishing effort in the lower Columbia consists of commercial gillnetting, state test fisheries, sports fishing, and tribal ceremonial and subsistence fisheries. As discussed in the adult hatchery returns section, this harvest has averaged about 25% of the returning coded-wire tagged, hatchery-released spring chinook salmon destined for the Yakima Subbasin. It is possible that the wild fish may suffer a comparable harvest rate to these hatchery adults.

The smolt-to-adult (S_{sa}) survival based on the 1984 smolt outmigration estimated at Prosser and the 1985 return of 423 jacks, the 1986 return of 7,275 4-year-old adults, and the 1987 return of 898 5-year-old adults to the Yakima River is reported in Table 48. No adult 6-year-old fish returned from the 1983 smolt class, as determined by scale analysis of the spawner carcasses in 1988. This total estimated return of 8,596 adult spring chinook from the 1984 outmigration of 143,331 wild smolts gives an estimated smolt-to-adult survival of 6.%. This was the highest smolt-to-adult survival rate observed during the five years that this statistic was calculated.

The smolt-to-adult (S_{sa}) survival based on the 1985 smolt outmigration estimated at Prosser and the 1986 return of 349 jacks, the 1987 return of 2,986 4-year-old adults, the 1988 return of 1,372 S-year-old adults, and the 1989 return of 11 6-year-old adults to the Yakima River is reported in Table 49. A total of 4,718 adults returned from an estimated smolt outmigration of 96,413 fish for a survival rate of 4.89%.

The smolt-to-adult (Ssa) survival based on the 1986 smolt outmigration of 180,789 wild fish estimated at Prosser and the 1987 return of 346 jacks, the 1988 return of 2,735 4-year-old fish, and the 1989 return of 1,128 5-year-old adults to the Yakima River is reported in Table 50. This adult total of 4,209 fish from a smolt outmigration of 180,789 fish gives a smolt-to-adult survival of 2.33%.

The smolt-to-adult (Ssa) survival based on the 1987 smolt outmigration estimated at Prosser and the 1988 return of 328 jacks, the 1989 return of 3,458 4-year-olds, and the 1990 return of 708 5-year-old adults to the Yakima River is reported in Table 51. This total of 4,494 adults returning from the 254,494 outmigrating smolts gave the lowest estimate of smolt-to-adult survival, only 1.77%. The in-basin causes of this low rate of return are discussed in the smolt-to-smolt survival section of this report. The out-of-basin causes are discussed in general in the earlier part of this section and in the hatchery adult return section.

The mean smolt-to-adult survival rate estimated for Yakima spring chinook, 3.75%, is rather high for a system four mainstem dams above the ocean. Bjomn (1978) reported a smolt-to-adult survival of 2.19% for the Lemhi River in 1963, when four mainstem dams were present in the Snake and lower Columbia rivers. Lindsay et al. (1982) reported that smolt-to-adult survival rates ranged from 2% to 3.2% for wild spring chinook in the Deschutes River, a system only two mainstem dams above the ocean. Finally, Lindsay et al. (1985) reported that smolt-to-adult survival rates in the John Day River, which is three dams above the ocean, ranged from 0.98% to 1.255%.

The seemingly high smolt-to-adult survival rates estimated for Yakima spring chinook can be explained to some degree by the (unusually?) high smolt-to-smolt survival rate that also characterizes the Yakima. If the -50% survival of outmigrating smolts through the middle Yakima is *not* characteristic of other Columbia and Snake tributaries, then outmigrant totals would have to be doubled to make Yakima estimates comparable to other systems. If this is done, the Yakima estimates range from 0.9% 3%, well within the expected range.

Table 47. Estimation of smolt-to-adult survival of the 1983 smolt outmigration from the Yakima system.

Age Classes Returning		Number of Fish
1984 Jacks (IIIs) returning to Prosser		217
1985 IVS		
American River	(59.8% IVs)(10.2% of redds)(4,104 adults)=	250
Naches River	(71.3% Ivs)(20.8% of redds)(4,104 adults)=	609
Yakime River	(86.4% IVs)(69.0% of redds)(4,104 adults)=	2,446
1986 vs		
American River	(83.3% Vs)(14.9% of redds)(9,093 adults)=	1,129
Naches River	(53.2% Vs)(27.4% of redds)(9,093 adults)=	1,325
Yakima River	(4.8% Vs)(57.7% of redds)(9,093 adults) =	252
1987 Vls		
American River	(2.2% VIs)(12.9% of redds)(4,018 adults)=	11
Naches River	(1.7% VIs)(26.5% of redds)(4,018 adults)=	18
Yakima River		0
Total Adult Return of 1981 Brood/1983 Smelts =		6,257
Total Estimated 1983 Wild Smolt Outmigration =		167,077
Smolt-to-adult Survival = 6,257 / 167,077 =		3.74%

Table 48. Estimation of molt-to-adult survival of the 1984 smolt outmigration from the Yakima system.

Age Classes Returning		Number of Fish
1985 Jacks (Ills) returning to Prosser		423
1986 IVS		
American River	(13.6%IVs)(14.9% of redds)(9,093 adults) =	1,236
Naches River	(41.9%IVs)(27.4% of redds)(9,093 adults) =	1,044
Yakima River	(95.2%IVs)(57.7% of redds)(9,093 adults) =	4,995
1987 vs		
American River	(40.0% Vs)(12.9% of redds)(4,018 adults) =	207
Naches River	(25.9% Vs)(26.5% of redds)(4,018 adults) =	275
Yakirna River	(17.1% Vs)(60.6% of redds)(4,018 adults) =	416
1988 VIs		0
Total Adult Return of 1982 Brood/1984 Smolts =		8,596
Total Estimated 1984 Smolt Outmigration =		143,331
Smolt-to-Adult Survival = 8,596 / 143,331		6.0%

Table 49. Estimation of smolt-to-adult survival of the 1985 smolt outmigration from the Yakima system.

Age Classes Returning		Number of Fish
1986 Jacks (111-s) Returning to Prosser		349
1987 IVs		
American River	(57.8% IVs)(12.9% of redds)(4,018 adults) =	300
Naches River	(70.7% IVs)(26.5% of redds)(4,018 adults) =	753
Yakima River	(79.4% IVs)(60.6% of redds)(4,018 adults) =	1,933
1988 vs		
American River	(67.4% Vs*)(22.7% of redds)(4,028 adults) =	615
Naches River	(53.9% Vs)(23.5% of redds)(4,028 adults) =	510
Yakima River	(11.4% Vs)(53.8% of redds)(4,028 adults) =	247
1989 VIs		
American River		0
Naches River	(1.0% VIs)(23.6% of redds)(4,673 adults) =	11
Yakima River		0
Total Adult Return of 1983 Brood/1985 Smolts =		4,718
Total Estimated 1985 wild Smolt Outmigration =		96,413
Smolt-to-Adult Survival = 4,718 / 96,613 =		4.89%

. The mean of the 1986, '87, '89, and '90 age class structure was used in 1988 due to a tow number of readable scales being collected on the American River that year.

Table 50. Estimation of smelt-to-adult survival of the 1986 smolt outmigration from the Yakima system.

Age Classes Returning		Number of Fish
1987 Jacks (IIIs) returning to Prosser		346
1988 IVS		
American River	(31.0%IVs[a])(22.7% of redds)(4,028 adults) =	283
Naches River	(42.3% IVs)(23.5% of redds)(4,028 adults) =	LOO
Yakirna River	(94.7% IVs)(53.8% of redds)(4,028 adults) =	2.052
1989 Vs		
American River	(75.0% vs)(12.7% of redds)(4,673 adults) =	445
Naches River	(49.0% Vs)(23.6% of redds)(4,673 adults) =	540
Yakima River	(4.8% vs)(63.7% of redds)(4,673 adults) =	143
1990 VIs		0
Total Adult Returns of 1984 Brood/1986 Smolts =		4,209
Total Estimated 1986 Wild Smolt Outmigration =		180,789
Smolt-to-Adult Survival = 4,209 / 180,789 =		2.33%

[a] The mean of the 1986, '87, '89, and '90 age class structure was used in 1988 due to a low number of readable scales being collected on the American River that year.

Table 51. Estimation of smolt-to-adult survival of the 1987 smolt outmigration from the Yakima system.

Age Classes Returning		Number of Fish
1988 Jacks (111s) returning to Prosser		328
1989 IVs		
American River	(25.0% IVs)(12.7% of redds)(4,673 adults) =	148
Naches River	(50.3% IVs)(23.6% of redds)(4,673 adults) =	551
Yakima River	(92.7% IVs)(63.7% of redds)(4,673 adults) =	2,759
1990 Vs[a]		
American River	(71.3% Vs)(11.9% of redds)(3,698 adults) =	314
Naches River	(31.0% Vs)(26.8% of redds)(3,698 adults) =	307
Yakima River	(3.8% Vs)(61.7% of redds)(3,698 adults) =	87
1991 VIs Have not returned yet - expected to be insignificant		
Total Adult Returns From 1985 Brood/1987 Smolts =		4,494
Total Estimated 1987 Wild Smolt Outmigration =		254,494
Smolt-to-Adult Survival = 4,494 / 254,494 =		1.77%

[a] The adult return to Prosser Dam is estimated based on the number of redds in the basin and a factor of 2.4 fish per redd. See the adult return section for more details.

FACTORS LIMITING REARING POTENTIAL

Overview

Spring chinook production in the Yakima Subbasin is limited by four types of rearing constraints. These constraints are:

1) Suboptimal instream flows.
2) Passage around diversions.
3) Degraded riparian and instream habitat.
4) Water quality.

Suboptimal instream flows are the direct result of the available water supply in the Yakima Subbasin being overallocated. This problem of water-rights holders claiming more water than is available in low water years is currently being adjudicated in the Washington State Court System. There are currently no legally binding minimum instream flows for the Yakima. Current instream flows are determined by the difference between total available water (natural runoff plus irrigation storage reservoir releases) minus irrigation and all other demands for water. Instream flows are rarely optimal anywhere in the subbasin, and may be catastrophically low for fish production in drought years. Large volumes of water are released during irrigation season, resulting in mainstem flows that are much greater than optimal. Water releases are cut back dramatically after the irrigation ends and virtually overnight the resulting mainstem flows become suboptimal or even critically low for fish.

Most of the major mainstem irrigation diversion canals in the Yakima Subbasin have been outfitted with state-of-the-art bypass screening systems between 1985 and 1990 under the Phase I Screening Project. These efforts have improved smolt outmigration by reducing direct mortalities, reducing the delay in travel time, and reducing long-term mortality due to injury and descaling. Approximately 67 small to medium sized diversions, however, are not screened or have inadequate, obsolete or deteriorating screens. These Phase II diversions are located in spring chinook production areas and collectively constitute a major hazard for dispersing fry and outmigrating smolts. The Phase II screening projects are currently being developed by the Fish Passage Technical Work Group and will be constructed by 1995. The successful construction and operation of the Phase I and II diversion screening projects will greatly reduce the mortality associated with passage around diversions in the subbasin.

The riparian and instream habitat of the Yakima Subbasin has been degraded due to poor forest practices in the headwater areas, which has increased stream temperatures, accelerated sedimentation, accentuated sudden changes in flow, and caused earlier runoff and lower late summer natural flows. Habitat has also been degraded by agriculture, which is responsible for overgrazing many riparian areas and channelizing many sections of the mainstem and especially the tributaries of the subbasin, and streamside development that has

removed riparian habitat and buttressed streamside areas to prevent loss of property and buildings.

Water, both quantity and quality, present limitations to the natural production of spring chinook in the Yakima Subbasin. Water quantity was discussed in the suboptimal instream flow section. Water quality ranges from good to excellent in the upper reaches down to fair to poor in the lower Yakima Valley. The Yakima receives pollutants from both irrigated agricultural lands and from municipalities and industrial wastes as it flows to the Columbia. The Yakima River below Union Gap is generally unfit for salmonid survival during the summer months when irrigation return flows can comprise over 80% of the total stream flow. Water temperatures that often exceed 70°F and occasionally reach 80°F are responsible for the lack of salmonid production in the lower river. Suspended sediments from irrigation return drains also present problems in the lower basin. Under current water management there is little chance to improve the water quality in the Yakima Subbasin.

Suboptimal Instream Flows

Water supplies in the Yakima Subbasin are severely overtaxed by the competing demands of irrigation and instream flows for fish production. There are no binding minimum instream flows for fish except for a minimum flow below Prosser Dam and a court-ordered minimum flow for egg incubation in the Yakima from Easton Dam to the Teanaway River. The Washington Department of Ecology is prevented by state law from requiring existing water rights to be modified to meet new instream flow requirements. Subject only to the above exceptions, current instream flows represent the difference between available water (storage releases plus natural runoff) minus irrigation and other demands. As available water and demand are rather precariously balanced, instream flows are rarely optimal anywhere in the subbasin, and may be catastrophically low for fish production in drought years.

In an average year, the total available water supply in the subbasin is barely adequate for irrigation and never adequate for optimal fish production. To satisfy irrigation needs, a great volume of water is released during the irrigation season, resulting in flows in many reaches of the mainstem Yakima that are much greater than optimal. The lack of water for fish production is felt in the main river after the irrigation season ends and when releases are cut back dramatically to refill the reservoirs. Flows in most mainstem reaches then become suboptimal or even critically low for fish. Instream flows can become critically low even during the irrigation season, especially in reaches below diversion dams. hloreover, instream flows in many tributaries (the Teanaway River and Taneum, manastash, Big, Wenas and Ahtanum creeks) are impacted by irrigation withdrawals more severely than the main Yakima. The lower reaches of these streams are actually or virtually dewatered by late spring or early summer. In dry years, water supply is wholly inadequate everywhere in the subbasin. Based on the historical record, rationing of irrigation water will be necessary in nine of 52 years (17.3%), and instream flows will be extremely low or nonexistent throughout the subbasin (Anonymous 1985).

Water supply in the subbasin is provided by natural runoff, storage releases and irrigation return flows (groundwater use is negligible). Although the mean total subbasin runoff (3.4 million acre-feet) is 1.5 times the irrigation demand (2.3 million acre-feet), problems still arise because only 1.07 million acre-feet can currently be stored, and because much of the runoff occurs quickly, in May and June (Yakima River Basin Water Enhancement Project Phase II Status Report 1985). The irrigation season extends from April through mid-October, and natural runoff is normally adequate to meet demands through June. By the first week of July, however, stored waters are required to meet delivery demands. Since storage capacity and normal irrigation demand from July 1 through the end of the season are almost identical, releases must be carefully timed, especially if precipitation is less than normal. Moreover, it is desirable that there be some "carryover" of stored water from one season to the next, as the reservoir system would not refill following two consecutive dry years.

The Yakima River Basin Water Enhancement Project Phase II Status Report made a series of predictions based on a 52-year period of record (1926- 1977) regarding the adequacy of irrigation supplies and anadromous fish production assuming the present demand and operating policies were maintained. As previously mentioned, some degree of rationing of irrigation water would be necessary in nine of 52 years, with less than 70% of "current diversions" (defined as the mean over the non-drought years from 1973 to 1982) being delivered in three years, and a lesser degree of rationing in six others. In the most water deficient year, a repetition of the 1941 supply conditions, "proratable irrigators" would receive less than 40% of current supply. From a fisheries perspective, mean discharge by reach would probably resemble Table 52, with most reaches of the Yakima experiencing critically low or fluctuating flows at some time of the year, and significantly suboptimal or supra-optimal mean flows throughout the entire year. An IFIM-based (instream flow incremental method) analysis (Stemple 1985) indicated total anadromous spawning runs would reach equilibrium at 17,600 adults under current conditions. Mean run size to the Yakima Subbasin for all anadromous fish from 1981 through 1990 has been 3,752 fish.

Table 52 Mean monthly flows • nd flow-related data in selected reaches of the Yakima Subbasin. First figure represents calculated mean with present demand and operating scheme for 1926 1977 Second figure represents the mu" of actual flows for 1981-1987. (Note that the number in parenthesis after location name is mean unregulated discharge) Critical flow is the critical low flow by the 'Montana Method." 1 /10 mean unregulated discharge. Flow fluctuations >300% i" a 24-hour period are indicated in the last row for each reach/tributary ("N 0 " indicates data not available.)

Location	Mean monthly discharge (cfs)											
	Oct	Nov	Dec	Jan	Fsb	Mar	Apr	May	Jun	Jul	Aug	Sep
Yakima, Keechelus to Eaton '26-'77	110	143	205	116	59	49	112	620	744	686	747	485
Yakima, Keechelus t o Easton '82-'87	159	40	90	110	107	49	137	604	526	570	862	436
IFTAG Optimal Flow	125	100	100	100	125	125	125	125	100	100	100	125
Critical Flow	35	35	36	35	35	35	35	35	35	35	35	35
Mean number days < critical '82-'87	12	19	10	4	5	17	12	<1	0	0	0	<1
N o days >300% change '82-'87	1	1	<1	C I	<1	<1	1	<1	0	0	0	<1
Kachess R , Easton 12951 '26-'77	170	99	110	66	31	18	30	306	496	832	806	779
Kachess R , Easton 12951 '81-'86	184	4	2	2	21	27	87	353	586	728	958	704
IFTAG Optimal Flow	N.O.	N.D	N 0.	N.D	N.O.	N 0.	N O	N 0.	N D	N O	N O	N O
Critical Flow	30	30	30	30	30	30	30	30	30	30	30	30
Mean number days < critical '82-'87	N 0.	N.O.	N.O.	N.O.	N.D.	N.D	N O	N.D	N 0.	N O	N 0.	N O
No days >300% change '82-'87	N.O.	N.O.	N.O.	N.D.	N 0.	N O	N 0.	N O	N 0.	N O	N O	N O
Yakima R Easton (945) '26-'77	196	473	661	482	338	322	501	966	773	479	593	235
Yakima R , Easton (945) '82 '87	232	295	243	389	392	440	457	618	458	431	726	320
IF TAG Optimal Flow	400	350	350	275	275	275	275	275	225	225	225	400
Critical Flow	95	95	95	95	95	95	95	95	95	95	95	96
Mean number days < critical '82-'87	5	1	0	0	0	0	C I	0	2	2	0	0
No days >300% change '82-'87	0	2	1	2	0	1	2	0	0	1	0	0
Cle Elum R Roslyn (950) '26-'77	183	417	574	303	199	183	263	1439	2346	2443	2363	502
Cle Elum R., Roslyn 1950) '81 -'86	326	199	147	162	154	134	242	882	1890	2917	2916	749
IFTAG Optimal Flow	200	200	200	200	275	275	275	275	300	300	300	200
Critical Flow	95	95	95	95	95	95	95	95	95	95	95	95
Mean number days < critical '82-'87	N.O.	N.O.	N O	N O	N.D	N 0.	N O	N 0.	N O	N O	N O	N 0.
N o days >300% change '82-'87	N 0.	N.O.	N.D	N 0.	N.D	N O	N O	N 0.	N O	N O	N D	N O

Table 52. Mean monthly flows and flow-related data in selected reaches of the Yakima Subbasin First figure represents calculated mean with present demand and operating scheme for 1926-1977 Second figure represents the mean of actual flows for 1981-1987 (Note that the number in parenthesis after location name is mean unregulated discharge) Critical flow is the critical low flow by the "Montana Method," 1/10 mean unregulated discharge Flow fluctuations >300% in a 24-hour period are indicated in the last row for each reach/tributary. ("N D " indicates data not available.)

Location		Mean monthly discharge (cfs)											
		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Yakima R , Cle Elum (21001	'26-'77	469	1019	1411	983	741	762	1165	2815	3398	3036	3065	856
Yakima R., Cle Elum (2100)	'82-'87	536	620	531	857	808	978	1057	2070	3022	3441	3706	1199
IFTAG Optimal Flow		650	600	600	525	525	500	500	500	600	600	600	650
Critical Flow		210	210	210	210	210	210	210	210	210	210	210	210
Mean number days < critical	'82-'87	1	0	0	0	0	0	0	0	0	0	0	0
No days >300% change	'82-'87	1	1	0	2	1	0	0	0	0	0	0	4
Yakima R., Ellensburg (2250)	'26-'77	775	1260	1829	1519	1406	1779	2438	3915	3912	3054	3077	1190
Yakima R., Ellensburg 122501	'82-'87	789	882	1218	1579	1513	2179	2212	3221	3511	3406	3588	1345
IFTAG Optimal Flow		1000	1000	750	750	900	900	750	760	750	750	750	750
Critical Flow		225	225	225	225	225	225	225	225	225	225	225	225
Mean number days < critical	'82-'87	0	0	0	0	0	0	0	0	0	0	0	<1
No. days >300% change	'82-'87	1	0	4	1	1	0	0	0	1	0	0	0
Yakima R., Umtanum (24001	'26-'77	986	1465	1 se4	1573	1477	1828	2773	4406	4359	3276	3317	1473
Yakima R , Umtanum (2400)	'82-'87	1053	1008	920	1655	1864	2511	2437	3286	3792	3766	4014	1957
IFTAG Optimal Flow		1000	1000	750	750	900	900	750	750	750	750	750	1000
Critical Flow		240	240	240	240	240	240	240	240	240	240	240	240
Mean number days < critical	'82-'87	0	0	0	0	0	0	0	0	0	0	0	0
No. days >300% change	'82-'87	0	1	2	1	0	0	0	0	0	0	0	0
Yakima R, Pomona (2433)	'26-'77	368	813	1282	841	742	826	1330	2630	2324	1163	1248	365
Yakima R Pomona 12433)	'81-'87	N D	N 0.	N O	N O	N O	N O	N O	N 0.	N O	N O	N 0.	N.D
IFTAG Optimal Flow		800	800	750	750	900	900	750	750	750	750	750	750
Critical Flow		240	240	240	240	240	240	240	240	240	240	240	240
Mean number days < critical	'82-'87	N.D	N O	N 0.	N.D	N.D	N.D	N O	N O	N.O.	N O	N O	N.O.
No. days >300% change	'82-'87	N O	N 0.	N O	N D	N.D	N O	N O	N D.	N.D	N O	N 0.	N.D

Table 52 Mean monthly flows nnd flow-related data in • elect-d reaches of the Yakima Subbasin. First figure represents calculated mean with present demand and operating scheme for 1926-1977 Second figure represents the mu" of actual flows for 1 981-1987. (Note that the number in parenthesis after location name i. mean unregulated discharge) Critical flow i. the critical low flow by the "Montana Method," 1110 mean unregulated discharge Flow fluctuations >300% in a 24-hour period are indicated i" the last row for each reach/tributary ("N.D " indicates data not available.)

Location	Mean monthly discharge (cfs)											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Yakima R., Yakima I-4200) '82-'87	1699	1896	1752	3106	3522	4945	4054	6002	6052	3724	3301	2692
IFTAG Optimal Flow	BOO	000	750	750	900	900	750	750	750	750	750	750
Critical Flow	420	420	420	420	420	420	420	420	420	420	420	420
Mean number days < critical '82-'87	0	0	0	0	0	0	0	0	0	0	0	0
No days >300% change '82-'87	0	0	0	2	2	0	0	0	0	0	0	0
Bumping R Nile 12931 '26-'77	110	213	748	204	176	93	145	498	807	391	334	299
Bumping R , Nile 12931 '81 -'86	203	183	225	241	195	281	202	405	757	273	147	320
IFTAG Optimal Flow	150	150	150	150	150	200	200	200	100	100	150	150
Critical Flow	30	30	30	30	30	30	30	30	30	30	30	30
Mean number days < critical '82-'87	N D	N.D	N D.	N D	N D	N D.	N D	N D	N.D.	N.D.	N D	N.D
No. days >300% change '82-'87	N D	N D	N.D	N D	N D	N.D.	N.D	N D	N D	N D.	N D.	N.D.
Tieton A , Rimrock (510) '26-'77	149	91	192	194	zoo	29	141	820	1033	882	868	1702
Tieton R Rimrock (510) '81 -'86	268	133	155	228	315	433	284	650	911	729	704	1353
IFTAG Optimal Flow	N D	N D	N D	N D	N D	N D	N D	N D	N D.	N.D.	N.D.	N.D.
Critical Flow	50	50	50	50	50	50	50	50	50	50	50	60
Mean number days < critical '82-'87	N D	N D	N D	N D	N D	N D.	N D	N D	N.D.	N D	N D	N.D.
No. days >300% change '82-'87	N D	N D	N D	N D	N D.	N D	N D	N.D	N.D	N D.	N D	N.D
Tieton R , Canal Hdwks (562) '26 '77	162	111	237	240	753	96	221	530	SO4	585	555	1483
Tieton R , Canal Hdwks (562) '81-'85	?A5	146	208	327	427	410	300	524	705	387	316	1143
IFTAG Optimal Flow	200	200	zoo	zoo	125	125	125	125	200	200	150	150
Critical Flow	55	55	55	55	55	55	55	55	55	55	55	55
Mean number days < critical '81-'85	N D	N D	N.D	N D	N D.	N D	N D	N D	N D.	N.D.	N D.	N D.
No days >300% change '81-'85	N D	N D	N.D.	N D.	N D.	N.D.	N.D	N D	N.D.	N D.	N.D.	N D.
Naches R., Cliffdell (1210) '26-'77	242	472	631	537	533	537	1126	2195	2142	871	490	408
Naches R., Cliffdell (1210) '82-'87	368	466	520	747	674	1060	1250	2179	2170	709	373	440
IFTAG Optimal Flow	400	400	300	300	300	300	300	300	300	300	500	500
Critical Flow	120	120	120	120	120	120	120	120	120	120	120	120
Mean number days < critical '82 '87	0	0	0	0	0	0	0	0	0	0	0	0
No. days >300% change '82-'87	0	1	0	1	1	0	0	0	0	0	0	1

Table 52. Mean monthly flows and flow-related data in selected reaches of the Yakima Subbasin First figure represents calculated mean with present demand and operating scheme for 1926-1977 Second figure represents the mean of • ctu(ll flows lo, 1981-1987. (Note that the "umber in parenthesis after location name is mean unregulated discharge) Critical flow is the critical low flow by the "Montana Method," 1/10 mean unregulated discharge Flow fluctuations >300% in . 24-hour period are indicated in the last row lo, each reach/tributary ("N D " indicates data not available.)

Location	Mean monthly discharge (cfs)											
	Oct	Nov	Dec	Jan	Feb	Mar	AP,	May	Jun	Jul	Aug	Sep
Naches, below Wapatox (1768) '26-'77	124	357	684	556	564	447	1383	3065	3078	1127	534	1380
Naches, below Wapatox (1768) '82-'87	290	347	301	752	922	1866	1516	3034	2868	809	220	940
IFTAG Optimal Flow	500	400	400	400	400	400	400	400	400	400	400	500
Critical Flow	160	180	180	160	160	180	180	180	180	180	180	180
Mean number days < critical '82-'87	14	14	16	17	9	0	0	0	0	4	16	1
No days >300% change '62 '87	1	4	7	5	3	0	0	0	0	0	0	4
Yakima R , Parker (45 171 '26-'77	793	2477	3351	2876	2902	2689	2804	4475	3987	826	200	zoo
Yakima R , Parka, (45 17) '82'-87	1099	1982	1777	3044	3684	4669	2295	3000	2787	588	385	400
IFTAG Optimal Flow	700	700	700	700	600	700	800	800	ROO	800	ROO	800
Critical Flow	450	450	450	450	450	450	450	450	450	450	450	450
Mean number days < critical '82-'87	7	0	0	0	0	0	2	3	9	19	21	21
No. days >300% change '82-'87	0	0	0	2	1	0	1	6	1	2	1	2
Yakima R., Prosser (5620) '26-'77	265	1261	1952	1445	1445	1354	1814	3769	3531	359	50	900
Yakima R., Prosser (5620) '82-'87	1662	2319	1729	3095	3838	5012	2587	2607	2909	715	382	710
IFTAG Optimal Flow	1000	1000	800	800	800	800	700	700	BOO	800	800	BOO
Critical Flow	560	560	560	560	560	560	560	560	560	560	560	560
Mean number days < critical '82-'87	2	<1	0	2	0	0	2	3	10	18	25	9
No. days >300% change '82-'87	0	1	0	0	0	1	0	0	0	0	0	0
Yakima R., Kiona 156001 '26-'77	2133	3393	4992	3909	4056	4006	4140	5664	5518	1674	1382	1685
Yakima R , Kiona (5600) '81-'85	2319	2764	3579	5031	5758	3980	4481	4751	1902	1627	2106	2106
IFTAG Optimal Flow	1300	1300	900	900	900	900	800	800	800	800	BOO	1300
Critical Flow	560	560	560	560	560	560	560	560	560	560	560	560
Mean numb., day. C critical '81-'85	N D	N D	N D	N.D	N.D	N D	N D	N D	N D	N D	N D	N D
N o days >300% change '81-'85	N D	N D	N D	N D	N D	N D	N D	N D	N D	N D	N D	N D

As the data summarized in Table 52 illustrates. the instream flow problem in the yakima River is not so much that flows are consistently suboptimal or critical. Rather. fluctuations in flow cause periodic suboptimal or critical situations. Many reaches suffer from a decided excess of flow during the irrigation season (note that "critical" is used here as defined by the "Montana Method" of instream flow assessment: discharge one-tenth or less of the mean annual discharge). A more pertinent measure of lack of instream flow is the mean number of days per month discharge was less than critical. The latter statistic has been computed for some of the reaches in Table 52. In descending order of set erity . the worst major reaches in the Yakima system from 1982 through 1987 have been the yakima from Keechelus Darn to Easton Dam (397 days). The Naches below Wapatox diversion (91 days). the Yakima below Sunnyside Dam (Parker gauge. 81 days), the yakima below Prosser Dam (7 1 day s) and the yakima below Easton Dam (10 days). Note that episodes of critically low flow in the reach of the Yakima from Easton Dam to the Cle Elurn confluence can be especially damaging uhen they occur in the late spring and early summer (May through early July). This reach includes the most heavily used spring chinook spawning area in the entire subbasin and contains numerous braids and side channels. When discharge falls to critical levels in the late spring, it is probable that large numbers of spring chinook fry are trapped in isolated side channels where they are killed either directly from physical stranding. or indirectly from predation,

hlongillo and Falconer (1980) assessed the frequency of critically low flows in the Yakima system for the very dry years of 1373 and 1977 and found a similar. but more severe situation. In descending order. the most frequently critical reaches in these five years were Keechelus to Easton (143 days). Parker (142 dabs), Prosser (96 days), the Naches below Wapatox, the Yakima at Pomona (both 48 days), and the Yakima at Easton (20 days). (It should be noted that the period hlongillo and Falconer investigated preceded "flip-flop" operations. Therefore. the precise ordinal pattern they observed should not be expected to reflect the current situation exactly.)

Another important measure of the quality of instream flow is the lack of rapid, large-scale fluctuations. hlongillo and Falconer (1980) proposed that fluctuations of 300% or more over a 24-hour period be considered unacceptable. By this criterion, the worst major reaches in the Yakima system from 1982 through 1987 have been the Yakima from Keechelus Dam to Easton Dam (30 days): the Naches below Wapatox (19 days); the Yakima at Parker (16 days); the Yakima at Cle Elum and the yakim at Easton (both nine days); the Yakima at Ellensburg (eight days); and the Yakima at Umptanum. the Yakima at Yakima and the Naches above Wapatox (all four days). Mongillo and Falconer (1980) determined that the order of the most severely fluctuating reaches in 1973 through 1979 was the Yakima from Keechelus Dam to Easton Dam (six days); the Yakima at Pomona (three days); the Yakima at Parker and Prosser (both two days); and the Yakima at Easton and the Naches below Wapatox (both one day). Compared to 1973 through 1977, severe fluctuations over the last six years have become more frequent and occur in different reaches. These changes may be attributable to flip-flop system operation.

It should be noted that the preceding analysis of instream flows has been limited to major reaches of the mainstem Yakima and Naches rivers. The situation in the lower reaches of many tributaries is considerably worse, especially in the lower reaches of the Teanaway River, and Big, Taneum, Manastash, Swauk, Wenas and Ahtanum creeks.

Low instream flows during the period of reservoir refilling (roughly mid-October through early July) constitute another constraint on spring chinook production in the Yakima Subbasin. Low flows from October through February probably do not impact incubation significantly in most years, because the federal court has ordered that sufficient incubation flows be provided redds in the upper Yakima and the Cle Elum. However, critically low flows still occur in the upper Yakima in the period immediately after emergence -- mid-April through early July. As has been mentioned, there is some evidence that flows below ~ 150 cfs in the Easton reach have strongly depressed smolt production in recent years, probably by stranding or increasing the predatory vulnerability of fry, especially in side channels and braids. It should be noted that the Easton reach is at least 50% side channel, that many side channels are dry at a total flow of 90 cfs, and that spring chinook fry prefer and seek out side channels for early rearing. Low flows in the winter may also reduce production by substantially reducing the availability of overwinter habitat. The type of microhabitat typically used by over-wintering spring chinook -- interstices among boulders, rubble and rip rap; undercut banks; and submerged brush and root wads -- is usually associated with the bank. A water level several feet lower than normal could dewater most of these areas.

Low flows in April and May also impact spring chinook at the outmigrating smolt stage. Low spring flows increase the in-basin travel time and vulnerability of outmigrating smolts. As mentioned previously, there are preliminary indications that low flows in the reach from Sunnyside Dam to Prosser Dam may be especially conducive to high predatory mortality. It should be noted that a long in-basin outmigration, even without large predatory losses, could have severe impacts if passage on the Columbia were also slow.

Sustained high flows also pose problems. An IFIM (instream flow incremental method) analysis of the Yakima Canyon has indicated that flows are much higher than optimal for spring chinook during the pre-flip-flop portion of the irrigation season (Fred Crase, BOR, pers. commun. 1987). After flip-flop, flows in the lower Naches and especially the Tieton are much above optimal.

Finally, there are adverse impacts associated with abrupt changes in flow. Sudden increases in flow cause fish to vacate feeding territories and migrate to new areas. This forced relocation is believed to increase competition and stress, reduce growth, and increase the likelihood of mortality either through predation or by being displaced to unsuitable downriver habitat. The adverse impacts of sudden decreases in flow are that if fish are not able to relocate to nearby pools or runs, they are stranded and killed. The impacts of sudden decreases in flow will be especially severe in braided areas, such as the Easton reach of the Yakima, and the Naches below Wapatox. Abrupt changes in flow in the Yakima Subbasin are concentrated in reaches below storage reservoirs and diversion dams, especially the

Yakima River between Keechelus and Easton dams, the Yakima River below Easton, the Cle Elum River, the Naches below Wapatox diversion and the Yakima below Roza, Sunnyside and Prosser dams (Mongillo and Falconer 1980).

Upstream passage of adults may also be impeded by low flows, particularly below Horn Rapids, Prosser, Sunnyside, Wapatox and Roza dams. Impaired passage may not be directly lethal, but it may delay and exhaust fish to such a degree that they are easily snagged by poachers. Adult passage below all dams but Sunnyside is adequate at all but the lowest commonly observed flows. Between Sunnyside Dam and Zillah Wasteway, however, upstream migration is severely restricted when flows are less than 300 cfs to 400 cfs (Payne 1982). During April and May of 1981, 1985, 1986, 1987 and 1988, mean daily discharge below Sunnyside has been less than 400 cfs a total of 13 days, four days, 15 days, nine days and 10 days, respectively.

Low fall flows prevent spawning adults from ascending five major tributaries that would otherwise contribute substantially to production. These tributaries -- the Teanaway River and Big, Taneum, Manastash and Ahtanum creeks -- were productive historically, and even today afford good to excellent spawning and rearing habitat in their upper reaches. Natural runoff in these tributaries is fully appropriated for irrigation, and from late spring through late fall, virtually all water is diverted from them once they reach the valley floor. They also suffer from unscreened or poorly screened diversions and assorted barriers to upstream migration. These passage problems are relatively easily rectified. The difficult problem is obtaining more water.

The Little Naches River is a special case of a spawning tributary currently producing below capacity. A moderate amount of spawning has been documented in the Little Naches up to Salmon Falls (RM 4.4), which until 1988 was an impassible natural barrier for spring chinook. The river below the falls was degraded by a series of floods in the late 1970s and by an emergency floodplain reclamation project that removed deposited bedload material, widened the channel and destroyed the riparian corridor. An extensive restoration project in this area was completed the same time as the fishway at Salmon Falls. The fishway opens up about 18 miles (252,853 square yards) of habitat; spawning gravel is abundant, the riparian zone is excellent, summer flows are adequate (but not optimal), and large organic debris and instream cover are plentiful.

Assuming 252,853 square yards, 0.12 smolts per square yard (Easterbrooks and Kessler 1984), and 2% smolt-to-adult survival, the new habitat should support upwards of 600 adults. The factor limiting production for this new system will probably be less than optimum instream flows during the summer. The major limiting factor now is that no spring chinook have been imprinted on the area above the falls.

False attraction flows from wasteways and power plant discharges are a relatively minor problem that can occasionally become serious when flows in the Yakima are very low. Three sites in particular, the Sulphur Creek Wasteway, the Snipes Creek M'asteway (Roza

Wasteway No. 6). and the wasteway from the Wapato Irrigation Project's Satus No. 3 pumping station. can become troublesome. Sulphur Creek spills 250 cfs to 500 cfs in April and May from Sunnyside and Roza Canals: Snipes Creek, 40 cfs to 80 cfs from Roza Canal: and the Satus No. 3 pumping station wasteway can spill as much as 100 cfs. Adults homing to the upper Yakima are thus attracted to all of these wasteways when flows in the Yakima River are low. (Note. however, that the problem with the Satus pumping station wasteway is worse for steelhead than spring chinook. as the water it discharges contains a considerable component of Toppenish Creek water with the balance consisting of middle yakim water diverted at Wapato Dam.) There is no barrier to adults on Sulphur Creek or the Satus pumping station wasteway A temporary barrier. which has been breached a number of times, was installed in Snipes Creek only during the 1987 spring chinook run. but has since been removed. Permanent barriers should be installed at all sites.

Passage Around Div ersions

Approximately 67 small to medium diversions (the "Phase II" diversions) are not screened or have inadequate, obsolete or deteriorating screening. These diversions are located in present production areas for spring chinook and steelhead. and collectively constitute a major hazard for dispersing fry and outmigrating smolts. Migrating fry stay close to shore where they are vulnerable to entrainment in even the smallest of diversions. The Washington Department of Fisheries salvaged 10,000 spring chinook and 2,000 steelhead parr from just one of the Phase-II diversions, the Selah-Naches Canal, in September of 1987 (J. Easterbrooks. WDF, pers. commun.. 1988).

From studies of fry impingement at Wapatox diversion (Eddy 1988) and from numbers of spring chinook parr salvaged from Wapatox and Selah/Naches canals (J. Easterbrooks, WDF, pers. commun., 1989), researchers have estimated that Phase-II diversions are responsible for killing 0.02% of all upstream fry production per cfs diverted, and 36% of all smolts passing through the headworks.

The Wapatox diversion, the largest on the Naches River, bypasses smolts and parr poorly, and represents a major hazard to fry. Fry that do not move directly into the bypass ports on the sides of the canal are quickly (within two hours) impinged on the screens and carried over to the other side. Moreover, the mesh of the screens is wide enough to allow newly emergent fry to pass through directly. It has been estimated that the Wapatox bypass system successfully passes no more than 2.5% of the fry diverted at the headworks (Eddy 1987) and 64% of the smolts.

The overall magnitude of the losses attributable to entrainment at Wapatox diversion has been estimated to be on the order of 6% of all outmigrating spring chinook smolts, 5% of steelhead smolts, and 1.2 % of the upstream production of spring chinook and steelhead fry. Another impact, not reflected in the preceding figures, is attributable to the dewatering of the reach between the diversion dam and the powerplant outfall.

One final comment should be made about diversions in the Yakima system. Predatory birds (primarily gulls and herons) and predatory fish (largemouth bass and northern squawfish) have been observed feeding on smolts in the bypass outfall regions below Wapato, Sunny side and Prosser dams. Squawfish up to 20 inches have been taken by hook and line in the outfall region of all of these dams (16 squaw fish averaging 13 inches were taken by one Yakima tribal biologist in 30 minutes at Sunnyside in 1990). Moreover. many squaw fish up to 17 inches were electrotished from Chandler canal when it was deuatered in November 1983 (Wasserman et al. 1984). Thus, it may be assumed that smolts are lost to predation below the bypass outfall regions of Wapato. Sunnyside and Prosser dams. and perhaps within Chandler canal as well.

Three fairly small hydropower projects already exist in the subbasin, and developers have applied for permits to build many more small-head hydro projects. The existing projects, Roza, Chandler and Wapatox, all have the potential of reducing instream flows to serious levels, although the constraints put on juvenile rearing and upstream migration stemming from Chandler and Wapatox are probably more severe than Roza.

Degraded Riparian and Instream Habitat

The riparian and instream habitat in the mainstem spring chinook production areas is not severely degraded, with the exception of overgrazed and channelized sections of the Yakima River from Yakima to Wenas Creek, and Ellensburg to Taneum Creek. However, lack of streamside cover for overwintering, particularly when flows are low, may represent a more serious limitation. At normal flows, the margins of the Yakima River in a number of mid-river locations include large organic debris (LOD), undercut banks and rubble areas, and may afford abundant over-winter cover. Since 1983, the mean depth of this reach through the winter months (October to February) has varied by as much as two feet. The associated variation in the availability of overwinter cover may have strongly influenced egg-to-smolt survival.

Cover for summer rearing, in the form of large substrate or LOD, is lacking in most tributaries in agricultural areas, and in the lower Little Naches, the lower mainstem Naches, and the North Fork of the Teanaway. The lack of LOD is especially pronounced and may have an especially large impact in the Yakima Canyon. As has been mentioned, the Yakima Canyon is perhaps the single most important summer rearing area for upper Yakima spring chinook. Habitat quality in the canyon is seriously compromised by excessive flows released during the irrigation season (July to mid-October). Log jams and root wads, if present, would provide small pockets of the protected, medium-velocity microhabitat spring chinook parr prefer.

A problem of riparian and instream habitat degradation has arisen as increasing numbers of summer homes have been built along the Yakima River from Cle Elum to Easton. A “vicious cycle” of sorts starts when the landowner clears most or all riparian vegetation for an unobstructed view of the river, often sowing a grassed lawn to the water’s

edge. The removal of woody vegetation destabilizes the bank, which begins to slough off and prompts the landowner to riprap the bank. In the process, the stream has been widened, pools have been lost, tines have been added to spawning gravel and the stage has been set for accelerated erosion downstream.

Other areas where riparian and instream habitat degradation has potentially caused problems are in the forested headwater areas where poor forest practices have removed streamside vegetation and increased stream temperature. Other problems include accelerated sedimentation, an accentuation of sudden changes in flow, earlier runoff and lower late summer flows.

Water Ouality

Water is central to the productivity of the agricultural economy and the fisheries of the Yakima Subbasin. While the water resources of the subbasin are subject to problems of both quantity and quality, quantitative concerns are more important. Water quality in the Yakima Subbasin is good to excellent in the upper reaches, but only fair to poor in the lower valley. As the Yakima River passes through the Kittitas Valley (headwaters to Roza Dam), it receives pollutants from irrigated pasturelands and municipalities. Although almost all water quality indices suffer a progressive deterioration through this section, overall water quality would still be considered good as the river passes Roza Dam.

Through its middle reaches (Roza to Sunnyside Dam), the Yakima River receives treated wastes from Yakima, Selah, Union Gap and Terrace Heights as well as irrigation returns from the Ahtanum Creek and the Moxee area. Normally, however, water quality is only slightly degraded because pollutants are diluted with large volumes of high quality water from the Naches River. Water quality can therefore still be considered good as far as Union Gap.

Water quality degrades rapidly in the lower subbasin (Sunnyside Dam to Columbia River). Most of the summer flow is diverted at Wapato and Sunnyside dams, and large volumes of warm, turbid irrigation water with a high content of nutrients, suspended sediments and fecal bacteria are added a short distance downstream. While irrigation return flows comprise about 5% of the yearly Yakima River flows in the reach from Sunnyside Dam to Wilson Creek, below Sunnyside Dam this percent increases to more than 30% on an annual basis, and to more than 80% in the summer months (Anonymous 1973). The summertime concentrations of (nitrate + nitrite) orthophosphate, chlorophyll A, specific conductance and turbidity all reflect the virtual transformation of the Yakima River below Granger (RM 83) to a seasonal irrigation return; in all cases, concentrations rise to levels approaching those observed in irrigation drains (Mongillo and Falconer 1980). However, these levels are not acutely toxic to fish.

In the mainstem Yakima above Sunnyside Dam, and in all of the Naches system, temperatures rarely exceed 70°F (21°C; see Table 53). There has, however, been some fear

that release of warm surface waters from Bumping and Kachess lakes could excessively warm the upper Naches and Yakima rivers in years of low flow (Fred Crase, BOR, pers. commun., 1987).

Summer temperatures at Prosser and Kiona frequently exceed 75°F and occasionally reach 80°F in July and August. These high temperatures preclude summer rearing of salmonids in the lower river. The precise downstream boundary for rearing habitat in the summer probably varies from year to year, sometimes being as high as Sunnyside Dam (RM 103.8), and sometimes as low as Marion Drain (RM 82.6). In a survey in the summer of 1988, temperatures in all tributaries except the lower portions of the Satus Creek and Toppenish Creek drainages were observed to be well within the acceptable range for summer rearing of salmon.

Substrate quality also presents problems in the lower Yakima. Although a survey of particle size distribution of substrate materials in the lower river has never been conducted, the deposition of fine materials is undoubtedly a problem, especially between Union Gap and Kiona. Eleven major irrigation drains enter the Yakima River in this reach, discharging between 122,000 and 127,000 tons of suspended sediments yearly (USGS Open-File Report 78-946). As summarized in Table 54, the top five sources of sediment loading to the Yakima River, which together account for the introduction of over 200 tons of suspended solids per day, are found between Union Gap and Spring/Snipes Creek. All of the sources in Table 54 are either man-made irrigation returns or natural streams receiving large irrigation returns. By far the worst source is Sulphur Creek, which drains lands irrigated by the Roza and Sunnyside Valley irrigation districts. It is possible that much of this material settles out before reaching Kiona as summertime turbidity begins rising at Union Gap, peaks in the vicinity of Granger, and falls at Kiona to levels not substantially greater than those observed at Union Gap (Mongillo and Falconer 1980).

Table 53. Physical and chemical water quality, Yakima River at Union Gap gauging station (RM 106.8), 1980-1985. Datd from the U.S. Geological Survey Uater Data Reports WA-80-2, WA-81-2, WA-82-2, UA-83-1, WA-85-I and USGS Open-File Report 84-145-B.

Station and year	Month	Oisch. (cfs)	Spec. cord. (us/cm)	pH	Temp. (deg C)	Turbidity (NTU)	Diss. oxygen (mg/l)	Coliform fecal bacteria UM-MF (counts/100 ml) per 100 ml)	Hardness (mg/l as CaCO3)	Alkalinity (mg/l as CaCO3)	Sodium (mg/l)	Nitrogen (NO2 + NO3) (mg/l)	Phosphorus (total) (mg/l)	Sediment disch. (tons/day)
Union Gap (1985)	Nov	1640	158	7.2	6.5	2.3	12.5	67	64	74	9.4	0.2	0.06	22
	Jan	1370	153	7.4	0	2.5	12.9	54	61	79	8.9	0.38	0.06	26
	Mar	1530	175	7.7	8	2.9	11.9	12	69	81	11	0.26	0.05	41
	May	2980	110	7.8	11	4.6	11.2	54	48	47	6	0.11	0.08	129
	Jul	3760	102	7.4	19	7.3	8.7	170	40	54	4.2	0.43	0.09	335
	Sep	2750	133	8.2	14	2	12.6	120	48	60	7.2	0.21	0.07	82
Union Gap (1984)	Nov	2270	146	8.4	7.5	1	9.8		52	54	7	0.23	0.05	61
	Jan	5660	112	8.2	2.5	17	12.5	110	41	44	4.9	0.18	0.14	2340
	Mar	3020	134	8.4	7.5	3.1	12.4	4	52	60	7	0.27	0.05	122
	May	2820	117	a.3	11	4.4	9.6	24	44	52	5.5	0.1	0.05	175
	Jul	3390		7.9	15.5	6.2	10.4	52	39	42	4.9	0.1	0.05	384
	Sep	3290	107	7.4	15.5	9.1	10.2	180	42		5.7	0.18	0.06	320
Union Gap (1983)	Nov	1920	167	8.6	a.5	2.4	13.6	47	64	73	8.9	0.29	0.11	124
	Jan	8800	108	8.6	3.5	35	12.6	210	43	47	4.9	0.28	0.2	4210
	Mar	11200	142	7.8	6.5	34	11.5	93	49	54	5.6	0.26	0.18	6020
	May	5060	106	8.4	13	2.1	11.9	65	43	47	4.8	0.1	0.06	164
	Jul	3620	112	8.3	18	3.5	11	160	41	47	5.1	0.17	0.08	440
	Sep	2900	113	a.3	18	5.4	11	150	42	45	5.8	0.18	0.07	227
Union Gap (1982)	Nov	1650	166	8.2	11.5	1.6	11.5	35	67	69	10		0.07	45
	Jan	1140	157	8.2	0.5	2.9	13.2	33	59	70	8.4	0.67	0.11	86
	Mar	5550	125	7.8	7.5	5.6	12.1	120	44	53	5	0.17	0.05	435
	May	4630	105	8	10.5	4.6	12	55	42	46	4.9	0.12	0.09	438
	Jul	3420	104	8.1	17.5	6.4	9.4	110	39	46	4.8	0.15	0.09	443
	Sep	2840	117	7.8	19.5	4.4	9.8	680	46	52	5.6	0.18	0.06	123

Table 53. Physical and chemical water quality, Yakima River at Union Gap gauging station (RM 106.8), 1980-1985. Data from the U.S. Geological Survey Water Data Reports WA-80-2, WA-81-2, WA-82-2, WA-83-1, WA-85-1 and USGS Open-File Report 84-145-B.

Station and year	Month	Disch. (cfs)	Spec. cond. (us/cm)	pH	Temp. (deg C)	Turbidity (NTU)	Diss. oxygen (mg/l)	Coliform fecal bacteria UM-MF (counts/100 ml) per 100 ml)	Hardness (mg/l as CaCO3)	Alka-linity (mg/l as CaCO3)	Sodium (mg/l)	Nitrogen (NO2 + NO3) (mg/l)	Phos-phorus (total) (mg/l)	Sediment disch. (tons/day)
Union Gap (1981)	Nov	1720	156	7.7	5.2	0.7	11.7	34	59	66	8.5	0.3	0.09	42
	Jan	3180	129	7.8	2.4	1.5	13.2	20	47	49	6.1	0.34	0.06	86
	Mar	3270	131	7.7	7	4.5	12.4	--	51	48	6.5	0.11	0.06	256
	May	3070	108	8	12.2	5.5	11.7	9	41	47	5.7	0.08		182
	Jul	3160	112	7.6	16.6	5.6	9.6	55	42	37	5.5	0.57	0.08	341
	Sep	2950	110	8.4	17.9	5.5	9.9	120	43	47	5.7	0.1	0.05	191
Union Gap (1980)	Nov	1070	167	7.7	6.9	3.6	11.9	230	67	71	11	0.36	0.09	37
	Jan	1100	147	7.3	0	3.3	14.1	20	53	61	8.4	0.36	0.11	47
	Mar	4060	139	7.8	5.5	4.5	12.3	230	58	58	6.9	0.75	0.11	428
	May	4330	93	7.8	10.1	5.6	11.1	140	35	34	4.4	0.18	0.07	246
	Jul	3220	100		19.9	5.9	9.4	22,000	38	46	4.9	0.15	0.11	252
	Sep	2630	132		16.4	2.6	9.8	220	51	49	6.6	0.16	0.09	142
Union Gap mean 1980-85	Nov	1712	160	8.0	7.7	1.9	11.8	0	62.2	67.8	9.2	0.28	0.078	55
	Jan	3542	134	7.9	1.5	10.4	13.1	0	50.7	58.3	6.9	0.37	0.113	1133
	Mar	4772	141	7.9	7.0	9.1	12.1	0	53.8	59.0	7.0	0.30	0.083	1217
	May	3815	107	8.1	11.3	4.5	11.3	0	42.2	45.5	5.2	0.12	0.070	222
	Jul	3428	106	7.9	17.8	5.8	9.8	0	39.8	45.3	4.9	0.26	0.083	366
	Sep	2893	119	8.0	16.9	4.8	10.6	0	45.3	50.6	6.1	0.17	0.067	181
Kiona (1985)	Nov	2660	263	8	7	4	12.5	200	110	120	16	1.2	0.08	115
	Jan	2000	250	7.8	2.5	1.6	13.7	73	100	114	15	1.2	0.08	32
	Mar	2390	252	8.2	7.5	5.6	11.4	28	110	118	16	0.96	0.1	142
	May	2130	191	7.8	15	9.6	9.8	30	77	86	10	0.6	0.12	178
	Jul	1140	307	7.9	25.5	8.5	7.7	150	120	133	17	1.2	0.15	86
	Sep	2690	289	8.1	16.5	19	9.1	420	110	125	16	1.3	0.1	421

Table 53. Physical and chemical water quality, Yakima River at Union Gap gauging station (RM 106.8), 1980-1985. Data from the U.S. Geological Survey Water Data Reports WA-80-2, WA-81-2, WA-82-2, WA-83-1, WA-85-1 and USGS Open-File Report 84-145-B.

Station and year	Month	Disch. (cfs)	Spec. cond. (us/cm)	pH	Temp. (deg C)	Turbidity (NTU)	Diss. oxygen (mg/l)	Coliform fecal bacteria UM-MF (counts/100 ml) per 100 ml)	Hardness (mg/l as CaCO3)	Alka-linity (mg/l as CaCO3)	Sodium (mg/l)	Nitrogen (NO2 + NO3) (mg/l)	Phos-phorus (total) (mg/l)	Sediment disch. (tons/day)
Kiona (1984)	Nov	4630	210	8.4	7	12	11.2	160	80	83	11	0.76	0.13	1050
	Jan	4650	194	8.2	0	6.6	14.4	120	76	80	11	0.76	0.1	490
	Mar	4090	200	7.8	7.5	5.9	12.2	83	77	83	11	0.69	0.05	232
	May	4320		7.8	14.5	9.8	8.8	210	72	78	9.5	0.55	0.11	595
	Jul	1770	249	7.9	11	7.4	11.8	54	100	102	14	0.94	0.07	105
	Sep	1740	294	8	17.5	9.9	9.4	52	120	121	16	1.1	0.07	127
Kiona (1983)	Nov	2880	266	7.6	12	4.3	9.7	190	100	114	15	1.1	0.12	311
	Jan	2790	255	8.1	1.5	2.1	13.9	37	94	103	15	1.1	0.12	701
	Mar	7530	186	8.2	7.5	8.2	11.1	210	70	65	9.8	0.55	0.15	2260
	May	8170	145	7.5	12	19	10.5	80	56	59	6.6	0.43	0.11	1390
	Jul	2440	280	8.1	23	8.2	9.2	510	110	115	15	1.4	0.19	323
	Sep	2250	265	8.2	13.5	5.7	9.9		100	112	15	1.1	0.08	152
Kiona (1982)	Nov	2060	312	8.1	12	5	10.2	210	120	130	18	1.5	0.08	145
	Jan	2380	270	8.2	0	2	15.1	120	100	110	15	1.3	0.09	39
	Mar	6720	176	7.4	7.5	10	10.9	380	69	75	9	0.45	0.06	1610
	May	3390	190	8.4	12	5.1	10.6	120	74	80	9.8	0.35	0.07	220
	Jul	2170	276	8.6	23.5	4.8	10.2	180	100	109	14	0.98	0.18	117
	Sep	2210	253	7.6	20.5	1.3	9.2	270	100	115	15	0.98	0.08	167
Kiona (1981)	Nov	3040	247	7.8	6	4.7	11.6	--		98		1.1	0.12	131
	Jan	7960	175	7.9	6.1	5.1	12	700	60	60	9.3	0.68	0.15	2110
	Mar	4500	201	7.9	8	6.9	11.6	21	72	68	10	0.62	0.11	389
	May	1150	304	8.7	15.3	5.2	12.3	20	120	130	19	1.1	0.2	56
	Jul	1920	284	7.9	18.9	10	9	250	110	100	15	1.3	0.17	202
	Sep	2070	297	8.2	19.5	8.3		89	110	76	15	1.2	0.14	240

Table 53. Physical and chemical water quality, Yakima River at Union Gap gauging station (RM 106.8), 1980-1985. Data from the U.S. Geological Survey Water Data Reports WA-80-2, WA-81-2, WA-82-2, WA-83-1, WA-85-1 and USGS Open-File Report 84-145-B.

Station and year	Month	Disch. (cfs)	Spec. cond. (us/cm)	pH	Temp. (deg C)	Turbidity (NTU)	Diss. oxygen (mg/l)	Coliform fecal bacteria UM-MF (counts/100 ml) per 100 ml)	Hardness (mg/l as CaCO3)	Alka-linity (mg/l as CaCO3)	Sodium (mg/l)	Nitrogen (NO2 + NO3) (mg/l)	Phos-phorus (total) (mg/l)	Sediment disch. (tons/day)
Kiona (1980)	Nov	1850	308	7.4	10	5.2	10.2	63	123	130	20	1.9	0.13	170
	Jan	4770	245	7.8	2.1	3	14.7	28	94	100	16	1.2	0.15	3786
				[illegible]	[illegible]			88	74			1.1	0.42	9612
	May	18320	124	7.9	15.6	21	9.6	310	50	50	6.5	0.36	0.16	2853
	Jul	1360	306	8.4	23.6	7.3	8.6	100	116	120	17	1.6	0.14	99
	Sep	1750	319	8.6	20.6	6.9	10.4	200	114	120	17	1.7	0.09	94
						5.9		0						
Kiona mean 1980-85	Nov	2853	268	7.9	9.0	3.4	10.9	0	88.8	112.5	13.3	1.26	0.110	320
	Jan	4092	232	8.0	2.0	[illegible]	14.0	0	87.3	94.5	13.6	1.04	0.115	1193
	Mar	5872	202	7.9	7.6	14.1	11.4	0	78.7	80.5	11.0	0.73	0.148	2374
	May	4580	191	8.0	14.1	11.6	10.3		74.8	80.5	10.2	0.57	0.128	882
	Jul	1800	284	8.1	20.9	7.7	9.4	0	109.3	113.2	15.3	1.24	0.150	155
	Sep	2118	286	8.1	18.0	8.5	9.6	0	109.0	111.5	15.7	1.23	0.093	200

Table 54. Suspended solid discharge from various sources in the Yakima Subbasin.

Source	Location	Suspended Solids (tons/day)
Sulphur Creek	RM 61.0 Yakima River	191.1[1]
Spring/Snipes Creek	RM 41.8 Yakima River	17.3[1]
Marion Drain	RM 82.6 Yakima River	13.4[1]
Ahtanum Creek	RM 106.9 Yakima River	13.0[2]
Granger Drain	RM 85.7 Yakima River	12.1[1]
Moxee Drain	RM 107.6 Yakima River	11.8[1]
Wenas Creek	RM 122.4 Yakima River	10.7[2]
Wilson Creek	RM 147.0 Yakima River	4.8[1]

[1] Agricultural Return Flow Management in the state of Washington, 1975. Prepared for Washington Department of Ecology by CH2MHill.

[2] Mean of 1975 and 1976 irrigation seasons as reported in USGS Open-File Report 78-946.

Particle size distribution of streambed material has been quantified only in a few reaches of the upper Yakima and the Little Naches (Wasserman et al. 1984, Fast et al. 1986), but field biologists have qualitatively observed that substrate quality, especially as regards deposition of fine materials, generally falls off along a downstream gradient. In the mainstem Yakima, substrate quality is worst in the reach from Sunnyside Dam to Kiona, and improves somewhat from Kiona to the Columbia confluence as fine materials settle out and/or are resuspended by river flows augmented with irrigation returns.

Pesticide contamination is also a potential problem to fish in the lower Yakima. In 1985 the Washington Department of Ecology's water quality investigations division conducted an evaluation of the hazards to human health and aquatic life presented by toxic chemicals (DDT and metabolites, 15 additional organochlorine pesticides, PCBs and mercury) in water, sediments and fish tissues. Major organochlorine compounds detected in fish were DDT, DDE, dieldrin and PCB-1260. Fish in the lower river had higher

concentrations than fish in the upper river, and resident fish had higher concentrations than juvenile anadromous salmonids. Concentrations of all substances were, however, well below federal Food and Drug Administration "action levels." The concentrations of all substances in fish tissues were not high enough to suggest the possibility of impaired reproduction. DDT, DDE, DDD, dieldrin and endosulfan, evidently of historic origin, were detected in water samples taken from irrigation drains (Sulphur Creek, Birchfield Drain, Granger Drain, and Snipes/Spring Creek) and in one instance from the Yakima River at Kiona. All were present in concentrations below those known to be acutely toxic to aquatic life. However, concentrations in a number of tributaries (Birchfield Drain, Sulphur Creek, Granger Drain and Snipes/Spring Creek) were above levels considered safe to aquatic animals subjected to chronic exposure. Fish in affected drains might not meet FDA standards for human consumption (Johnson et al. 1986).

Table 53 summarizes 12 important water quality parameters in terms of monthly means observed at a mid-river (Union Gap) and a lower river (Kiona) site from 1980 through 1985. Not surprisingly, the concentration of all dissolved and suspended materials is greater at Kiona than Ahtanum, and is greater during the irrigation season at both stations. Although dissolved oxygen concentrations are good at both stations at all times, some observers suspect there may be localized zones of low dissolved oxygen, especially at the bottom of deeper holes in the lower river during the summer.

When flows are low and the pH is high in a IO-mile stretch downstream of the Prosser Municipal Sewage Treatment Plant, there is the potential for the buildup of toxic concentrations of ammonia. The treatment plant cannot process the volume of sewage it now receives, and there are plans to build a new, larger facility. However, until such a facility is built, the old plant must not discharge wastes into the Yakima River when instream flows are low. When discharged into the river when flows are low and the pH is high, conditions that occur frequently in the summer, ammoniacal wastes will present a hazard to aquatic life.

B) Hatchery Operations

INTRODUCTION

An important objective of this project was to evaluate several methods of supplementation that could potentially be used to help rebuild the spring chinook salmon runs of the Yakima Basin and elsewhere in the Columbia System. In this study, supplementation is defined as the use of hatchery-reared fish to increase the magnitude of natural production. The critical uncertainties that were tested included the manner of release, the time of release, and the brood stock used.

To evaluate the manner of release, tribal researchers tested fish released volitionally from acclimation ponds against fish that were trucked and released directly into the river. The time of release was evaluated by releasing test groups of fish as fry in June, parr in September, and pre-smolts in November. The effect of parentage was tested by comparing survival of progeny produced by three different mating scenarios -- wild Yakima River males with Yakima females (WxW), wild Yakima males with Leavenworth Hatchery females (WxH), and Leavenworth Hatchery males and females (HxH).

Success was evaluated only in terms of post-release survival. The response variables that were measured included both survival of smolts from their release site to the juvenile evaluation facility at Chandler canal, and also as adults returning to the Columbia and Yakima rivers. Smolt-to-adult survival was estimated in terms of the number of smolts released at upriver release points, and the number of fish estimated to have survived to Prosser Dam. This distinction was made in an attempt to define the sources of mortality geographically.

In 1984, 1985, and 1986, the returning adults were collected in various fisheries, and from carcasses collected on spawning surveys and at various screens and dams to allow recovery of the coded-wire tags used as treatment marks. From 1987 through 1990, the majority of the returning experimental adults were collected at Roza fish ladder adult trap. This was done both to maximize the number of coded-wire tags recovered, and to minimize the genetic risks associated with the spawning of non-native hatchery adults with wild/natural fish. Thus, since little if any spawning of hatchery-reared salmon occurred, the reproductive success of the adults produced by these three mating scenarios was not determined in this study.

Biological and tagging information describing the experimental releases made from 1983 through 1987 is presented in Table 55. A brief discussion describing the materials and methodologies followed for each year's experimental releases will be presented under the following sections on method of release, time of release, and brood stock. An analysis and discussion of survival from smolt-at-release to smolt-at-Prosser (smolt-to-smolt survival), and

of survival from smolt-at-release and smolt-at-Prosser to returning adult, will also be presented under each section.

Table 56 summarizes the estimated expanded returns of recovered hatchery adults. The two releases from Nile Springs and the upper Yakima for the first year of the study (1980 brood stock) were not included in this analysis because the smolt trap at Prosser was not operational and thus unable to collect release-to-smolt survival data. In addition, the sample and mark rates were so low that data expansion resulted in 208 adults estimated from five actual recoveries for the acclimated fish, and 451 returning adults from nine recoveries from the upper Yakima.

The coded-wire tag data for adult salmon caught during the 1990 season on the Columbia River and in the ocean was not on line at the Pacific Marine Fisheries Commission data base as of Jan. 1, 1991, so it could not be factored into this report.

Beyond describing the general methodology of the releases and recaptures (both as smolts and adults), attention will be given to particular problems that could have affected survival rates.

Table 55. Tag data on all experimental hatchery release groups that were released into the Yakima system during the spring chinook enhancement study.

Brood Year	Tag Code	Total Number Released	Release Site	Number Tagged	Mark Rate (%)
1980	5-10-41	100,050	Nile Springs	21,814	21.8%
1980	5-10-61	401,714	Upper Yakima	45,523	11.3%
1981	5-13-38	99,725	Nile Springs	94,523	94.8%
1981	5-13-39	97,725'	Upper Yakima	94,198	97.1%
1982	5-11-47	29,636	Nile Springs	28,450	96.0%
1982	5-11-48	45,552	Upper Yakima	41,573	97.7%
1983	5-15-33	45,195	Mary's Pond	43,297	95.8%
1983	5-15-32	42,210	Up. Yakima(Apri1)	40,436	95.8%
1983	5-15-28	102,837	Up. Yakima(June)	93,064	90.5%
1983	5-15-29	102,833	UP. Yakima(Sept)	93,064	90.5%
1983	5-15-30	108,305	UP. Yakima(Nov)	102,229	94.4%
1984	5-15-45	100,750	UP. Yakima(June)	96,216	95.5%
1984	5-15-46	101,724	UP. Yakima(Sept)	95,621	94.0%
1984	5-15-47	101,522	UP. Yakima(Nov)	95,431	94.0%
1984	5-15-48	50,657	Upper Yakima	46,858	92.5%
1984	5-15-49	51,846	Mary's Pond(HxH)	47,076	90.8%
1984	5-15-50	46,476	Mary's Pond(HxW)	40,434	87.0%
1984	5-15-51	33,052	Mary's Pond(WxW)	29,449	89.1%
1985	5-17-38[b] 5-17-56	50,113	Upper Yakima	42,796	85.4%
1985	5-17-38 5-17-56	50,519	Mary's Pond(HxH)	44,436	84.8%
1985	5-17-55	52,392	Mary's Pond(HxW)	44,899	85.7%
1985	5-14-46 5-14-47 5-14-48	56,841	Mary's Pond(WxW)	47,576	83.7%

[a] Only half of these fish may have escaped predation and actually have been released.

[b] Tag numbers 5-17-38 and 5-17-56 were originally intended to separate the upper Yakima trucked smolts and the Mary's Pond acclimation smolts. These two groups were accidently mixed together at the Leavenworth Hatchery.

Table 56. Estimated expanded returns of recovered hatchery adults.

Tag Code	Source of Recoveries'	Number Recvrd.	Sample Rate	Sample Expanded	Mark Rate	TOTAL
5-10-41	3 (1984)	4	.074	54	.266	203
Nile	2	1	.709	1	.266	5
Springs						208
5-10-61	5 (1984)	8	.179	44	.113	394
Upper	5 (1985)	1	.155	6	.113	57
Yakima						451
5-13-38	1 (1985)	7	.333	21	.948	22
Nile	3	7	.134	52	.948	55
Springs	1 (1986)	2	.286	7	.948	7
	3	2	.109	18	.948	19
						103
5-13-39	1 (1985)	3	.750	4	.971	4
Upper	2	1	.295	3	.971	3
Yakima	5	4	.155	26	.971	26
	1 (1986)	3	.273	11	.971	11
	5	12	1.00	12	.971	12
						56
5-11-47	1 (1986)	4	.363	11	.960	11
Nile	3	2	.109	18	.960	19
Springs	1 (1987)	3	.429	7	.960	7
	3	2		2	.968	2
						39
5-11-48	4 (1986)	12	1.00	12	.977	12
Upper	1 (1987)	3	.333	9	.977	9
Yakima	4	5	1.00	5	.977	5
						26
5-15-33	4 (1986)	1	1.00	1	.958	1
Mary's	1 (1987)	9	.474	19	.958	20
Pond	4	56	1.00	56	.958	58
	5	2		2	.958	2
	1 (1988)	8	.333	24	.958	25
	4	28	1.00	28	.958	29
	1 (1989)	1	.500	2	.958	2
						137

(continued)

Table 56 cont. Estimated expanded returns of recovered hatchery adults.

Tag Code	Source of Recoveries'	Number Recvrd.	Sample Rate	Sample Expanded	Mark Rate	TOTAL
5-15-32	1 (1987)	3	.600	5	.958	5
Upper	4	35	1.00	35	.958	37
Yakima	2	1		1	.958	1
(trucked)	3	1		1	.958	1
	1 (1988)	8	364	22	.958	23
	4	22	l:oo	22	.958	2 3
						90
5-15-28	4 (1986)	1	1.00	1	.905	1
Upper	4 (1987)	20	1.00	20	.905	22
Yakima	1	2	.286	7	.905	8
(June)	3	1		1	.905	1
	5	1		1	.905	1
	4 (1988)	2	1.00	2	.905	2
						35
5-15-29	4 (1986)	1	1.00	1	.905	1
Upper	1 (1987)	6	.462	13	.905	14
Yakima	4	31	1.00	31	.905	34
(Sept.)	5	1		1	.905	1
	1 (1988)	3	.333	9	.905	10
	4	21	1.00	21	.905	23
	1 (1989)	1	.500	2	.905	2
						85
5-15-30	4 (1986)	1	1.00	1	.944	1
Upper	1 (1987)	1	.500	2	.944	2
Yakima	4	39	1.00	39	.944	41
(Nov.)	1 (1988)	5	.263	19	.944	20
	4	18	1.00	18	.944	19
						83
5-15-45	4 (1988)	3	1.00	3	.955	3
Upper	1 (1989)	1	.500	2	.955	2
Yakima						5
(June)						
5-15-46	4 (1987)	3	1.00	3	.940	3
Upper	4 (1988)	84	1.00	84	.940	89
Yakima	1 (1989)	4	.500	8	.940	5
(Sept.)	4 (1989)	6	1.00	6	.940	6
						103

Table 56 cont. Estimated expanded returns of recovered hatchery adults.

Tag Code	Source of Recoveries'		Number Recvrd.	Sample Rate	Sample Expanded	Mark Rate	TOTAL
5-15-47	4	(1987)	1	1.00	1	.940	1
Upper	1	(1988)	4	.667	6	.940	6
Yakima	4		27	1.00	27	.940	29
(Nov.)	5		1		1	.940	1
	1	(1989)	2	.500	4	.940	4
	4		5	1.00	5	.940	5
							46
5-15-48	4	(1988)	6	1.00	6	.925	6
Upper	1	(1989)	1	.500	2	.925	2
Yakima	4		4	1.00	4	.925	4
(trucked)							12
5-15-49	4	(1987)	1	1.00	1	.908	1
Mary's	1	(1988)	2	.500	4	.908	4
Pond	4		13	1.00	13	.908	14
(HxH)	5		1		1	.908	1
	1	(1989)	2	.500	4	.908	4
	4		3	1.00	3	.908	3
							27
5-15-50	4	(1987)	3	1.00	3	.870	3
Mary's	1	(1988)	2	.333	6	.870	7
Pond	4		6	1.00	6	.870	7
(HxW)							17
5-15-51	5	(1987)	1		1	.891	1
Mary's	1	(1988)	1	1.00	1	.891	1
Pond	4		3	1.00	3	.891	3
(WxW)							5
5-17-38	1	(1989)	5	.556	9	.854	10
Up. Yak	4	(1989)	24	1.00	24	.854	28
& Mary's	4	(1990)	11	1.00	11	.854	13
Pond (HxH)							51

(continued)

Table 56 cont. Estimated expanded returns of recovered hatchery adults.

Tag Code	Source of Recoveries'		Number Recvrd.	Sample Rate	Sample Expanded	Mark Rate	TOTAL
5-17-56	4	(1988)	1	1.00	1	.848	1
Up. Yak.	1	(1989)	9	.600	15	.848	18
& Mary's	4		34	1.00	34	.848	40
Pond (HxH)	4	(1990)	10	1.00	10	.848	12
	5		2				2
							73
5-17-55	1	(1989)	4	.571	7	.857	8
Mary's	4		32	1.00	32	.857	37
Pond	5		1				1
(HxW)	4	(1990)	6	1.00	6	.857	7
							53
5-14-46,47,48	4	(1988)	1	1.00	1	.837	1
Mary's	5		1		1	.837	1
Pond	1	(1989)	1	.500	2	.837	2
(WxW)	4		43	1.00	43	.837	51
	5		2		2	.837	2
	4	(1990)	4	1.00	4	.837	5
							62

OVERVIEW

Smolt-to-Smolt Survival: Acclimated vs. Trucked Fish

In three years (1983, 1984 and 1986) of the four in which trucked and acclimated fish can be compared, the survival of acclimated fish to Prosser exceeded that of trucked fish. (No comparison is possible in 1987 because falling river levels trapped many acclimation fish in the acclimation pond). In 1985, survival to Prosser was approximately equal between the groups. Estimated survival to McNary was greater for acclimated fish in all four comparable years. For all releases but 1987, the mean survival to Prosser for acclimated fish was 48.4%, ranging from 17.8% (1986) to 89.1% (1983), while the mean survival of trucked fish was 24.6%, ranging from 8.2% (1986) to 40.4% (1984). Over these same years, the mean survival of acclimated fish at McNary was 39.7%, with a range of 8.8% (1986) to 89% (1983). The mean survival of trucked fish at McNary was 22%, with a range of 4.8% (1986) to 44.6% (1983). Interestingly, the survival of both acclimated and trucked groups from Prosser to McNary was greater than survival from release point to Prosser.

In all years but 1987, the migration rate of acclimated fish was also greater than trucked fish. This was true at both Prosser Dam and and McNary Dam.

There was no indication that differential size at release impacted relative survival of acclimated and trucked smolts. It was, however, observed that all hatchery-reared fish, regardless of group, were significantly larger when observed at Prosser than they were at release. This observation was assumed to result from a combination of growth and size-dependent differential mortality.

Smolt-to-Smolt Survival: Optimal Time of Release

The maximum survival to Prosser for fall-released pre-smolts was 11%; the maximum survival to McNary was 5.5%. There was, however, no indication of the specific release time (in the fall) for optimal survival; September releases were better than November releases in 1984 (Prosser survival September ‘84 = 10.96%, November ‘84 = 3.71%), while the reverse was true in 1985 (Prosser survival November ‘85 = 9.39%, September ‘85 = 0.79%). It should be noted that the survival rates to Prosser and McNary are almost certainly underestimated because neither facility was operated in the winters of 1984-85 and 1985-86, and there is evidence that an undetermined number of fall-released pre-smolts emigrated during this period. It should also be noted that survival from Prosser to McNary (for the portion of the population that emigrated during the spring monitoring period) was again greater than survival from release point to Prosser.

The fry released in the upper Yakima in early June of 1984 and 1985 did not behave as expected. Instead of taking up residence and emigrating as smolts the following spring, most of the fish that could be accounted for simply left the system immediately, passing

Prosser within two months of release. About 11% of the 1984 fry and 2.5% of the 1985 fry passed Prosser the summer they were released. No 1984 fry were observed at Chandler in the spring of 1985, and only 28 of the 9,102 branded fry released in 1985 were estimated to have passed Prosser in the spring of 1986. Note, however, that no winter monitoring was possible during the winters of 1984-85 and 1985-86. Thus, as is true of the fall pre-smolts, total passage at Prosser for the June fry is probably underestimated to some extent.

The most significant aspect of the observed patterns of outmigration is that, both in 1985 and 1986, the passage of both groups of fall pre-smolts was well ahead of wild smolts. It is therefore possible that fall-released hatchery pre-smolts migrate farther downriver during the winter than does the average wild pre-smolt.

As was the case for acclimated and trucked smolts, there was no indication that differential size at release impacted survival.

Smolt-to-Smolt Survival: Optimal Release Stocks

The stocks investigated included hatchery-reared native fish (the "wild" group), hatchery-reared Leavenworth x Yakima crosses (the "hybrid" group) and hatchery-reared Leavenworth fish (the "hatchery" group). Releases of all of these groups were made in 1986 and 1987, and in each year, all groups were acclimated together in Mary's Pond on the upper Yakima River. It should be noted that the 1987 groups incorporated "quasi-replicates," as each treatment included four distinctly branded subgroups.

Estimated survival to Prosser was (marginally) greatest for the wild group in both 1986 and 1987. In 1986, the survival to Prosser of the wild, hybrid and treatment groups were 20.2%, 18.7% and 17.896, respectively. The mean survival to Prosser of the combined subgroups of wild, hybrid and hatchery fish in 1987 was 10.6%, 2.8% and 3.7%, respectively. (Recall that the lower overall survival rates of the 1987 groups are an artifact attributable to an unknown number of test fish being stranded in the acclimation pond when river flows fell.) The superior survival to Prosser of wild fish was marginal in 1986, and in fact, all groups were regarded as equivalent. The difference in 1987 was more substantial. If the subgroups are regarded as replicates, the survival of wild fish in 1987 was significantly greater than the other groups, although the hybrid and hatchery groups are indistinguishable.

Estimated survival to McNary was slightly less than half the survival to Prosser in 1986 for all groups. However, the order of survival was reversed relative to Prosser, with hatchery fish doing best, hybrid fish next best and wild fish worst. The absolute differences were quite small, ranging from 6.9% (wild) to 8.8% (hatchery), and the survival of all groups to McNary should probably be regarded as equivalent. In 1987, on the other hand, the "apparent survival" of wild fish to McNary was again significantly greater than the other groups. Note that the higher recovery rates of wild fish in 1987 may not reflect better inriver survival so much as the inclination and ability to swim through a small channel in the process of drying up.

Again, for all groups and over both years, the apparent survival from Prosser to McNary was greater than the survival from release point to Prosser.

The study provided little evidence that hatchery-reared smolts that are genetically identical to natural Yakima fish will enjoy higher in-basin survival rates than non-native hatchery-reared fish. Wild recovery rates were clearly superior to hybrid and hatchery rates only in 1987, and even then it was not clear whether higher recover rates reflected higher survival of outmigrating smolts in the Yakima River.

Adult Return Rates: Acclimated vs. Trucked Fish

Smolt-to-adult survival for acclimated fish was higher than survival of trucked fish in all four experimental releases. The mean survival of acclimated smolts, from the site of release to returning adult at Prosser, was 45% higher for acclimated smolts. The relative superiority of acclimated smolts falls to 23% when survival is expressed in terms of "smolts at Prosser." The diminution of the relative superiority of acclimated smolts when survival is expressed as smolts surviving to Prosser undoubtedly reflects the higher survival rate of acclimated smolts in the period immediately following release. It is, however, significant that acclimated smolts still return at higher rates than trucked fish even when based on Prosser survivors. Therefore, the benefits of acclimation apparently persist after the brief period immediately following release. On the basis of this study, it would appear that about 50% of the survival benefits attributable to acclimation are expressed immediately after release.

Adult Return Rates: Optimal Release Time

Expressed in terms of fish at release, the mean adult return rate of June-released fry was only 0.016%. This low rate was greatly impacted by the extremely low (0.003%) return rate of the fry released in June of 1984. Return rates of this magnitude would obviously contribute little to overall production in the Yakima. It should, however, be noted that a previous, larger-scale study on the Lemhi River in Idaho suggested that fry released in May and June *probably did* result in a substantial increase in the production of what we have called winter migrants and, to a much lesser degree, spring smolts (Bjomn 1978). Studies of this sort indicate that the issue has not yet been settled, and a considerable amount of research involving fry releases is currently planned in Idaho.

The mean return rate per fish released for September parr was O-08%, and the comparable figure for November pre-smolts was 0.05 %. While parr and pre-smolt releases were clearly superior to fry releases, the rates we have observed in the Yakima do not justify their utilization as a means of augmenting production. Again, the Yakima study may not be applicable to other systems. Researchers in Idaho believe the technique has potential in a number of systems, and plans are under way for a number of major research projects.

Adult Return Rates: Optimal Release Stock

The limited results of two years' releases of acclimated wild, hybrid and hatchery smolts indicated that the mean return return rates per fish released were 0.06% for the two "wild" groups and 0.055% for the two hybrid groups. Due to accidental mixing of tagged fish in the hatchery, only one group of hatchery fish can be evaluated. The return rate of this group, released in 1986, was 0.04%. Thus, the effect of ancestry alone had little effect on the post-release survival of hatchery-reared fish.

Although compromised in a number of ways, the results of this study are interesting because they suggest that hatchery-reared wild stock does not perform better than either non-native hatchery stock or hatchery-wild hybrids. Therefore, genetic considerations alone may not result in substantial improvements in the post-release survival of hatchery-reared fish. The emphasis in hatchery operations, especially those employed in supplementation, must be shifted from maximizing the number of smolts released and redirected to the development of new procedures designed to increase survival in the natural environment. Undoubtedly, genetic considerations are crucial to the reproductive success and long-term fitness of hatchery-reared fish that have survived to return as adult spawners. However, new procedures incorporating physiological and, especially, behavioral considerations, in addition to genetic considerations, may be necessary for real improvement in post-release survival.

Again, the current study investigated neither the reproductive success nor the long-term fitness of hatchery-reared salmon that spawn in the wild. Emphatically, such research is needed in the future.

OPTIMAL MANNER OF RELEASE

In 1983 about 100,000 spring chinook pre-smolts were acclimated at Nile Pond, located at RM 29 on the Naches River. Nile Pond is spring-fed and about 0.5 acre in size with a depth of about 2.5 m. It should be noted that heavy bird predation at Nile Pond affected the actual number of fish released from the pond (as opposed to the number initially stocked) in 1983. Twice since 1983, spring chinook and coho pre-smolts have been acclimated in Nile Pond and have suffered about a 50% loss due to bird predation (see subsequent section on 1984 Nile Pond acclimated fish). For this reason, researchers assumed that the actual number of acclimated fish released in 1983 was half of the original number stocked.

The pre-smolts were acclimated in the pond for about three months prior to release (January 26-April 20). On March 18, 9,905 fish were seined from the pond and marked with a freeze brand; 9,905/2 or 4,952 fish are assumed to have survived until release. The incidence of bacterial kidney disease in these fish may have affected their survival. The U.S. Fish and Wildlife Service estimated that the infection rate was 26.7% to 36.7%. Fish were volitionally released from the pond beginning April 20, 1983.

About 100,000 non-acclimated spring chinook were trucked from the Leavenworth National Fish Hatchery (LNFH) and released directly into the Yakima River between RM 155 and RM 200 on April 18, 1983. The estimated rate of BKD at the hatchery prior to release was 1.7%. Twelve different release locations were used for this release, with the intent of minimizing the density of hatchery fish at any one point in the river. These same sites were used throughout the course of this study. One variable of potential significance in evaluating the survival rates of these two groups is the initial difference in release locations.

In 1984, fish were transported from the Entiat National Fish Hatchery (ENFH) for acclimation in Nile Pond on October 25 and November 1, 1983. Each transport consisted of 25,000 fish. Volitional release began on April 10, 1984. The infection rate of BKD was 29.5%. Because of suspected losses attributable to predatory birds, population estimates were conducted March 1 and April 10. A total of seven Peterson mark-recapture population estimates were made; the estimated population size at release was 28,450 fish, with a 95% confidence interval of 23,347 to 35,925 fish. If this estimate is accurate, almost 50% of the initial plant was lost. A similar problem is assumed to have occurred in 1983.

The 1984 non-acclimated fish (about 50,000) were transported from the Entiat National Fish Hatchery on April 9-12 and released into the upper Yakima River. Methodology was the same as in 1983.

In 1985, approximately 45,000 spring chinook smolts from Leavenworth National Fish Hatchery were acclimated in Mary's Pond beginning April l-3. Mary's Pond is located at RM 192.5 on the upper Yakima River. This site was selected for the acclimation site to

reduce the variable of release location between the acclimated and trucked groups. Mary's Pond is an old gravel pit about 1.5 acres in size, with a maximum depth of 2 m. The pond connects with the Yakima River via a narrow, 200-meter outlet channel. A seine was placed at the outlet to prevent fish from exiting the pond prematurely. Volitional release began April 10. The pond was seined April 26, 1985, to force out the remaining fish.

A corresponding group of about 42,000 non-acclimated smolts from Leavenworth were released directly into the Yakima River on April 10-12, 1985, at the same locations as in previous years.

In 1986 about 50,000 smolts from Leavenworth National Fish Hatchery were acclimated in Mary's Pond beginning March 26-28 (releases were conducted over a three-day period). Over the course of the acclimation period, which extended to April 9, the seine net at the pond outlet was chewed through by beavers on several occasions. The first breaching of the barrier net occurred on March 27, even before all the smolts had been placed in the pond. The net was repaired each morning when damage was observed. Fish from this release, however, showed up at Prosser beginning April 1, suggesting that some fish were escaping immediately after being released into the pond. Researchers observed that large numbers of fish responded well at feeding time, indicating that the majority of fish remained in the pond for the entire acclimation period. Smolts were allowed unrestricted volitional release from the pond beginning April 9, 1986.

The corresponding 50,657 non-acclimated fish were transported from Leavenworth National Fish Hatchery and released into the Yakima River in a fashion similar to previous years. Half of the fish were planted on April 9 while the other half was delayed until April 28, 1986 because of suspicions that these smolts were infected with infectious hematopoietic necrosis (IHN) virus. Their release was delayed until they were retested and certified disease-free.

In 1987 about 50,000 smolts were transported from LNFH on March 19-23 to be acclimated in Mary's Pond. Smolts were allowed volitional release beginning April 14. This acclimation period was plagued with several problems. As in 1986, smolts from this release were observed at Prosser as early as April 8, indicating the outlet barrier was not completely fish-tight. An unknown number of fish were also consumed by an otter observed in the pond one week after initial acclimation (the otter was removed shortly thereafter). Finally, the water level in the pond dropped below the outlet elevation during the outmigration period due to low river flow, eventually drying up the outlet channel. Therefore, an undetermined number of fish were unable to exit the pond.

The corresponding non-acclimated release group of about 50,000 smolts was transported from LNFH on April 14, 1987. Smolts were again released at the 12 locations in the Yakima River between RN 155 and RM 200.

Smolt Survival

The basic survival data for experimental pond-acclimated smolts ("pond fish") and non-acclimated, direct-release smolts ("trucked fish") is summarized in Table 57.

In three years (1983, 1984 and 1986) of the four in which trucked and acclimated fish can be compared, the survival of acclimated fish to Prosser exceeded that of trucked fish. (No comparison is possible in 1987, because falling river levels trapped many acclimated fish in the acclimation pond.) In 1985, survival to Prosser was approximately equal between groups, with the trucked rate being just 4% greater. Estimated survival to McNary Dam was greater for acclimated fish in all four comparable years.

Although neither the Chandler nor the McNary entrainment estimator is capable of generating confidence intervals for the estimates they produce, the figures in Table 57 indicate smolt survival is probably greater for acclimated fish.

The estimated survival of fish from Prosser Dam to McNary Dam is also interesting. Pear in mind that *all* "smolt survival rates" estimated in this study should be regarded as relatively imprecise indices of survival. Prosser-to-McNary "survival estimates" are more unreliable than most because they represent the ratio of estimated passage at Prosser to estimated passage at McNary, and thus combine different estimation procedures that may have different biases. An indication of the occurrence of this type of problem is seen in the fact that putative survival from Prosser to McNary sometimes exceeds 100%. This sort of result indicates that Prosser-to-McNary survival estimates should only be considered qualitatively.

From this qualified perspective, then, it appears as though survival from Prosser to McNary is always considerably greater than survival from release point to Prosser. If true, this suggests that the reach from Prosser to McNary Dam is considerably less hazardous than the reach from upper Yakima release points to Prosser, or that "unfit" hatchery-reared individuals have been culled before reaching Prosser.

The former supposition is supported to some extent by two observations. First, Prosser-to-McNary survival rates for hatchery fish were quite comparable to the rates estimated for wild fish. The mean Prosser-to-McNary survival rate for wild fish in 1984, 1985, 1986 and 1988 was 53%, 50%, 42% and 71%, respectively (overall mean = 54%). The mean survival from Prosser to McNary of all hatchery smolts (not just trucked and acclimated) in 1984, 1985, 1986 and 1987 was 59.3%, 72.2%, 46.1% and 67.7%, respectively (overall mean = 61%). The second observation suggests, however, that hatchery fish fared considerably worse than wild fish when compared over a longer reach -- Prosser to John Day. One can crudely index relative wild/hatchery survival from Prosser to John Day by comparing recovery proportions of wild and hatchery fish. The recovery proportion of wild fish is the ratio of the unexpanded number of observations at John Day to the number of fish released at Prosser; the recovery proportion of hatchery fish is the ratio of

unexpanded observations at John Day to the number of fish estimated to have survived to Prosser. The ratio of these ratios represents a crude index of relative wild/hatchery survival from Prosser to John Day. This comparison has been made in Table 58.

Table 57. Summary smolt survival statistics for acclimated, volitionally released hatchery spring chinook molts versus non-acclimated, forced-released hatchery molts. Note that release and passage numbers are expressed in terms of branded fish only. Roughly 10% of all groups were freeze-branded. Note also that Wean water velocity at Sunnyside" refers to the mean velocity in this critical reach from the day of release until the day of median passage at Prosser.

YEAR/GROUP	RELEASE NUMBER (BRANDED FISH ONLY)	PASSAGE AT PROSSER (BRANDED FISH ONLY)	SURVIVAL TO PROSSER (%)	MEAN WATER VELOCITY AT SUNNYSIDE (fps)	PASSAGE AT McNARY (BRANDED FISH ONLY)	SURVIVAL TO McNARY (%)	SURVIVAL FROM PROSSER TO McNARY (%)
'83 TRUCKED	8225	1989	24.18	4.36	3664b	44.55[b]	~100[b]
'83 POND"	4952"	4412	89.08	4.33	4433[b]	89.52[b]	~100[b]
'84 TRUCKED	6818	2755	40.41	2.48	I 884	27.63	68.38
'84 POND	4653	3024	64.99	2.40	1528	32.84	50.53
'85 TRUCKED	3841	980	25.51	2.24	434	11.30	44.28
'85 POND	6056	1311	21.65	2.49	1670[b]	27.58[b]	~100[b]
'86 TRUCKED	6383	522	8.18	1.50	303	4.75	58.04
'86 POND	5910	1054	17.83	2.68	519	8.78	49.24
'87 TRUCKED	5040	1942	38.53	1.82	1059	21.0'1	54.53
'87 POND	5040	186	3.69"	2.01	269[b]	5.34[b]	~100[b]

[a] Heavy bird predation in the acclimation pond was noted, but not quantified in 1983. Losses in 1984 in the same pond were estimated to be on the order of 50%. Losses of pre-smolt coho in the same pond were also estimated to have been about 50% in 1986. For this reason, researchers assumed that only 50% of the 9,905 branded fish actually survived to release.

[b] These anomalous results reflect the inprecision of the Chandler and McNary passage estimators. Release groups are small enough that anomalous results are partially attributable to sampling variability. When the estimated survival to McNary exceeds estimated survival to Prosser, one should probably assume survival from Prosser to McNary "approached 100%."

' Low survival rates for all acclimated fish in 1987 are attributable to the fish becoming trapped in the acclimation pond when river flows fell, drying up the pond's outlet.

Table 58. Relative proportions of marked wild and hatchery-reared spring chinook smolts observed at John Day Dan in 1984, 1985 and 1986. For hatchery fish, the recovery proportion is expressed as the ratio of John Day observations to the number estimated to have survived from release point to Prosser. For wiLd fish, the recovery proportion is expressed as the ratio of the nu&er of John Day observations to the number released at Prosser.

YEAR	WILD FISH			HATCHERY FISH			RELAT JVE WILD/HATCHERY RECOVERY RATE AT JOHN DAY (%)
	# AT JOHN DAY	# RELEASED AT PROSSER	PERCENT RECOVERIES AT JOHN DAY	# AT JOHN DAY	# SURVIVING TO PROSSER	PERCENT RECOVERIES AT JOHN DAY	
1984	10	3,251	0.308	13	5,779	0.225	.308/.225 = 1.37
1985	33	3,851	0.857	6	2,291	0.262	.857/.262 = 3.27
1986	26	3,367	0.772	16	3,656	0.438	.772/.&38 = 1.76

As Table 58 indicates, wild fish survive from Prosser to John Day from 1.37 to 3.27 times better than hatchery fish. This would seem to be evidence against the hypothesis that hatchery survivors at Prosser have “learned the same lessons” as wild fish in, say, the matter of predator avoidance, and thenceforth enjoy the same survival rates as wild fish.

Table 57 also suggests an erratic, but positive relationship between water velocity (flows) below Sunnyside Dam and survival. As previously mentioned, this might be interpreted as the result of interference in squawfish foraging ability. Numerous large squawfish inhabit the Yakima from Wapato Dam to Prosser Dam, and these predators are suspected as the proximate cause of the large Smolt losses seen in years of low flow. Of course, higher discharge and faster water move fish through the “gauntlet” more rapidly, reducing duration of risk. Higher water usually is also turbid water, a definite hindrance to the feeding of visual predators like squawfish.

Reconciling this hypothesis with the unusually high survival rate of the 1987 trucked group -- both at Prosser and McNary -- is somewhat difficult. Over the entire outmigration period, the systemwide flows this group experienced were the second worst of any group monitored.

The characteristics that most distinguish this group are its size and its rapid emigration rate. Fish in the 1987 trucked group, as monitored at Chandler, were both longer and more robust (had a higher condition factor) than any other 1987 group. This group also moved through the system very rapidly. Sixty-six percent of this group, released on April 13, had passed Prosser by the end of April, 90% by May 7. The mean length of trucked fish in April of 1987 was 154 mm; the condition factor was 11.18. Their size probably afforded them an extra measure of protection from predators, their rapid emigration limited their period of exposure to predators, and their condition factor indicated they were feeding well.

Their rapid emigration may have been due to luck, as they reached the middle Yakima River in late April and early May just as a pronounced swell in discharge occurred. The mean discharge below Prosser from April 28 through May 4, when almost 35% of their cumulative passage occurred, was 5,624 cfs, with a high of 7,051 cfs occurring on May 2. By contrast, discharge below Prosser the week ending April 27 was only 2,189 cfs. It therefore appears as though many fish in this group benefitted from being in the right place at the right time.

Outmieration Timing

Table 59 summarizes basic statistics on the timing of acclimated and trucked smolts. The single most important relationship in these figures may be the fact that in all years but 1987 pond-acclimated fish moved faster than trucked fish. (Comparing migration rates of acclimated and trucked fish in 1987 is not meaningful because the Yakima River fell just after the beginning of the 1987 release, severely restricting and eventually eliminating egress from Mary's Pond.) The acclimated fish also maintained their lead at least as far as McNary Dam. It should be noted in this context that all trucked and acclimated groups were released on or very near to the same date.

The relatively faster movement of acclimated smolts is seen in Figures 63-72. Figures 63-67 plot the cumulative passage at Chandler of wild smolts, as well as trucked and acclimated hatchery smolts. Notice in these figures that the hatchery fish, which were released after the beginning of the wild outmigration, have "caught up" to the wild fish by mid to late May. Figures 68-72 plot cumulative passage of trucked and acclimated hatchery smolts at McNary, and indicate that trucked fish still lag behind the acclimated fish.

Figure 73 plots cumulative Chandler passage of all years' acclimated fish as a function of the number of days after release, and Figure 74 plots Chandler passage of all trucked fish. Figures 75 and 76 plot all years' acclimated and trucked passage at McNary in the same way. At least for the acclimated fish, Figures 73 and 75 suggest that migratory patterns become more varied the farther downstream passage is monitored. Specifically, the acclimated groups of 1984 through 1987, which had displayed a very similar pattern of outmigration at Chandler, have "spread out" by the time they reached McNary, and are no longer so well synchronized.

Median migration rates from release point to Chandler ranged from 3.1 to 7.87 miles per day. Not surprisingly, migration rates from release point to McNary increased, ranging from 5.08 to 9.94 miles per day. This acceleration probably reflects the faster water velocities fish encounter in the 43.4 miles from the Columbia confluence to McNary Dam.

It is interesting to reflect on the fact that even the fastest smolts are moving much slower than the water they move in. Consider that 1 foot per second is (1 x 24 hours x 3,600 sec/hr)/5,280 ft/mi, or about 16.4 miles per day. Even in the slowest sections of the Yakima in the years of lowest flow, water velocities were equal to or (usually) greater than 1

fps. The fastest-moving experimental group, the 1987 trucked fish, moved at a rate of 7.87 miles per day, or about half a foot per second.

The conventional explanation of this fact is that smolts move only at night. The die1 distribution of recaptures at Chandler supports this conjecture, at least to some degree. In 1983 and 1984, the old Chandler trap was monitored numerous times per day -- as frequently as bi-hourly at peak migration periods. Data from these years show that 80% to 90% of all spring chinook smolts enter the trap between 9 p.m. and 1 a.m. It is, however, unclear whether fish in the open river move continuously through the day until they encounter an obstruction, such as a dam or trap. Some believe that fish in fact move continuously in the open river, but "pile up" in front of physically obstructing traps during the day, when they can see the danger. With darkness, the threat is no longer visible and, presumably, fish have a short memory.

Table 59. Sumary of passage timing statistics for acclimated and trucked hatchery spring chinook, 1983-1987.

GROUP	DAYS AFTER RELEASE FOR PASSAGE OF 10%, 50% AND 90% AT CHANDLER			DAYS AFTER RELEASE FOR PASSAGE OF 10%, 50% AND 90% AT McNARY			MIGRATION RATE TO CHANDLER (mi/day)	MIGRATIOW RATE TO McNARY (mi/day)
	10%	50%	90%	10%	50%	90%		
83 TRUCK	11	17	31	15	22	34	6.94	9.47
83 POND'	10	13	19	15	19	28	7.58	9.94
84 TRUCK	14	35	42	34	42	49	3.37	4.96
84 POND-	13	28	38	28	33	45	3.52	5.72
85 TRUCK	18	36	42	39	43	61	3.28	4.84
85 POND[b]	18	26	42	27	40	47	5.57	5.88
86 TRUCK	16	37	51	29	41	52	3.19	5.08
86 POND[b]	11	27	46	36	43	60	5.37	5.47
87 TRUCK	7	15 32	18	18	21	25	7.87	9.92
87 POND[c]	22		43	41	45	46	4.53	5.23

[a] Nile Pond on Naches River used, 98.6 miles from Prosser Dam.
[b] Mary's Pond on upper Yakim used, 144.9 miles from Prosser Dam.
[c] Wary's Pond used. Falling river flows dried up outlet early in release, trapping many fish in pond.

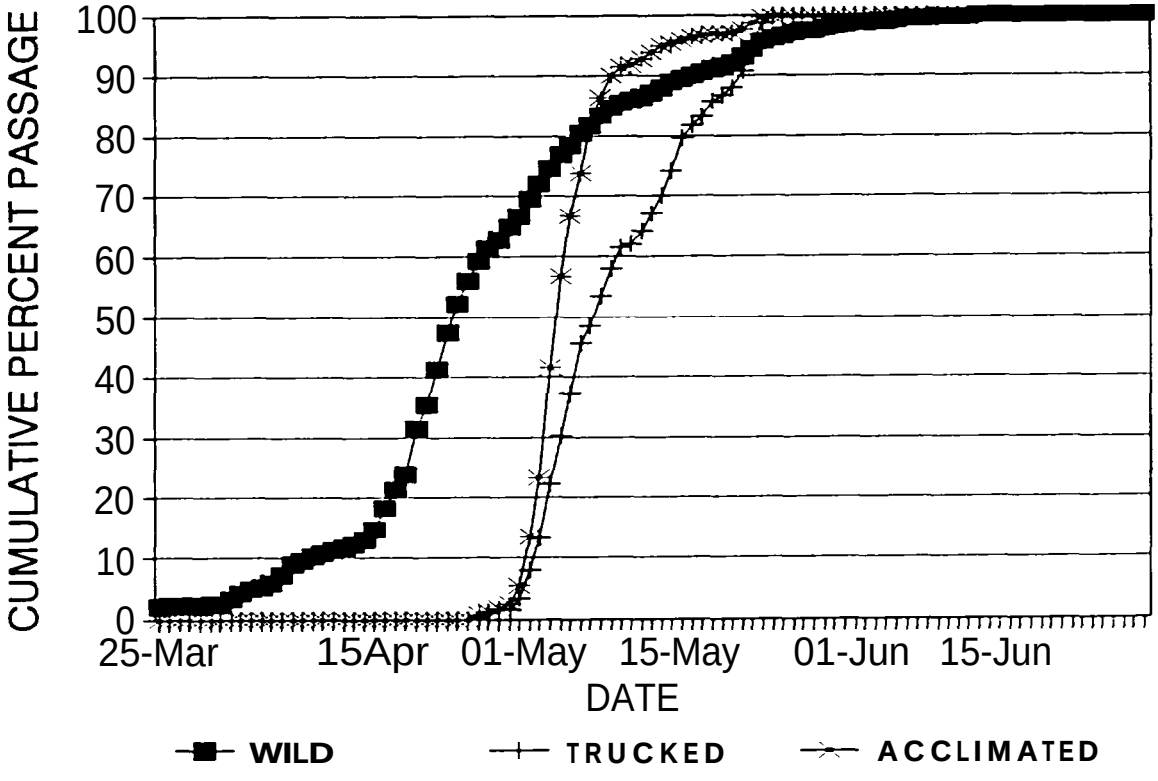


Figure 63. Passage of wild, trucked and pond-acclimated smolts, Chandler trap, 1983.

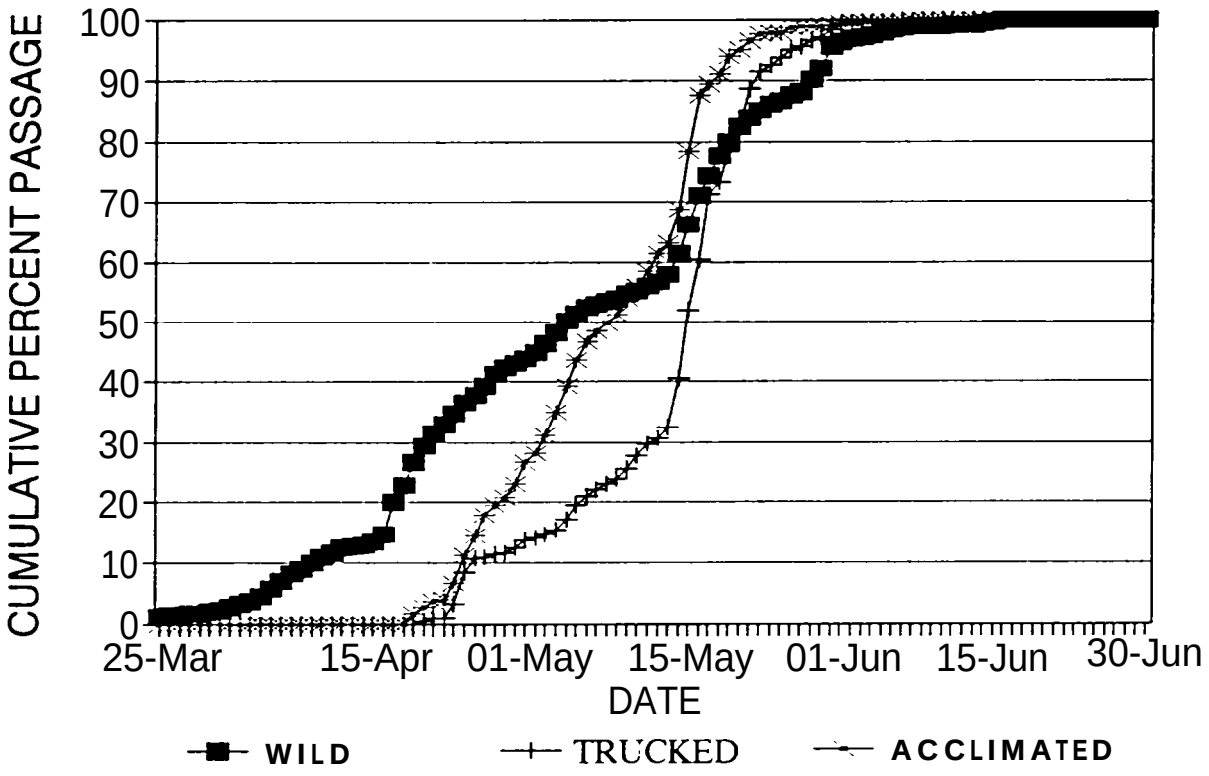


Figure 64. Passage wild, trucked and pond-acclimated smolts, Chandler trap, 1984.

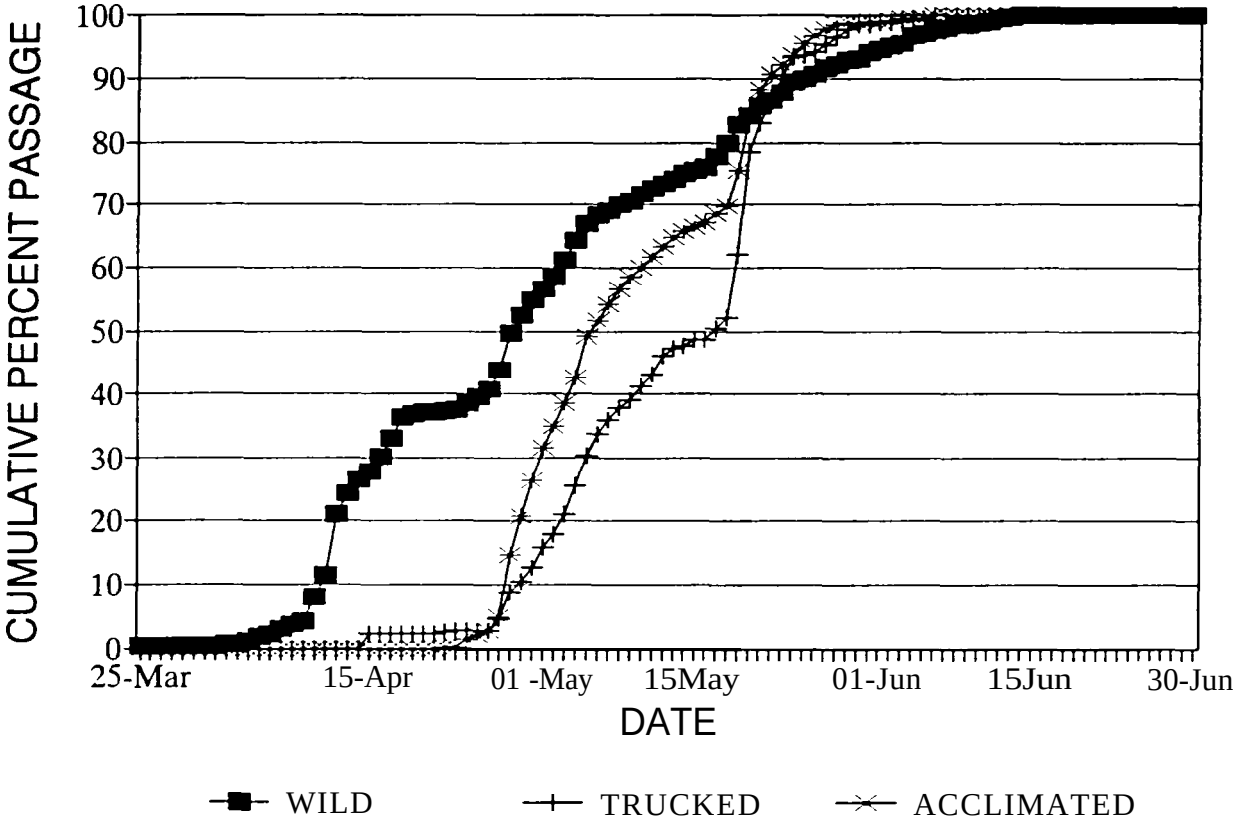


Figure 65. Passage wild, trucked and pond-acclimated smolts, Chandler, 1985.

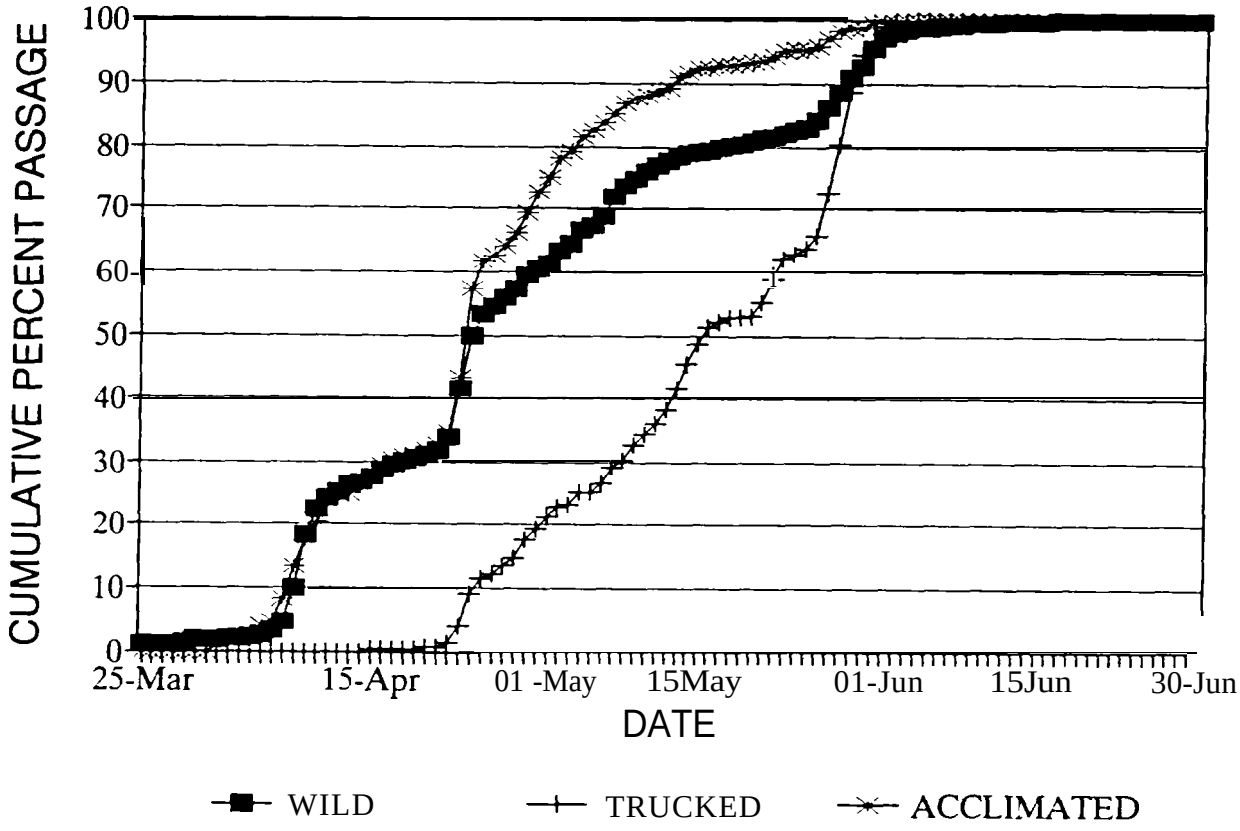


Figure 66. Passage wild, trucked and pond-acclimated smolts, Chandler trap, 1986.

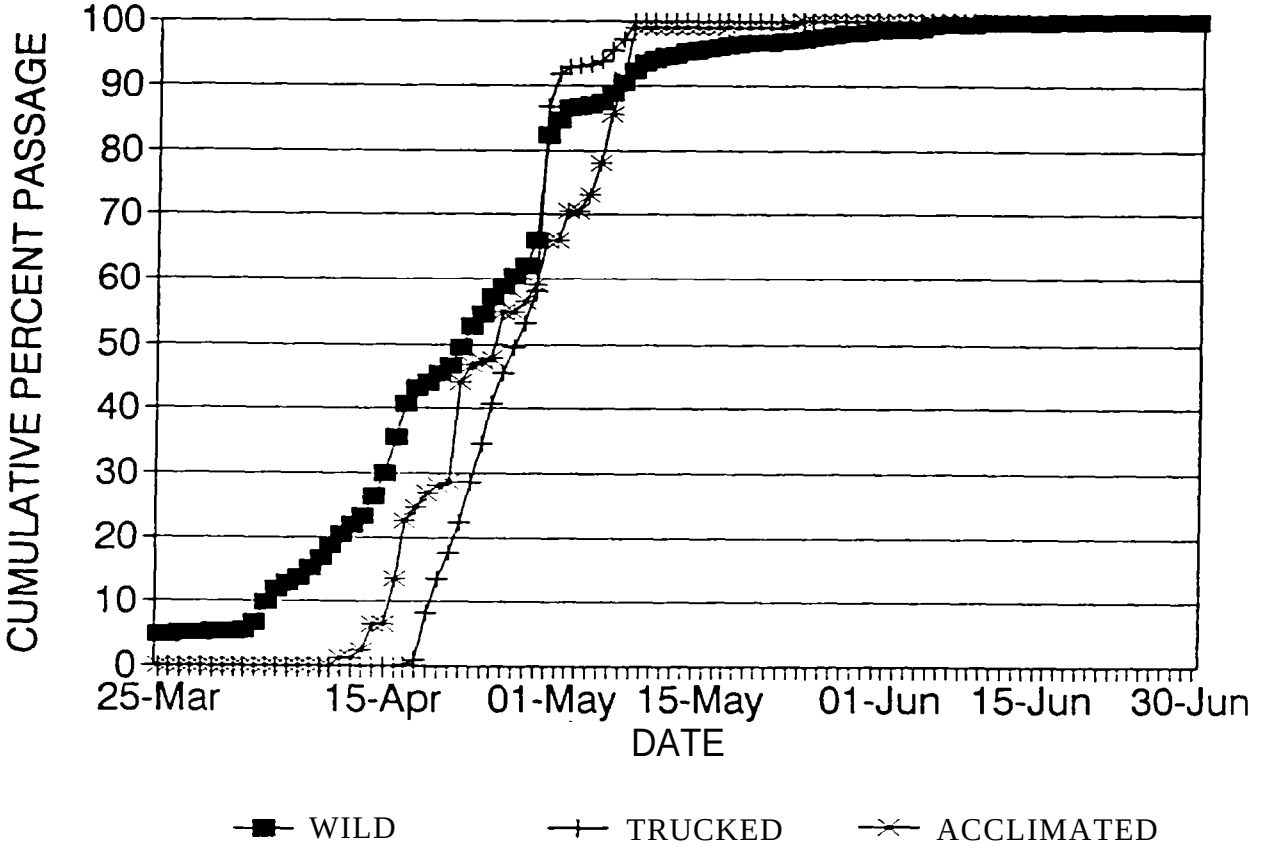


Figure 67. Passage of wild, trucked and pond-acclimated smolts, Chandler trap, 1987.

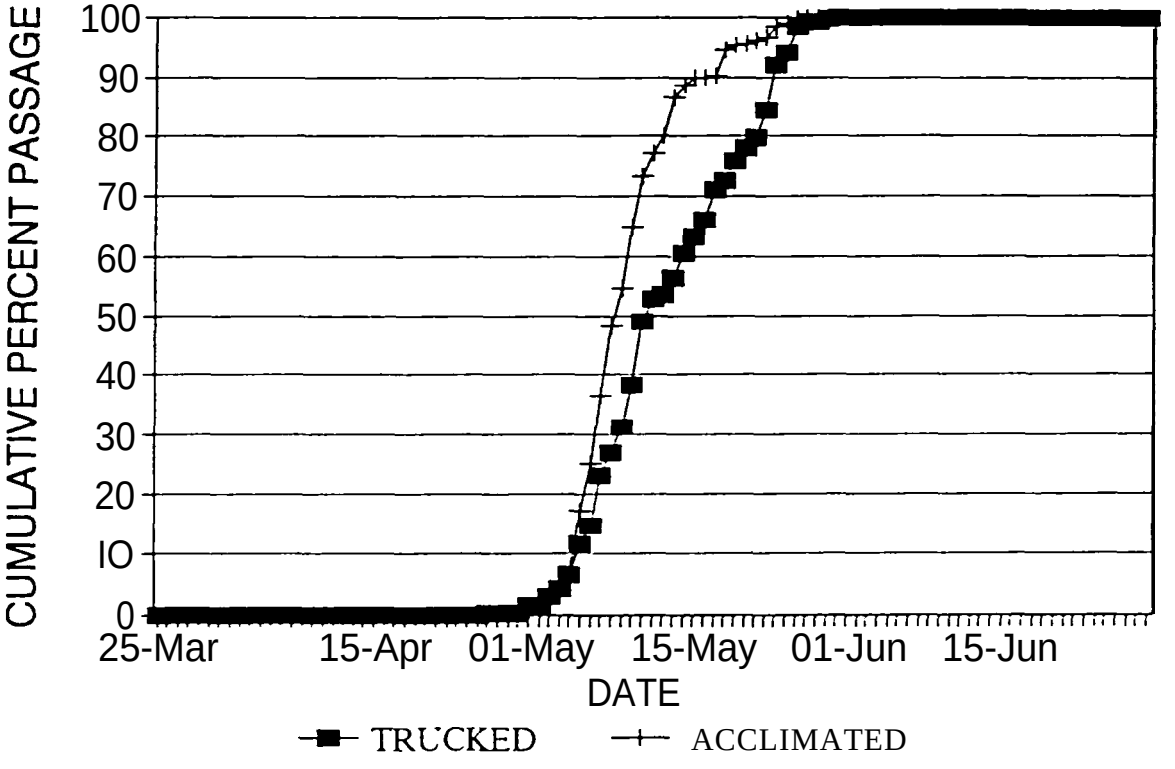


Figure 68. Passage of trucked and pond-acclimated smolts at McNary Dam, 1983.

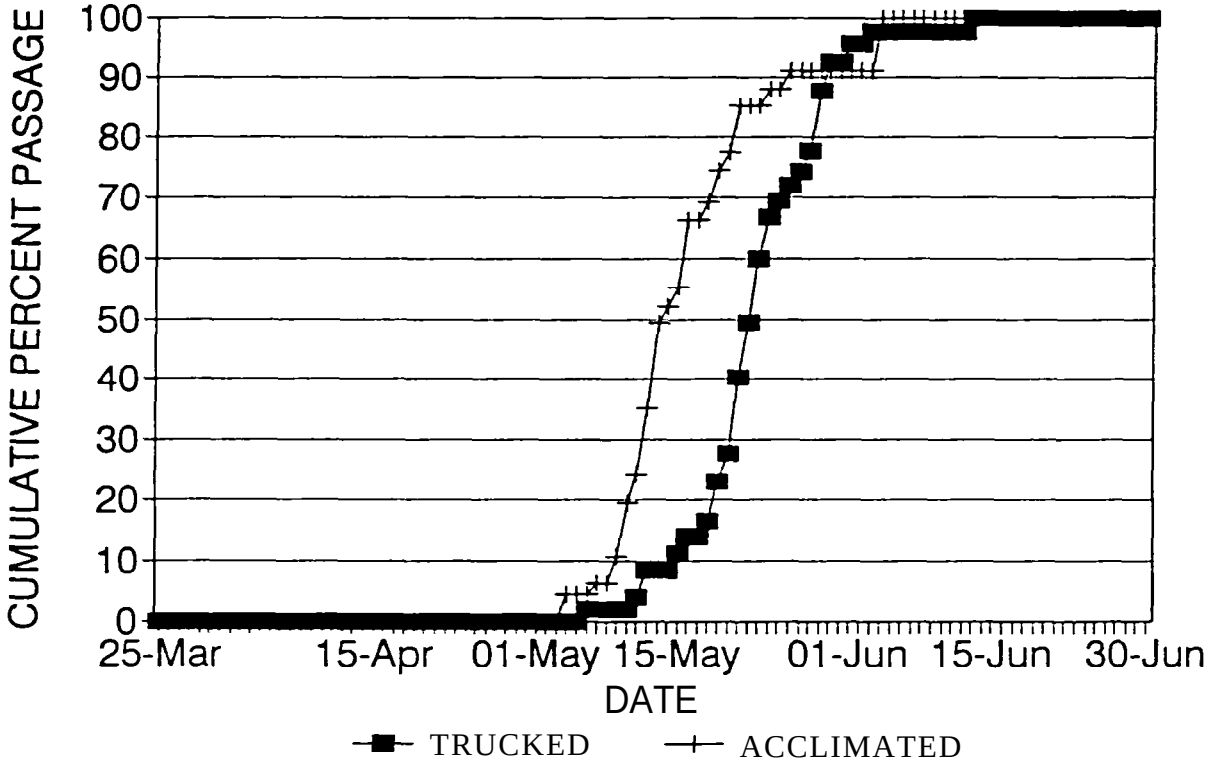


Figure 69. Passage of trucked and pond-acclimated smolts at McNary Dam, 1984.

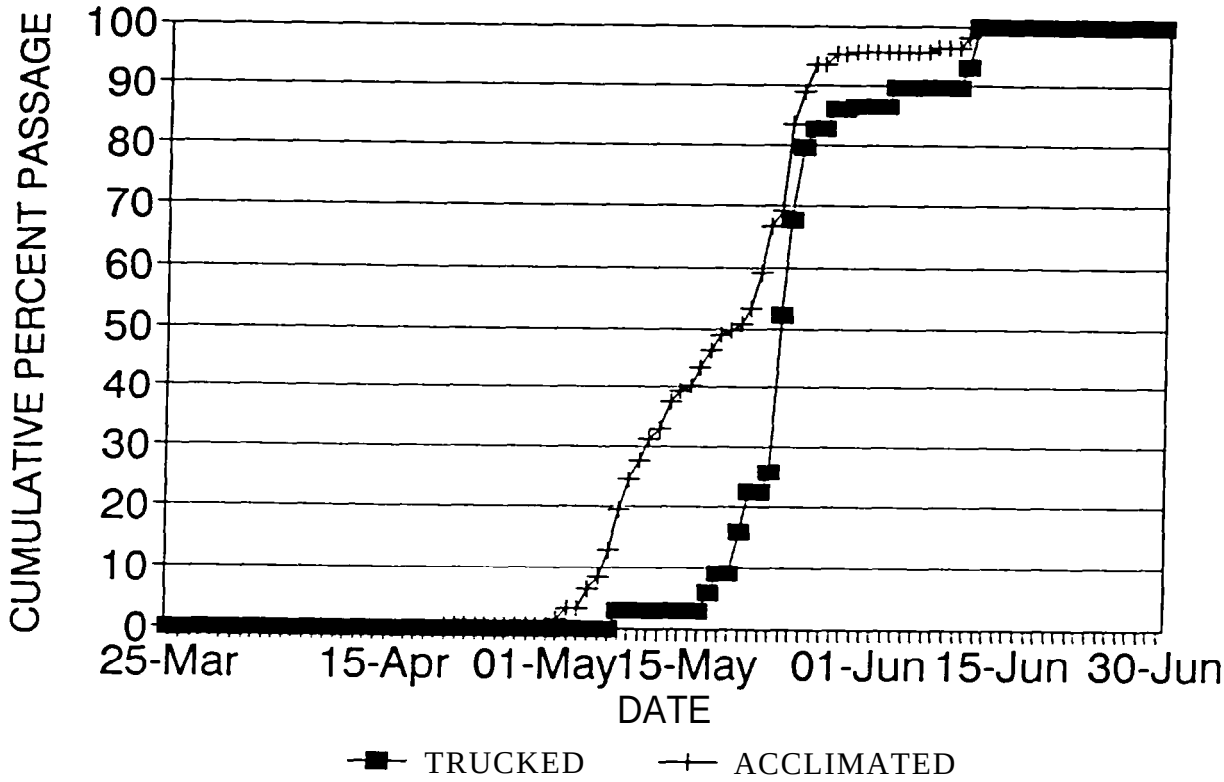


Figure 70. Passage of trucked and pond-acclimated smolts at McNary Dam, 1985.

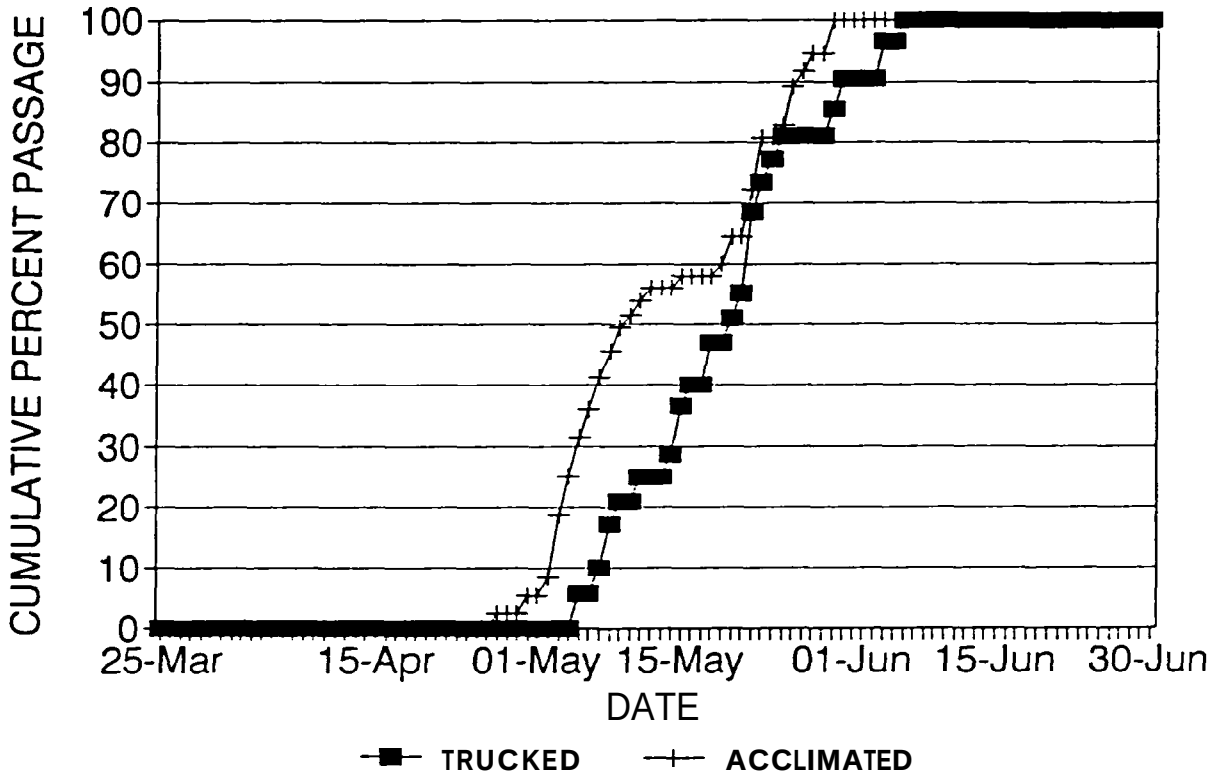


Figure 71. Passage of trucked and pond-acclimated smolts at McNary Dam, 1986.

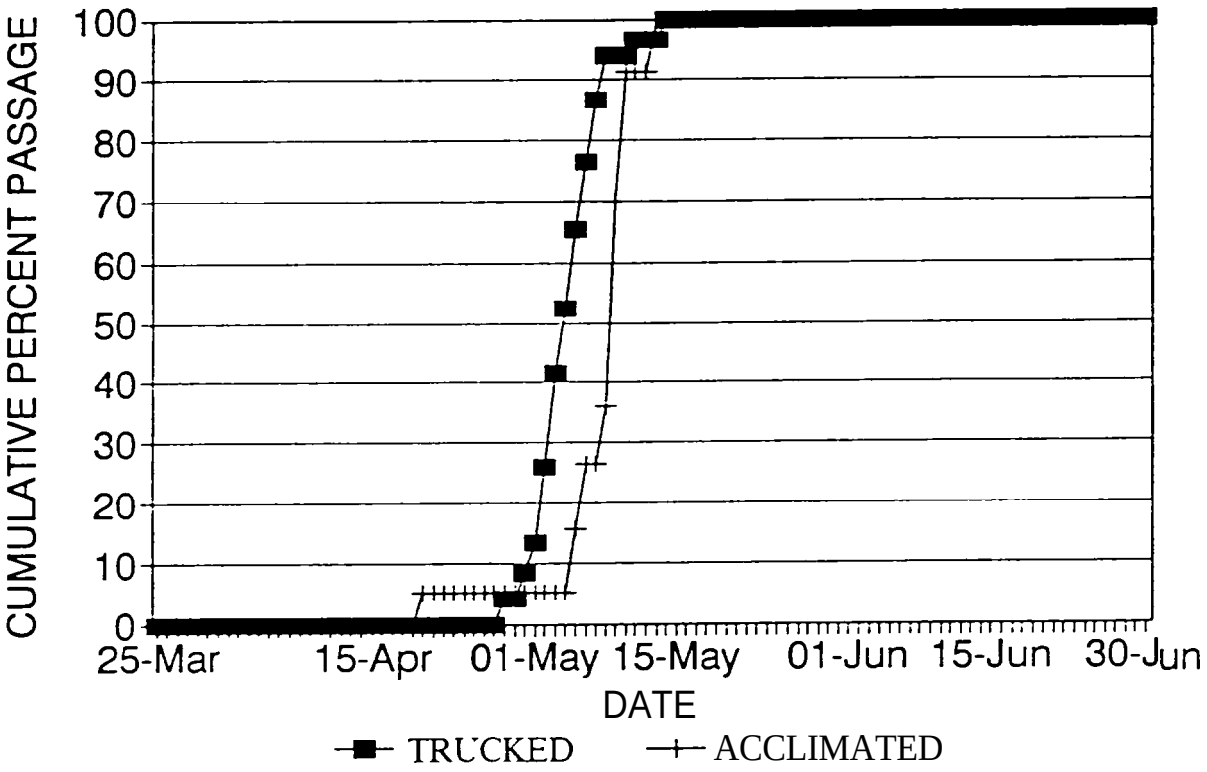


Figure 72. Passage of trucked and pond-acclimated smolts at McNary Dam, 1987.

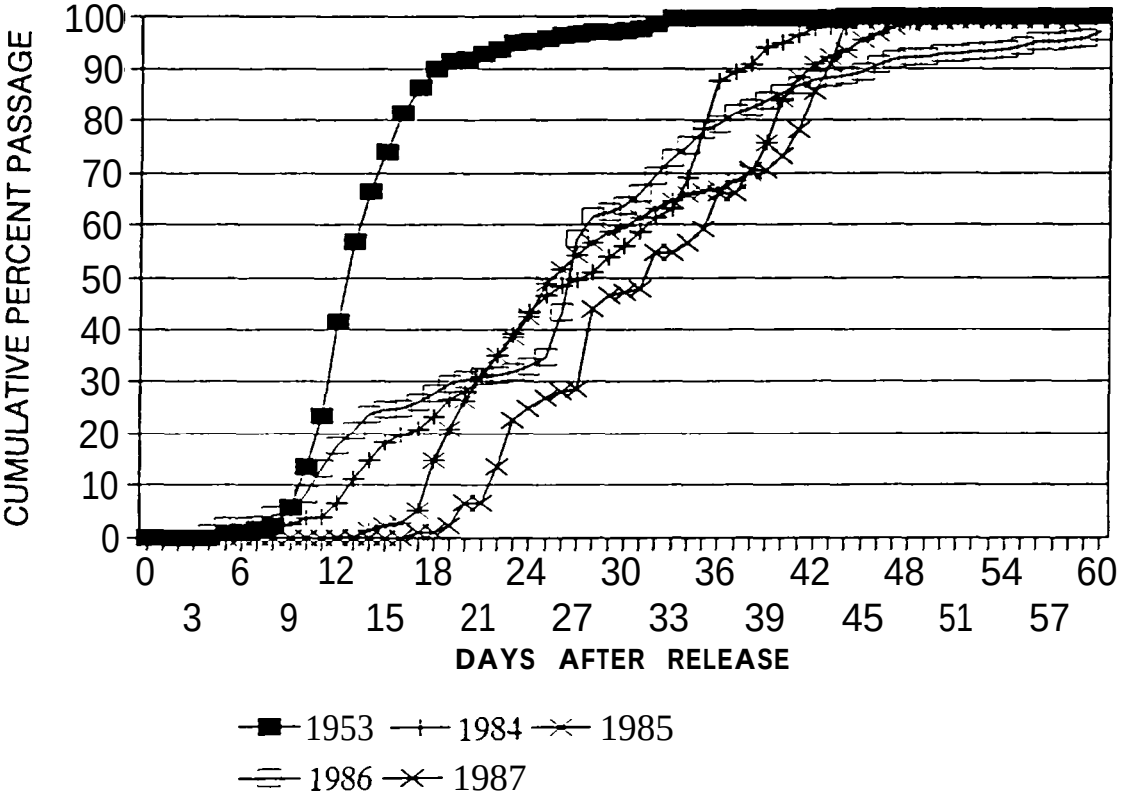


Figure 73. Passage of pond-acclimated hatchery smolts at Prosser Dam, 1983-l 987.

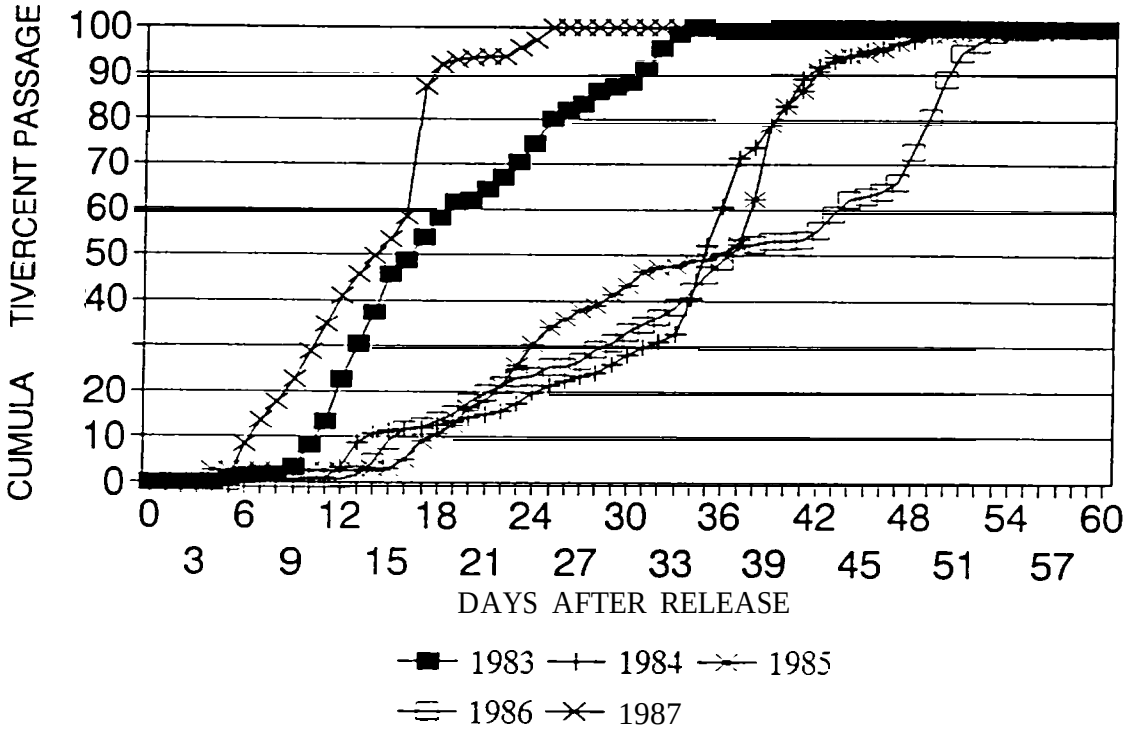


Figure 74. Passage of trucked hatchery smolts at Prosser Dam, 1983-l 987.

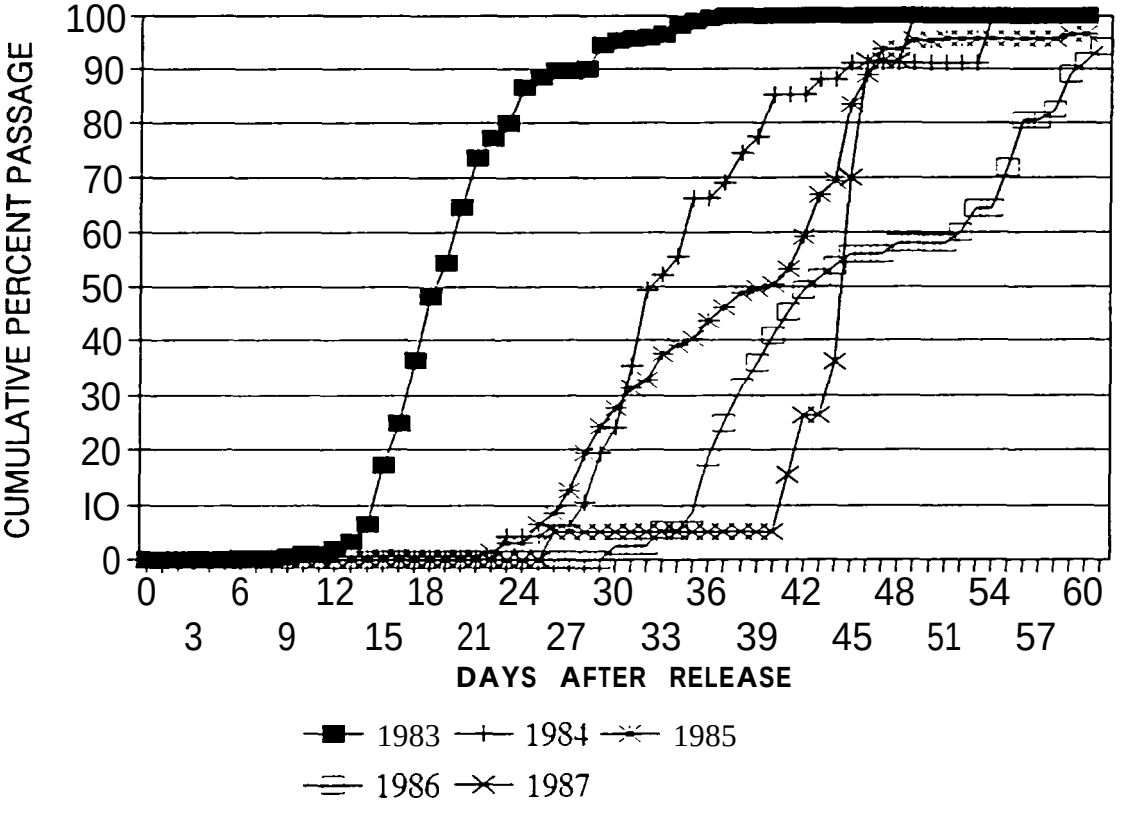


Figure 75. Passage of pond-acclimated hatchery smolts at McNary Dam, 1983-l 987.

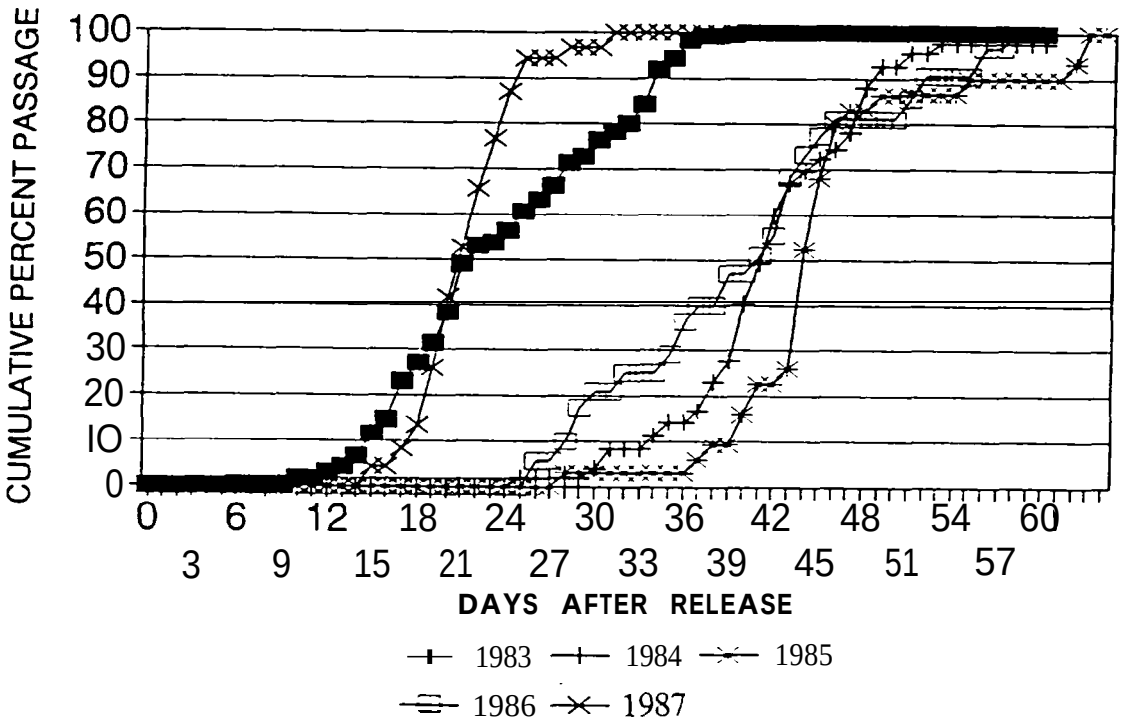


Figure 76. Passage trucked hatchery smolts at McNary Dam, 1983- 1987.

Size of Exwrimental Fish

Table 60 summarizes the mean length, weight and condition factor of experimental fish at release and as observed at Chandler. Chandler observations consist of means for the months of April and May only, as 95% of the passage of all experimental fish occurred in April and May.

The most striking feature of this data is the size differential between fish at release and as recaptured at Chandler in April. This is true for all experimental groups, not just acclimated and trucked fish. Unfortunately, it is impossible to determine whether this size differential represents growth or size-dependent differential mortality. Probably, it reflects both. If fish were not feeding at all, and the fish observed at Chandler were simply those that escaped predators, let us say, by virtue of their size, then one would expect to see a steady and pronounced drop in condition factor through the run. Although condition factor of trucked and acclimated fish does fall somewhat from April to May in three years (1985-1987), the condition factor of these groups is still fairly comparable to wild fish (see Table 60). On the other hand, the mean length of smolt groups seen at Chandler in April is, on average, 20 mm greater than the mean length at release. The greatest "apparent growth rates" -- size differentials among fish at the same site at different times -- for wild juveniles observed in the Yakima have been 10 mm to 15 mm per month. As it is improbable that the growth rate of hatchery-reared smolts would exceed the greatest rates observed for wild fish, it is likely that selective mortality has played some part.

The length of trucked and acclimated fish at release has varied from 114 mm (1984 trucked) to 142 mm (1983 trucked), There is no indication in Table 60 that larger fish enjoyed higher survival, either within or across years. Similarly, neither weight nor condition factor at release appear to affect survival. It is, however, apparent that all groups except the 1984 acclimated fish lost condition between release and May. The significance of this observation may be that these hatchery fish have not yet learned to forage in the wild effectively.

Smolt-to-Adult Survival for Trucked and Pond-Acclimated Hatchery Smolts

Smolt-to-adult survival was analyzed under four different scenarios. The results are reported as survival from smolt at release to adults returning to the mouth of both the Columbia and the Yakima rivers, and as survival from smolt at Prosser to adults returning to the Columbia and Yakima (Table 61 and Fig. 77).

Table 60. Mean length, weight and condition factor of experimental spring chinook smolts at release, and as observed at Chandler in April and May. Lengths are fork lengths in millimeters, weight is in grams and condition factor is expressed as $W/L^3 \times 10^6$.

GROUP	PARAMETERS AT RELEASE			PARAMETERS AS OBSERVED AT CHANDLER IN APRIL			PARAMETERS AS OBSERVED AT CHANDLER IN MAY			SURVIVAL TO PROSSER (%)
	LENGTH	UEIGHT	K	LENGTH	WEIGHT	K	LENGTH	WEIGHT	K	
83 TRUCK	142	23.8	9.8	No Data	No Data	No Data	129	No Data	No Data	24.18
83 POND	136	28.0	11.1	142 (n=5)	No Data	No Data	130	No Data	No Data	44.54
84 TRUCK	114	18.1	12.2	no captures	no captures	no captures	139	30.2	10.9	40.41
84 POND	128	24.0	11.4	no captures	no captures	no captures	145	39.8	11.5	64.99
84 SEP	115	18.1	11.9	147	33.3	10.4	145	30.4	9.8	10.96
84 NOV	117	21.0	13.1	153	39.4	10.2	148	34.2	10.1	3.71
85 TRUCK	126	22.6	11.3	154	37.6	10.2	147	31.3	9.8	25.51
85 POND	127	23.0	11.2	149	34.6	10.3	147	31.8	9.8	21.65
85 SEP	111	19.8	14.5	136	20.8	9.7	141	25.4	9.3	0.79
85 NOV	122	21.2	11.5	138	30.1	10.1	139	25.7	10.0	9.39
86 TRUCK	125	22.8	11.4	146	43.8	10.6	146	32.8	9.8	8.18
86 POND	124	22.0	11.2	142	34.0	10.4	142	23.7	8.4	17.83
86 HYB	130	26.4	11.6	143	36.7	10.3	145	34.8	10.2	18.68
86 WILD	129	26.5	11.5	153	41.5	10.7	146	33.2	10.7	20.21
87 TRUCK	125	22.8	11.7	154	39.0	11.2	142	29.9	10.8	38.53
87 POND	124	22.0	11.2	150	37.1	10.9	146	30.2	9.6	3.69*
87 HYB	130	26.4	12.0	149	33.4	9.8	144	29.2	10.3	2.81*
87 WILD	129	26.5	11.5	140	29.5	10.0	135	27.5	11.0	10.57*

* Survival of all acclimated groups in 1987 confounded with inability of fish to leave acclimation pond.

LEGEND: "TRUCK" = non-acclimated, direct-release hatchery smolts.
"POND" = pond-acclimated hatchery smolts.
"SEP" = non-acclimated, direct-release pre-smolts released in September.
"NOV" = non-acclimated, direct-release pre-smolts released in November.
"HYB" = pond-acclimated, Leavenworth X Yakima hybrid smolts.
"WILD" = pond-acclimated, hatchery-reared natural Yakima smolts.
Note that the number of observations is explicitly specified when this number is less than 20.

Table 61. Survival from smolt to adult of trucked versus acclimated spring chinook to the Columbia and yakima rivers.

BROOO YEAR	TREATMENT GROUP	SMOLT-TO-ADULT RETURN RATE AT THE MOUTH OF THE YAKIMA (%)		SMOLT-TO-ADULT RETURN RATE AT THE MOUTH OF THE COLUMBIA (%)	
		EXPRESSED IN TERMS OF NUMBERS OF SMOLTS RELEASED	EXPRESSED IN TERMS OF NLMBERS OF SMOLTS SURVIVING TO PROSSER	EXPRESSED IN TERMS OF NUMBERS OF SMOLTS RELEASED	EXPRESSED IN TERMS OF NUMBERS OF SMOLTS SURVIVING TO PROSSER
1981	TRUCKED	.04	.17	.06	.24
1981	ACCLIMATED	-14	.17	.20	.23
1982	TRUCKED	.04	.09	.06	.14
1882	ACCLIMATED	.07	.11	.13	.20
1983	TRUCKED	.15	.58	.21	.84
1983	ACCLIMATED	.20	.92	.30	1.40
1984	TRUCKED	.02	.24	.02	.29
1984	ACCLIMATED	.04	.21	.05	.29
MEAN, 1981-1984	TRUCKED	.06	.27	.09	.38
	ACCLIMATED	.11	.35	.17	.53

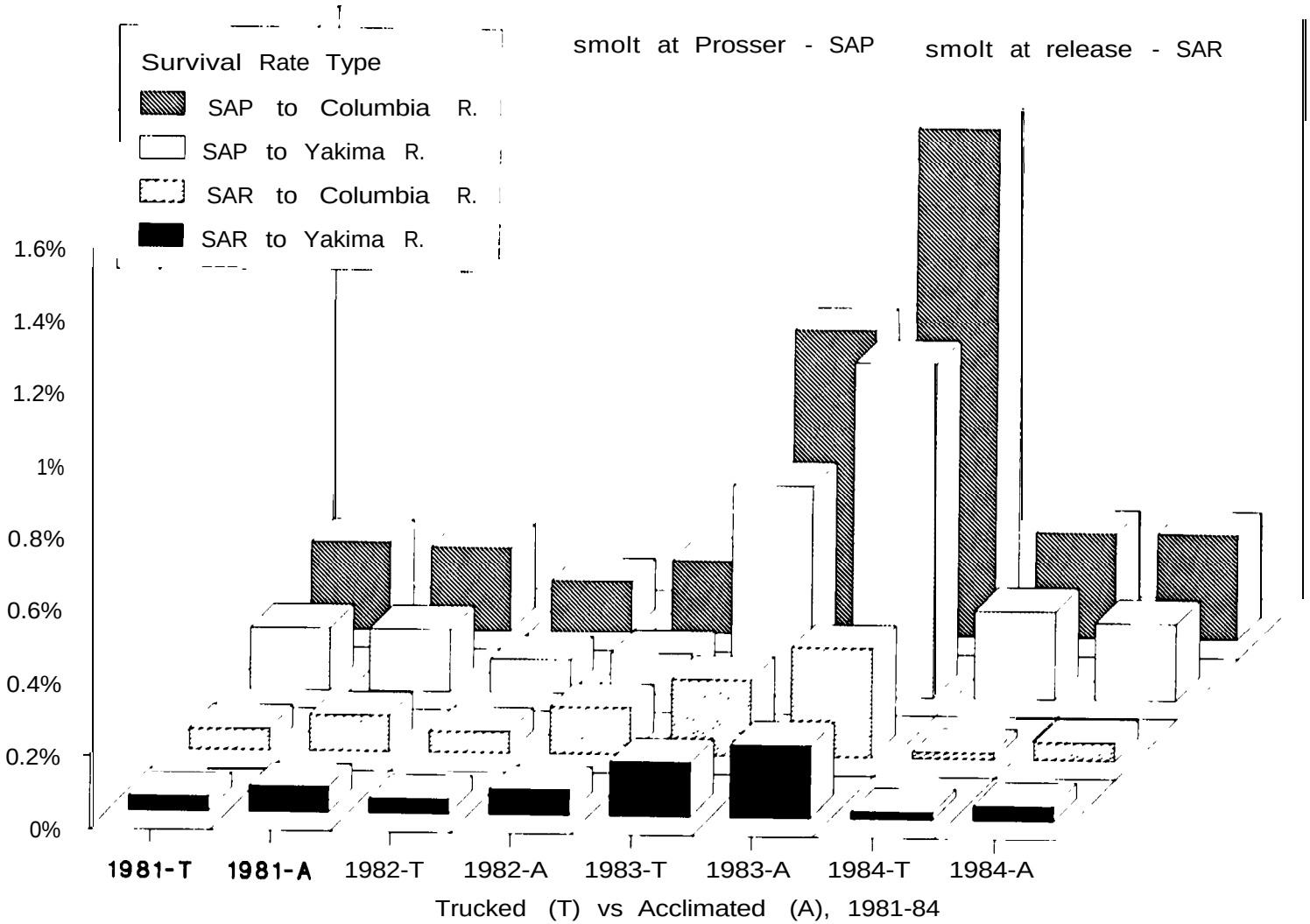


Figure 77. Percent survival from smolt to adult for trucked vs acclimated spring chinook to the Columbia River and Yakima River.

The acclimated smolts survived better than the trucked smolts in all four years when compared from the "smolt at release" stage. The mean survival for acclimated smolts over brood years 1981 through 1984 was 45 % higher than trucked smolts at the mouth of the Yakima, and 47% higher at the mouth of the Columbia. This survival advantage declines to 23% higher for acclimated smolts to the Yakima and 28% higher to the Columbia when return rates are expressed in terms of "smolts at Prosser." This relative decline in acclimated/trucked return rates when expressed as survivors at Prosser probably reflects the higher survival of acclimated fish immediately after release as discussed in the smolt-to-smolt survival section. This initial survival advantage is reduced, but not lost during later stages of life.

The mean return rate to the Yakima of trucked smolts that survived to Prosser was 0.27%. The comparable figure for acclimated smolts was 0.35%. These survival rates of about a quarter and a third of one percent are presented as a point of comparison between the hatchery releases and the only measure researchers have as a starting point for wild smolt survival (at Prosser smolt trap). Survival for wild Yakima smolts from this same starting point to returning adults averaged 3.75% over the five smolt outmigration years from 1983 through 1987 (see the smolt-to-adult survival section of this report). Over those five years, smolt-to-adult survival ranged from 1.77% for the 1987 outmigration to 6% for the 1984 outmigration. The mean survival of the wild fish was 10.7 times higher than for the acclimated fish and 13.9 times higher than the survival of the trucked fish. Again, these numbers should be regarded only as relative indices of survival. However, even as indices, they do suggest that the hatchery experience is not conducive to survival in the natural environment. As seen in the smolt-to-smolt survival section, much of the mortality observed in these hatchery releases occurs shortly after release. It is apparent that fisheries managers must learn more about preparing hatchery fish to survive the rigors of the natural environment.

Little is known about the survival of these fish between the passage of smolts at Prosser and McNary and the return of adults. The factors that affect survival can be both powerful and highly variable from year to year, or often even within a year. Some of the factors that are known to affect inriver survival are predatory birds and fish congregating in reservoirs and below hydropower dams; the hydropower dams themselves; and the smolt transportation program, which was intended to improve smolt survival, but which appears ineffectual for spring chinook. Even less is know about the factors determining ocean survival. Fishing is not believed to impact the spring chinook on the high seas. The returns of coded-wire tags from the many Yakima release groups indicated that 1.57% (17 tags from 1,086 of the total tags returned) were from the ocean fisheries. Other ocean conditions such as temperature (El Nino) and productivity can vary considerably from year to year, but quantifying the effects on salmon survival is a very speculative venture. Finally, survival of returning adults is based on river flow conditions, water temperatures, dam passage and fishing effort. The returns of coded-wire tags from the Columbia River fisheries indicated that there was a significant harvest of the experimental Yakima fish. A total of 275 tagged fish were estimated by the Pacific Marine Fisheries Commission to have been caught in all

Columbia River fisheries (sports, Columbia River gill net, test net fisheries, and the treaty ceremonial) from a total of 1,069 returned tags through 1989 catch seasons (the 1990 tag data was not available at the time of this report for the Columbia River so the tags recovered from adults in the Yakima Subbasin in 1990 were not included in this analysis of percent caught in the mainstem). This data indicates that a mean of 25.7% of the returning experimental fish were caught by various fisheries in the Columbia through 1989.

OPTIMAL TIME OF RELEASE

Three seasonal spring chinook juvenile releases were made in 1984 and again in 1985 to determine the optimal time of release of juvenile spring chinook into the river. Fry were released in June, parr in September and pre-smolts in November. Fish were transported from the Leavenworth Nation Fish Hatchery and released directly into the Yakima River at 12 different locations between RM 155 and RM200. Roughly 4,000 fish were released at each location over a two-day release period. All releases were approximately 100,000 fish each. Survival was again estimated for smolts at Prosser and as survival to adult in both the Yakima and Columbia rivers from juvenile at release and from smolt at Prosser.

Smolt Survival

Smolt-to-smolt survival rates for pre-smolts released in September and November of 1984 and 1985, and for fry released in June of 1984 and 1985, are summarized in Table 62.

Fall Releases of Pre-Smolts

Table 62 indicates that the maximum survival to Chandler for fall-released pre-smolts was about 1 1 %, whereas the maximum survival to McNary was about 5.5%. There is, however, no indication of the specific release time for optimal survival; September releases were better than November releases in 1984, and the reverse was true in 1985. As was the case with trucked and acclimated smolts, there is an indication that these fall released pre-smolts, in their outmigration as smolts the spring after release, enjoy a higher survival rate from Prosser to McNary than from their release point to Prosser. However, unlike the case of trucked and acclimated smolts, it is all but certain in this case that the much lower Prosser-to-McNary survival rate simply reflects normal over-winter mortalities.

June Releases of Fry

The fry released in the upper Yakima in early June of 1984 and 1985 did not behave as expected. Researchers expected that these fish would take up residence in the upper river and leave the system as smolts the following spring. It does not appear they did so. About 11% of the 1984 fry and 2.5% of the 1985 fry left the system before smolting, over a period of slightly less than two months from the date of release (Figs. 78-80). No 1984 fry were observed at Chandler in the spring of 1985, and only 28 of the 9,102 branded 1985 fry were estimated to have passed Prosser in 1986.

One of two things must have happened. Either virtually all fish “outmigrated” immediately after release, suffering tremendous losses before reaching Prosser; or most fish did take up residence in the upper river, but died over the winter and in the early stages of their outmigration.

Table 62. Summry smolt survival statistics for hatchery spring chinook pre-smolts released in September and November of 1984 and 1985, and for hatchery spring chinook fry released in Jme of 1984 and 1985. Note that release and passage nmbers are expressed in term of branded fish only, except for the 1984 June fry. These fish were readily identifiabte at Chandler by appearance; the group was therefore not monitored strictly by brand. Roughly 10% of all groups were freeze-branded.

YEAR/GROUP	RELEASE NUMBER	PASSAGE Al PROSSER	SURVIVAL TO PROSSER (%)	PASSAGE AT McNARY	SURVIVAL TO McNARY (%)	SURVIVAL FROM PROSSER TO McNARY (%)
'84 September pre-smolts	10,489	1,150	10.96	581	5.54	50.5
'84 November pre-smolts	10,526	391	3.71	370	3.52	94.6
'84 June fry[a] (in 1984[b])	102,837	11,712 (in 1984[b])	11.39	14[c]	0.17[b]	Inapplicable[b]
'85 September pre-smolts	10,489	83	0.79	5	0.05	6.02
'85 November pre-smolts	10,524	988	9.39	569	5.41	57.59
'85 June fry[d] (in 1985)	9,102	243	2.67	0	0	0
'85 June fry[d] (in 1986)	9,102	28	0.31	0	0	0

[a] June 1984 fry were monitored at Chandler only by appearance, as fish were readily identifiable in the Yakima at the time they appeared. Mcnary, however, could only monitor these fish by brand. Because no record uas kept of the branded '84 fry at Chandler, it is impossible to estimated the passage of branded fish at Chandler. Survival from Chandler to McNary is estimated as the ratio of branded fish at Chandler to branded fish at McNary. Accordingly, no Prosser-to-McNary survival estimate was possible for this group.

[b] Jw fry were expected to reside in the Yakima through the summer and winter, emigrating the next spring. No '84 June fry did so.

[c] McNary reported a passage index of 14 branded June '84 fry. The our&r of branded fish released was 8,124. Estimated survival to McNary was therefore 14/8,124 or 0.17%.

[d] June fry nere expected to reside in the Yakima until they emigrated the following spring. Most fry left immediately, however, and only 28 were estimated to have passed Prosser the following spring.

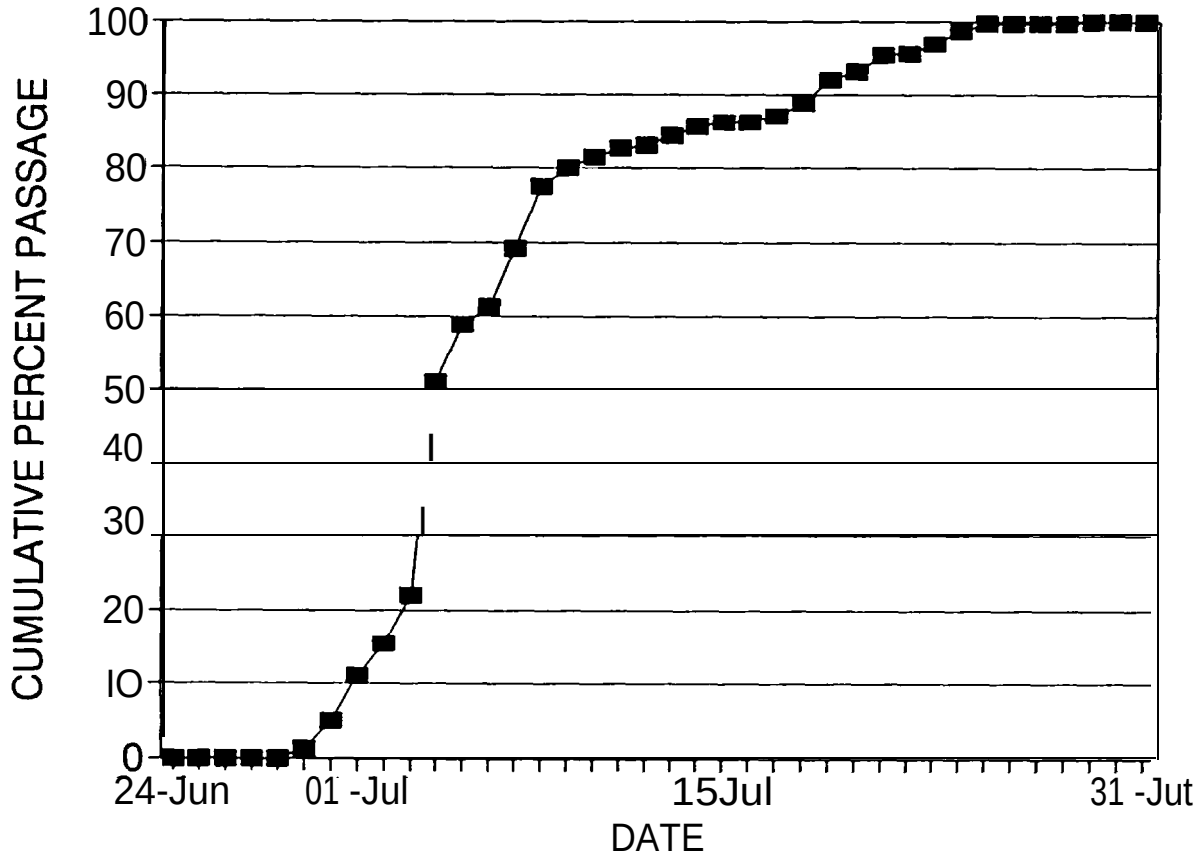


Figure 78. Passage of fry released in June of 1984 at Prosser Dam in 1984.

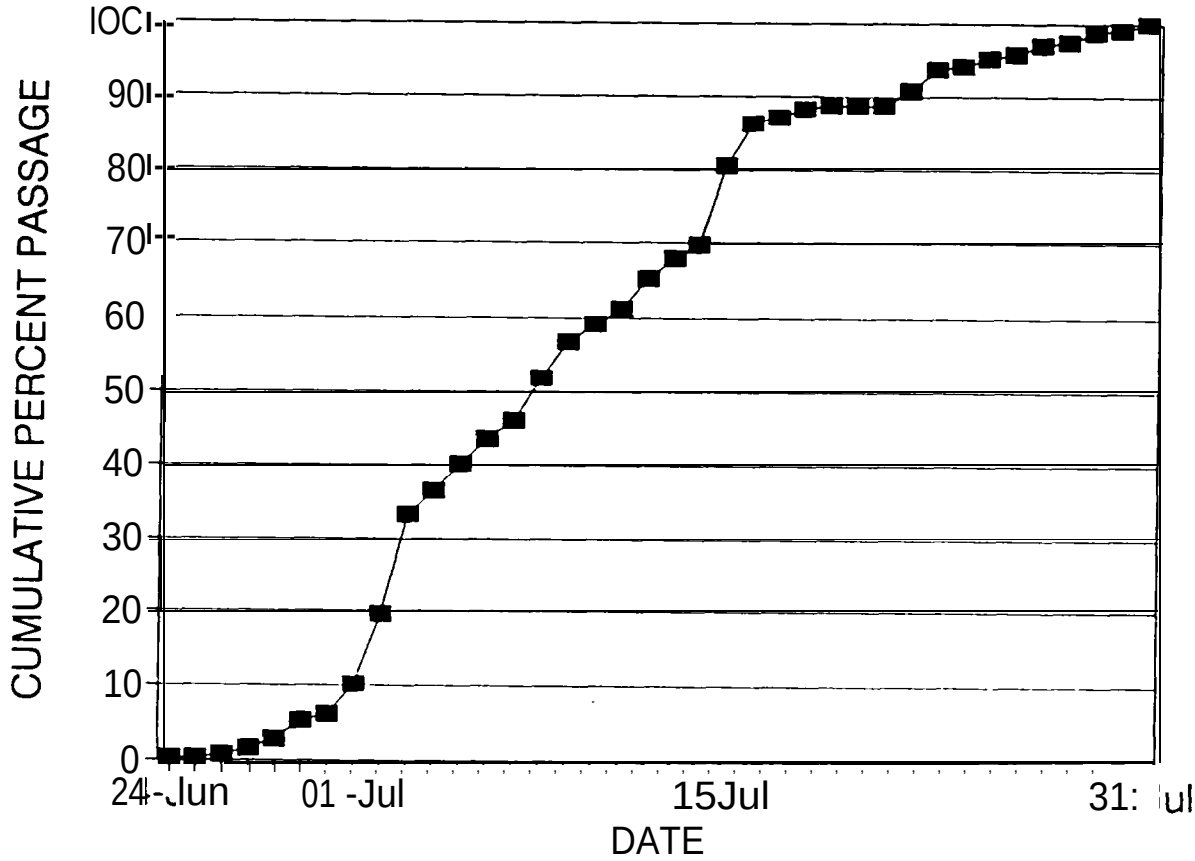


Figure 79. Passage of fry released in June of 1985 at Prosser Dam in 1985.

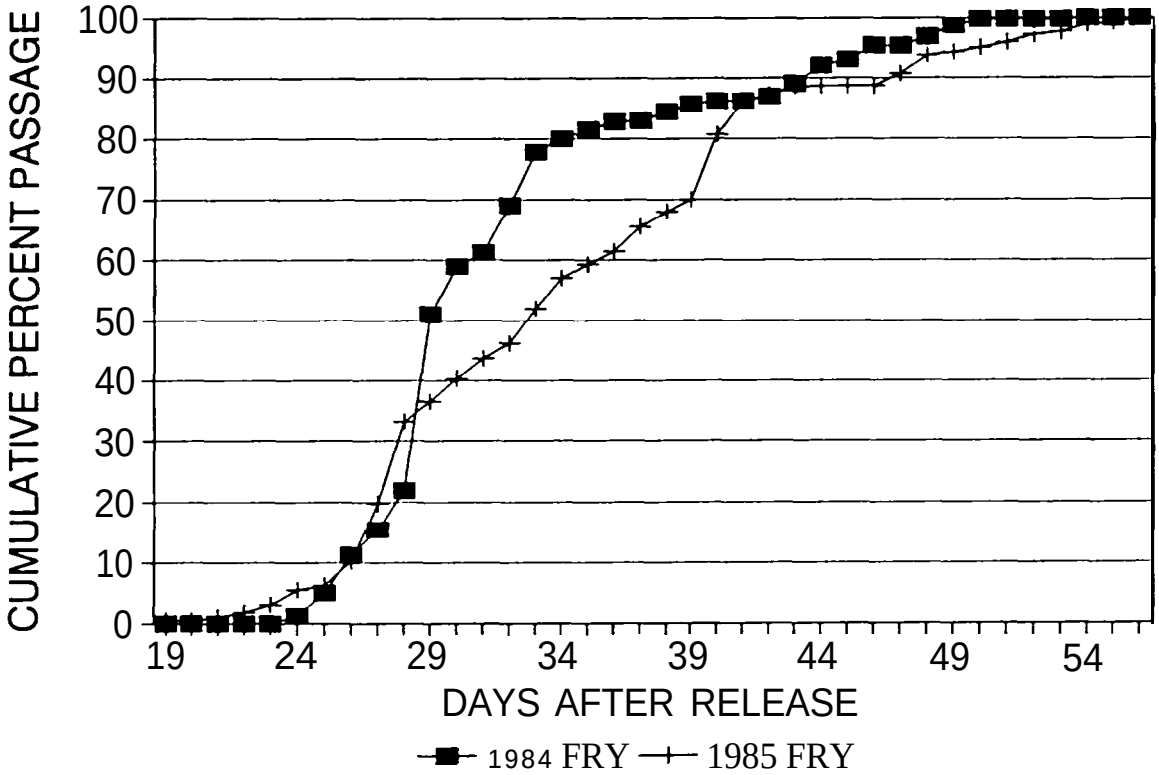


Figure 80. Passage at Prosser Dam of fry released in June of 1984 and 1985 in the year of release.

Outmigration Timing

Table 63 summarizes the timing of the outmigration of the September and November pre-smolt releases as well as the June fry releases. As is evident from Table 63 and Figures 81 and 82, fall-released pre-smolts emigrate rather early; indeed, in both 1985 and 1986, the outmigration of fall pre-smolts was ahead of the outmigration of wild smolts. The most likely interpretation of this fact is that fall pre-smolts move downriver in the winter, much as wild fish do. Being closer to prosser when outmigration begins, the bulk of these fish pass by earlier than most wild fish, which may begin their migration from staging areas farther upstream. At any rate, it is known that fall pre-smolts move downstream as far as Prosser in the winter, as several 1984 fall pre-smolts were recovered from a fyke net fished in Chandler canal in January and February of 1986 (Envirosphere 1985). Unfortunately, the magnitude of downstream movement of fall-released hatchery pre-smolts cannot be determined from tribal observations. Regular winter monitoring did not begin at Chandler until the winter of 1986-87; monitoring began in late February in 1986, well after the wild peak of winter movement. Chandler was experimentally monitored with a fyke net for only 27 days in January and February of 1985.

It is rather interesting that the outmigration pattern of September and November pre-smolts is as similar as it is at Chandler and at McNary as well (Fig. 83). Evidently, hatchery pre-smolts released two months apart in the fall “end up in the same place” by springtime; otherwise, the outmigration patterns would not be so synchronous. (Note that the apparent lack of synchrony for the September 1985 group at McNary in Figure 83 is an artifact of the small number (five) actually observed at McNary.)

The movement pattern of June fry was quite similar in 1983 and 1985, and was essentially complete at Chandler about two months after the fish were released. No 1985 fry were observed at McNary, and only 14 (of 102,837 fry released) were observed in 1984. The interesting thing about the handful of observations in 1984, however, is how quickly they follow observations at Chandler. Either these fish took about a month to move 118 miles from release point to Chandler (median migration rate = 4.07 mi/day in 1984, 3.58 mi/day in 1985), and then suddenly covered the 90.8 miles from Prosser to McNary in four days (22.7 mi/day); or the latter part of the run observed at Chandler simply never made it to McNary. The latter explanation seems much more plausible.

Table 63. Dates of 10%, 50% and 90% cumulative outmigration at Prosser and McNary dams for hatchery Pre-smolt spring chinook released in September and November of 1984 and 1985, and for hatchery spring chinook fry released in June of 1984 and 1985.

GROUP	DATES OF CUULAllWE PASSAGE AT PROSSER			DATES OF CUMULATIVE PASSAGE AT McNary		
	10 %	50 %	90 %	10 %	50 %	90 %
SEPTEMEER 1984 PRE-SMOLTS	APRIL 10, '85	APRIL 17, '85	MAY 12, '85	APRIL 19, '85	MAY 3, '85	NAY 24, '85
NOVEMBER 1984 PRE -SMOLTS	APRIL 6, '85	APRIL 28, '85	MAY 18, '85	APRIL 16, '85	APRIL 30, '85	HAY 16, '85
JUNE 1984 FRY	JULY 1, '84	JULY 4, '84	JULY 19, '84	JULY 3, 84	JULY 8, '84	JULY 11, '84
SEPTEMBER 1985 PRE-SMOLTS	APRIL 8, '86	APRIL 23, '86	MAY 13, '86	APRIL 11, '86	APRIL 18, '86	KAY 3, '86
NOVEMBER 1985 PRE-SMOLTS	APRIL 7, '86	APRIL 20, '86	MAY 3, '86	APRIL 12, '86	MAY 5 , '86	MAY 28. '86
JUNE 1985 FRY, MIGRATING IN 1985	JULY 1, '85	JULY 8, '85	JULY 22, '85	NO RECAPTURES	NO RECAPTURES	NO RECAPTURES
JUNE 1985 FRY, MIGRATING IN 1986	MARCH 29, '86	APRIL 3, '86	MAY 4, '86	NO RECAPTURES	NO RECAPTURES	NO RECAPTURES

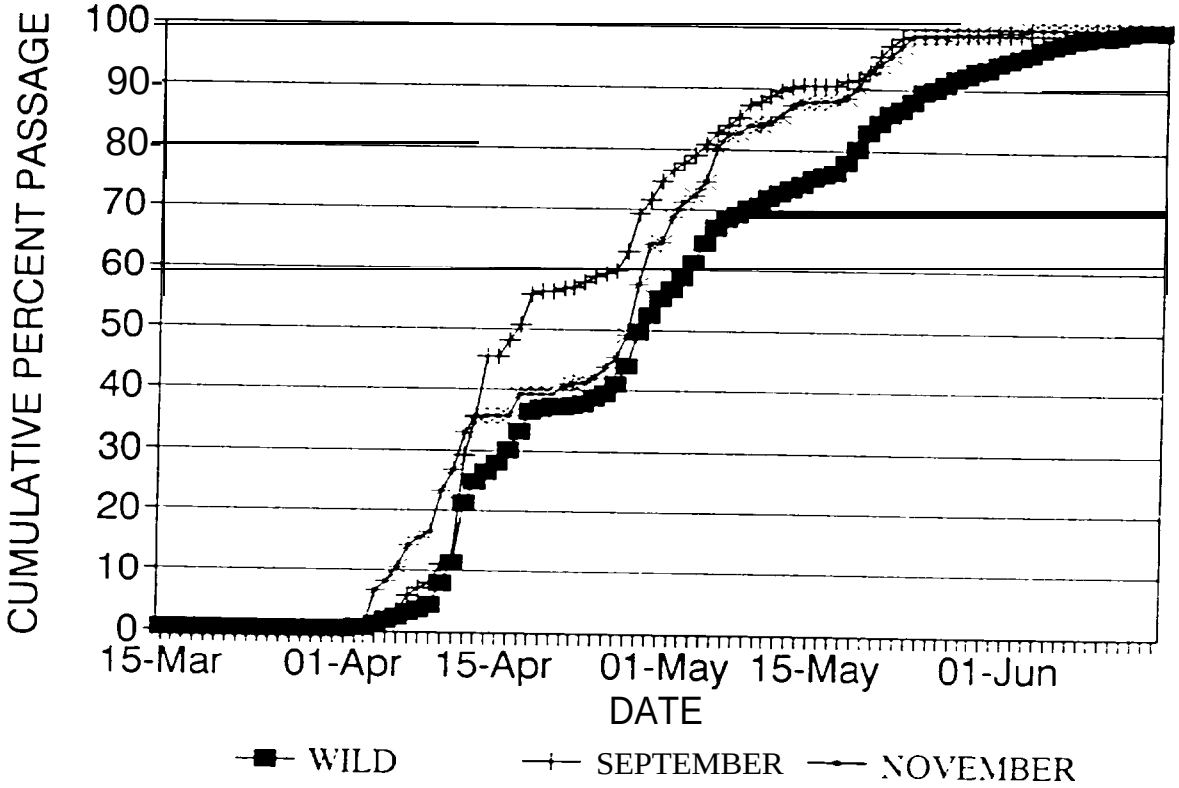


Figure 81. Passage at Prosser Dam in 1985 of wild smolts and hatchery smolts released in September and November of 1984.

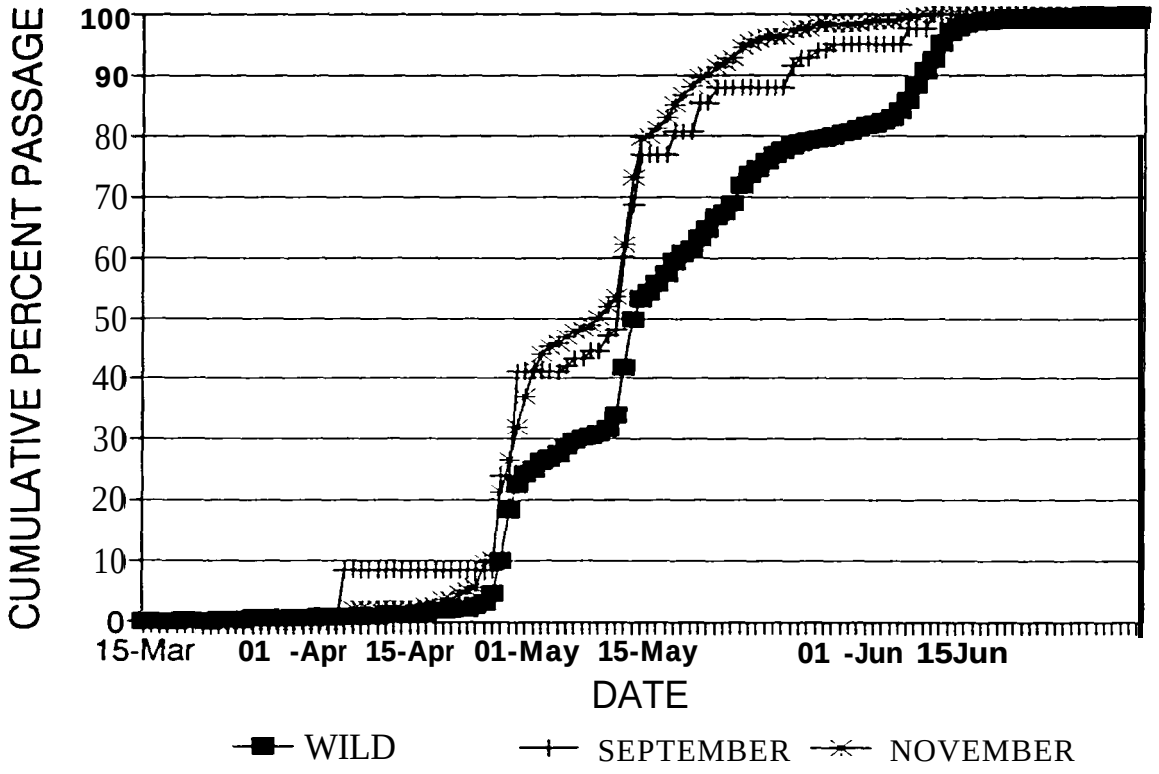


Figure 82. Passage at Prosser Dam in 1986 of wild smolts and hatchery smolts released in September and November of 1985.

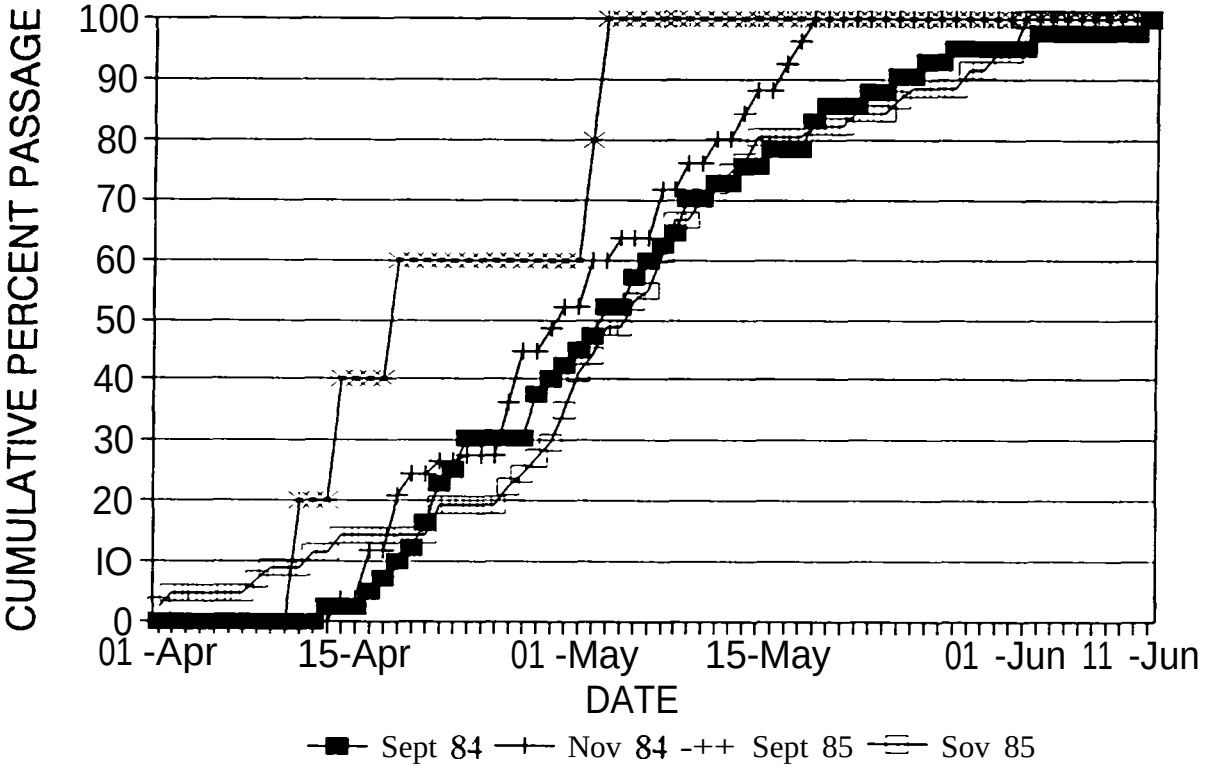


Figure 83. McNary passage in 1985 and 1986 of pre-smolts released in September and November of 1984 and September and November of 1985.

Size of Experimental Fish

Once again, minor differences in size at release had no clear effect on survival. As summarized in Table 60 in a previous section, September and November pre-smolts were quite comparable in length, weight and condition factor in 1984, although the November 1985 fish were both longer (122 mm vs. 111 mm) and "slimmer" (condition factor 11.5 vs. 14.5) than the September 1985 fish. In 1984, the survival of the September group, whose fish were 2 mm shorter than those in the November group, was about three times greater than the the November group; in 1985, the September fish were 11 mm shorter and survived at one-ninth the rate of the November group. As observed at Prosser, the length and weight of both groups in both years was quite comparable, and was also similar to other hatchery groups of the same year.

Smolt-to-Adult Survival

The survival from juvenile-at-release and smolt-at-Prosser to returning adult to the Yakima and Columbia rivers is presented in Table 64. Figures 84 and 85 also illustrate the relative survival among these estimates. Figure 84 depicts these relationships with the survival of the smolt at Prosser to adults back to the Yakima and the Columbia at their actual estimated survival rate of over 12%. Figure 85 depicts this rate at just over 2% to enhance the visual differences among the other estimates. The survival rate from June fry at release to returning adult was quite low, especially in the second year of this experiment. This low survival would be expected when juveniles are released as fry in June and required to survive in the rigors of the Yakima River until the following spring outmigration. The survival from parr in September and from pre-smolt in November to returning adult was also lower than from direct smolt releases in some releases, but surprisingly not in all cases. The real difference observed in these early releases is in the survival from smolt-at-Prosser to returning adult. The juveniles apparently suffered higher mortality under the selective pressures of predation and competition while rearing for up to one year in the natural environment, but the result was a smolt better able to survive the natural environment to the adult stage.

The discussion of survival in the Columbia River and in the ocean presented in the previous section also applies to these release groups. The survival from smolt-at-Prosser to adult for September parr released in 1984 (12.19%) is undoubtedly attributable to the very low survival of that group as measured as smolts at Prosser. The expanded passage for this release group was only 804 fish. This estimate is almost undoubtedly lower than the real number of smolts that actually migrated past Prosser, as an undetermined number of fish almost certainly migrated past Prosser during the winter when the trap was closed. When the number of returning adults was divided by this unrealistically low number of outmigrants, an equally unrealistic smolt-to-adult survival rate is produced. This again is another example of the inadvisability of using these estimates as absolute numbers rather that as indices of relative survival as discussed earlier.

While the results of these releases are highly variable, and the survival from fish-at-release to returning adult is generally very low, the survival from smolt-at-Presser to returning adult is somewhat higher than for the smolt releases studied in the trucked and acclimated fish portion of this study. The survival benefit derived from incubation and early rearing in a hatchery must balance the increased mortality suffered during "pre-migratory rearing" if releases of this type are to be practical. Another factor concerning pre-smolt releases is the increased probability of interactions between hatchery fish and natural resident and anadromous fishes residing in the release area. The potential for any type of interaction is minimized by smolt releases, as smolts "use" the stream simply as a migration corridor. This is especially true if smolts are acclimated before release and are released volitionally.

Table 64. Survival from release, and from smolt-at-Prosser, to adult (Yakima and Columbia) **for** fish **released as fry in June, parr in September,** and pre-smolts **in November.**

Brood Year	Treatment	Survival to Yakima from smolt at Release	Survival to Yakima from smolt at Prosser	Survival to Columbia from smolt at Release	Survival to Columbia from smolt at Prosser
1983	June (fry)	.03%	23%	.03%	.30%
	Sept (Parr)	06%	.52%	.08%	.75%
	Nov (pre-smolt)	.06%	1.52%	.08%	2.07%
1984	June (fry)	.003%	.11%	.005%	.19%
	Sept (Parr)	.10%	12.19%	.10%	12.81%
	Nov (pre-smolt)	.04%	.38%	.05%	.48%

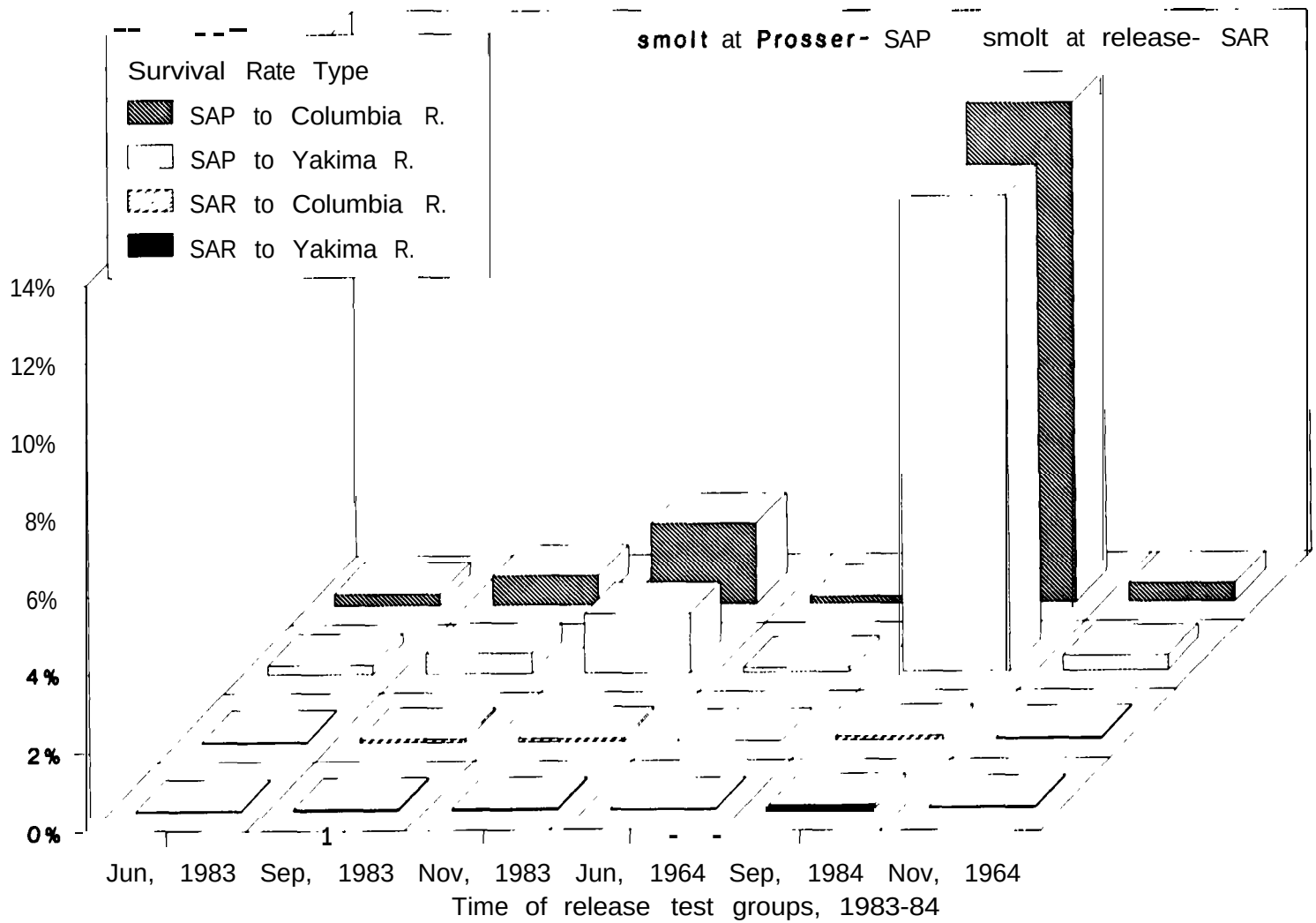


Figure 84. Percent survival from smolt to adult for time of release test groups.

While the results of these releases are highly variable, and the survival from fish-at-release to returning adult is generally very low, the survival from smolt-at-Prosser to returning adult is somewhat higher than for the smolt releases studied in the trucked and acclimated fish portion of this study. The survival benefit derived from incubation and early rearing in a hatchery must balance the increased mortality suffered during "pre-migratory rearing" if releases of this type are to be practical. Another factor concerning pre-smolt releases is the increased probability of interactions between hatchery fish and natural resident and anadromous fishes residing in the release area. The potential for any type of interaction is minimized by smolt releases, as smolts "use" the stream simply as a migration corridor This is especially true if smolts are acclimated before release and are released volitionally.

Table 64. Survival from release, and from smolt-at-Prosser, to adult (Yakima and Columbia) for fish released as fry in June, parr in September, and pre-smolts in November.

Brood Year	Treatment	Survival to Yakima from smolt at Release	Survival to Yakima from smolt at Prosser	Survival to Columbia from smolt at Release	Survival to Columbia from smolt at Prosser
1983	June (fry)	.03%	.23%	.03%	.30%
	Sept (Parr)	.06%	.52%	.08%	.75%
	Nov (pre-smolt)	.06%	1.52%	.08%	2.07%
1984	June (fry)	003%	.11%	.005%	.19%
	Sept (Parr)	:lo%	12.19%	.10%	12.81%
	Nov (pre-smolt)	.04%	.38%	.05%	.48%

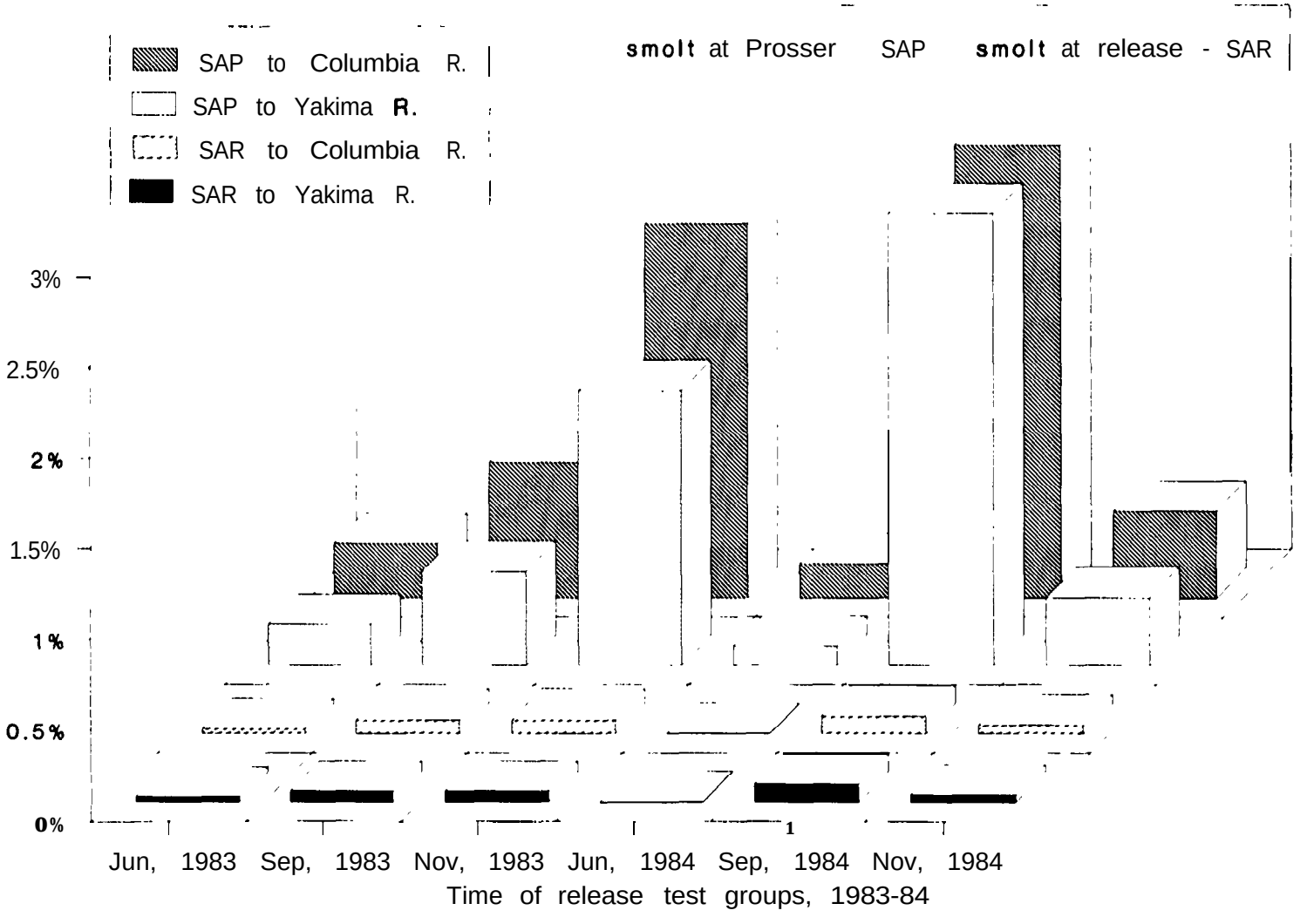


Figure 85. Percent survival from smolt to adult for time of release test groups (Same as Figure 84; the Y-axis was decreased to 3%for visual enhancement).

OPTIMAL RELEASE STOCKS

In both 1986 and 1987, three distinct hatchery-crossed stock groups were acclimated at Mary's Pond and allowed to volitionally release. The hatchery stock was Leavenworth National Fish Hatchery fish of Carson origin; the wild stock was wild Yakima River fish collected at Roza Dam. The three cross release groups were 1) hatchery x hatchery, 2) hatchery x wild, and 3) wild x wild. Each group approximated 50,000 fish in size. However, the 1986 hatchery x wild cross was only 46,476 fish, and the 1986 wild x wild cross was only 33,052 fish.

As stated above, the wild stock was wild brood stock collected at Roza Dam as they ascended this facility during their spring migration. These fish were then transported to an off-channel holding pond on the Naches River (RM 38.7) until they were spawned in late August. Green eggs from Leavenworth were brought to the Naches River pond at spawning time to produce the hatchery x wild cross. The wild x wild cross was made on site with the Yakima River brood stock fish. Because of the need to test all egg lots for IHN, and the fact that this test requires about one week to run, it was necessary to conduct the initial incubation in the Naches Basin. This was done at Nile Pond (RM 29) where a portable incubation trough was constructed and plumbed into the existing spring for a water source. Each lot was individually incubated in separate colanders. Once the eggs reached the eyed stage, they were transported to the Leavenworth National Fish Hatchery to complete their incubation period. The hatchery x hatchery cross was conducted and incubated at the Leavenworth facility.

Various acclimation dates and volitional release dates for these groups in 1986 and 1987 are the same as previously discussed in the optimal manner of release section. The various problems that occurred at Mary's Pond discussed in that section also effected all three release groups in both 1986 and 1987.

Smolt Survival

The survival statistics for the three stocks investigated -- hatchery-reared native ("wild"), Leavenworth x Yakima hybrids ("hybrid"), and pure Leavenworth ("hatchery") are summarized in Table 65. Note that all experimental groups -- hatchery, hybrid and wild -- were acclimated in Mary's Pond on the upper Yakima (as was the 1985 group of hatchery smolts). Note also that the 1987 groups included "quasi-replicates," as each treatment included four equal-sized, differently branded subgroups.

Table 65. Sunnary of smolt survival statistics for wild, hybrid and hatchery smolts released from upper Yakima acclimation ponds in 1986 and 1987.

GROUP	NUMBER RELEASED	PASSAGE TO PROSSER	SURVIVAL TO PROSSER (%)	PASSAGE TO McNARY	SURVIVAL TO McNARY (%)	SURVIVAL FROM PROSSER TO McNARY (%)
86 WILD	5,255	1,062	20.21	361	6.87	33.99
86 HYBRID	5,438	1,016	18.68	432	7.94	42.52
86 HATCHERY	5,910	1,054	17.83	519	8.78	49.24
87 WILD REP 1	1,410	156	11.06	110	7.80	70.51
87 WILD REP 2	1,410	104	7.38	69	4.89	66.35
87 WILD REP 3	1,410	189	13.40	251	17.80	~100
87 WILD REP 4	1,410	149	10.57	146	10.35	97.99
MEAN 87 WILD	5,640	596	10.57	576	10.21	96.64
87 HYBRID REP 1	1,310	39	2.98	0	0	0
87 HYBRID REP 2	1,310	12	0.92	0	0	0
87 HYBRID REP 3	1,310	55	4.20	29	2.21	52.73
87 HYBRID REP4	1,310	41	3.13	0	0	0
MEAN 87 HYBRID	5,240	147	2.81	29	0.55	19.73
87 HATCHERY REP 1	1,260	81	6.43	145	11.51	~100
87 HATCHERY REP 2	1,260	23	1.83	0	0	0
87 HATCHERY REP 3	1,260	32	2.54	94	7.46	~100
87 HATCHERY REP 4	1,260	50	3.97	30	2.38	60.00
MEAN 87 HATCHERY	5,040	186	3.69	269	5.34	~100

Estimated survival to Prosser was greater for the wild group in both 1986 and 1987, although the difference was small in 1986. If the subgroups used are treated as replicates, then the survival of the 1987 wild group was significantly (l-way ANOVA, $p = .05$) greater than the other groups, although the hatchery and hybrid groups were indistinguishable.

The fact that the survival of all acclimated groups in 1987 was half or less the survival of 1986 groups is attributable to the failure of many of the fish to exit the acclimation pond before falling river levels dried up the outlet and trapped an undetermined number of fish in the pond. Tribal researchers have assumed that access to the river was equal for all 1987 groups. If it was not, the statistical comparison of survival to Prosser reflects not survival so much as the "ability and inclination to traverse small, shallow channels."

Estimated survival to McNary was slightly less than half the survival to Prosser in 1986 for all groups. The order of survival was reversed relative to Prosser, with hatchery fish doing best, hybrid fish next best and wild fish worst. However, the rates ranged only from 6.87% (wild) to 8.78% (hatchery), and probably should be considered equivalent. In 1987, on the other hand, the "apparent survival" of wild fish was again significantly greater than the other groups, which were statistically indistinguishable. The same caveats applied to the analysis of 1987 survival rates at Prosser applies to the McNary analysis. In particular, it is unclear whether the higher recovery rates of wild fish reflect superior inriver survival, or simply the inclination and ability to swim through a small channel in the process of drying up.

Once again the index of survival from Prosser to McNary was higher than the release-point-to-Prosser survival rate and, for all groups but the 1987 hybrids, it was also comparable to the rates observed for wild fish over the years.

This study supplies little evidence that hatchery-reared smolts that are genetically identical to natural Yakima fish will enjoy higher in-basin survival rates than non-native, hatchery-reared fish. Wild recovery rates were clearly superior to hybrid and hatchery rates only in 1987, and even then, it is not clear whether higher recovery reflects higher survival of smolts in the mainstem Yakima or something else.

The lack of evidence for the clear superiority of hatchery-reared native smolts in their ancestral drainage has serious implications for proposed supplementation programs throughout the Columbia Basin. In short, "having the right genes" does not seem to be enough to guarantee smolt survival approaching the rates associated with "native," naturally reared fish. Certainly, the genetic emphasis of most ongoing and proposed supplementation programs is proper and necessary, but it is not at all clear that it is sufficient. Even in creatures as phylogenetically primitive as fish, "success in life" may depend to a large extent on proper schooling. Less rhetorically, it has been demonstrated that the recognition of predators and the recognition of palatable food items are subject to the laws of classical and operant conditioning, and are not wholly instinctive (Suboski and Templeton 1988). The

performance of the hatchery-reared wild smolts in this study cannot have been affected by maladaptive selection associated with hatchery practices, but possibly the acquisition of maladaptive behavior.

Outmigration Timing

The timing and pattern of the outmigration of the 1986 and 1987 wild, hybrid, acclimated hatchery and trucked hatchery groups is summarized in Table 66 and Figures 86-89.

Table 66 indicates that the passage rate of all acclimated groups in both years was quite similar. Figures 86-89 indicate that the outmigration patterns were also similar. An unusual feature of the acclimated releases in 1986 is that the median migration rate to Chandler was not appreciably higher than the migration rate from release point to McNary. The usual pattern -- faster rates at McNary than Prosser -- was, however, seen for the 1987 acclimated releases. The explanation of the unusual performance of the 1986 acclimated groups may be that flows below Prosser Dam were unusually low in late April and May of 1986. In 1986, mean flows declined from 2,386 cfs in the last 15 days of April to 2,251 cfs through May By contrast, mean flows in 1987 increased from 2,706 cfs in the last half of April to 3,675 cfs through May.

The difference in the apparent migration rates between trucked and acclimated fish in both years is basically spurious. In 1987, acclimated fish were simply handicapped at the start by a vanishing outlet stream. In 1986, trucked fish were released at two different times, April 9 and April 28. This measure was necessary because a “false positive” test for IHN forced the temporary quarantine and re-testing of half of the fish in the trucked group. The second load of trucked fish encountered possibly the worst conditions in the Yakima researchers have observed in the eight years of the study. Even so, some of this second load probably reached Prosser, as the steepening of the “hatchery, non-acclimated” line after the “plateau” in Figure 86 may indicate. These late-arriving trucked fish prolonged the duration of outmigration, resulting in a “later” median arrival time and a slower overall migration rate. If all trucked fish arriving after the “plateau” are discounted, the outmigration pattern of the trucked fish would be similar to the acclimated groups. Such a possibility is suggested by Figure 87, which shows that the outmigration timing of all 1986 groups, acclimated and trucked, was quite similar at McNary. The change from the pattern at Prosser to the pattern at Mcnary might be attributed to the virtual elimination of the second load of trucked fish, which would have encountered much worse conditions in the lower river.

Table 66. Summary of outmigration timing statistics for 1986 and 1987 wild, hybrid and hatchery acclimated groups, and 1986 and 1987 trucked groups.

GROUP	DAYS AFTER RELEASE REQUIRED FOR Cumulative PASSAGE OF 10% 50% AND 90% AT PROSSER			MEDIAN MIGRATION RATE FROM RELEASE POINT TO PROSSER (mi/day)	DAYS AFTER RELEASE REQUIRED FOR CUMULATIVE PASSAGE OF 10% 50% AND 90% AT PROSSER			MEDIAN MIGRATION RATE FRDM RELEASE POINT TO McNARY (mi/day)
	10%	50%	90%		10%	50%	90%	
86 TRUCKED	16	37	51	3.19	29	41	52	5.08
86 WILD	11	27	55	5.37	38	47	62	5.00
86 HYBRID	11	27	44	5.37	33	40	57	5.88
86 HATCHERY	11	27	46	5.37	36	43	60	5.47
87 TRUCKED	7	15	18	7.87	18	21	25	9.92
87 WILD	29	39	45	3.72	40	43	54	5.47
87 HYBRID	23	37	44	3.92	42	42	42	5.60
87 HATCHERY	22	32	43	4.53	41	45	46	5.23

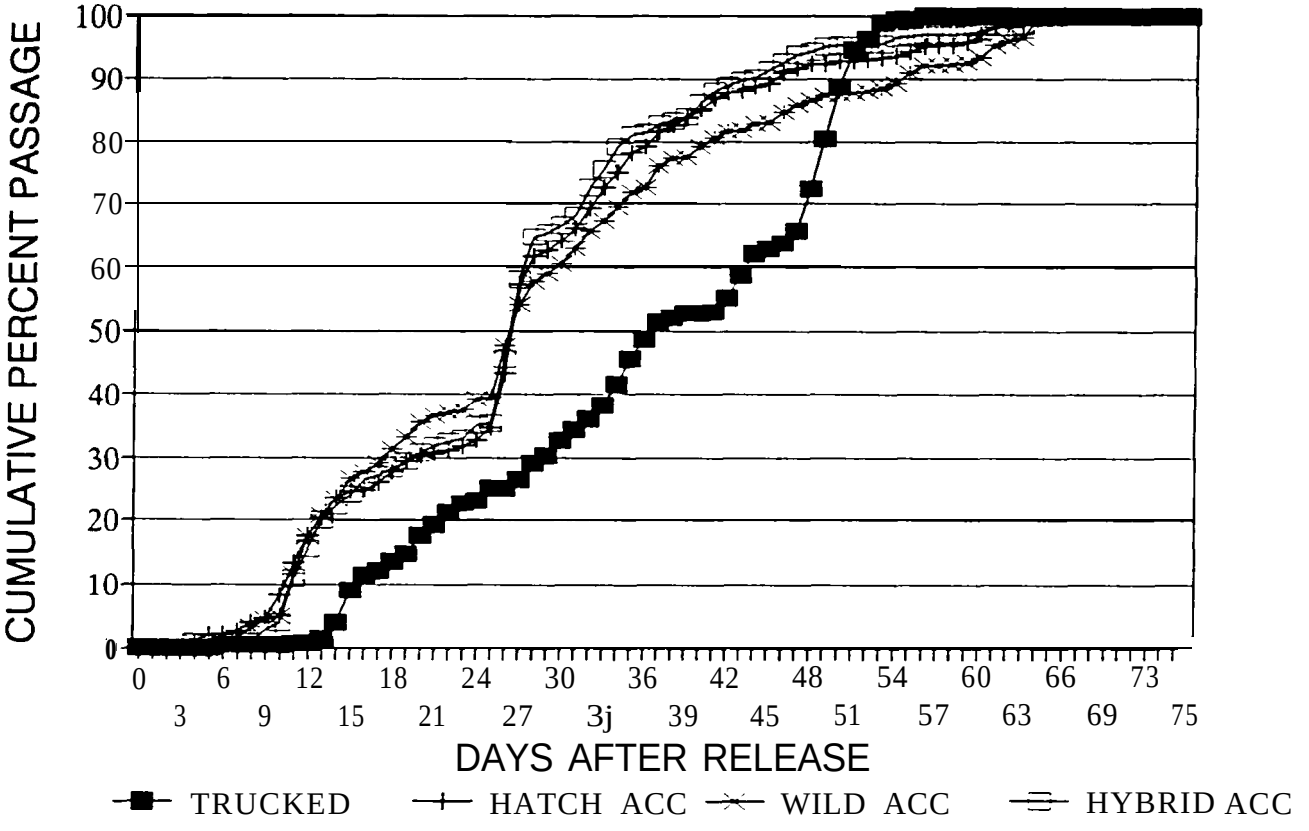


Figure 86. Prosser passage, 1986, of experimental groups released as smolts in 1986.

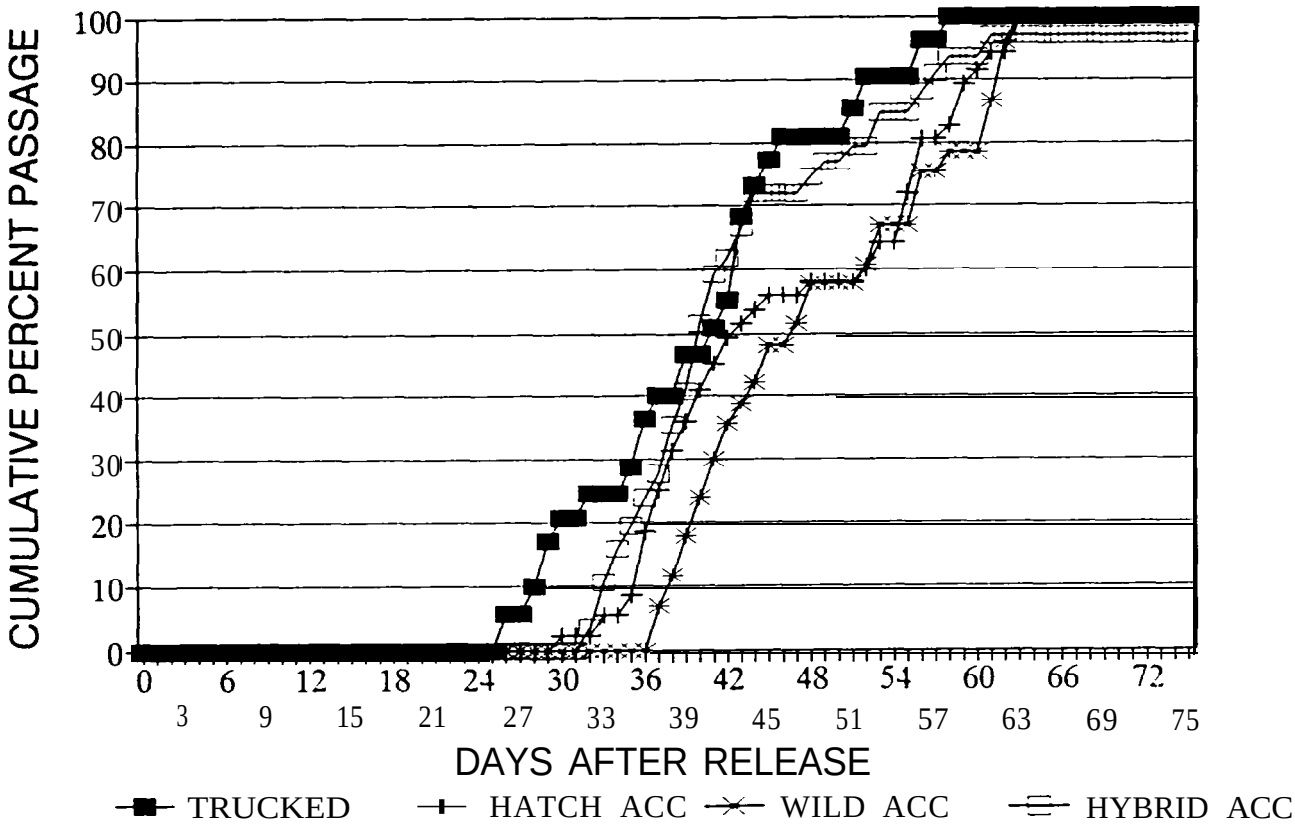


Figure 87. McNary passage, 1986, of experimental fish released as smolts in 1986.

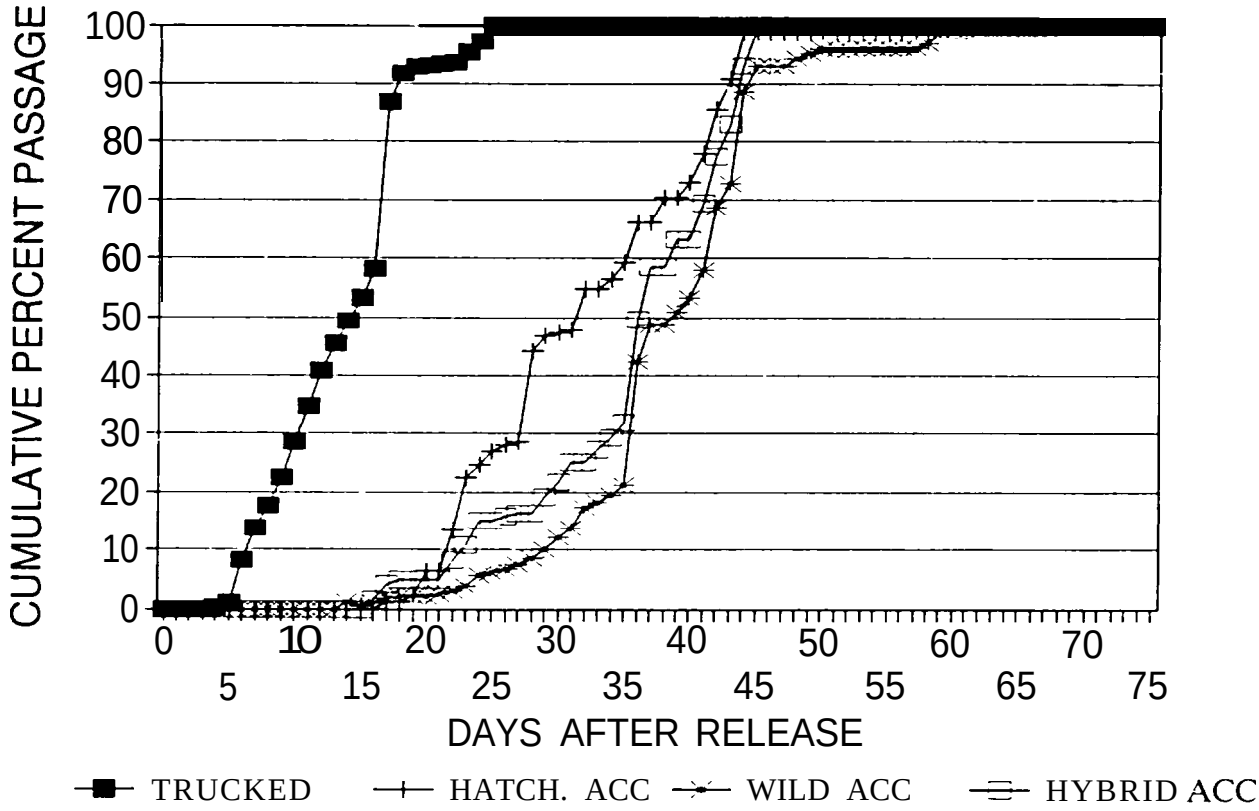


Figure 88. Prosser passage, 1987, of experimental fish released as smolts in 1987.

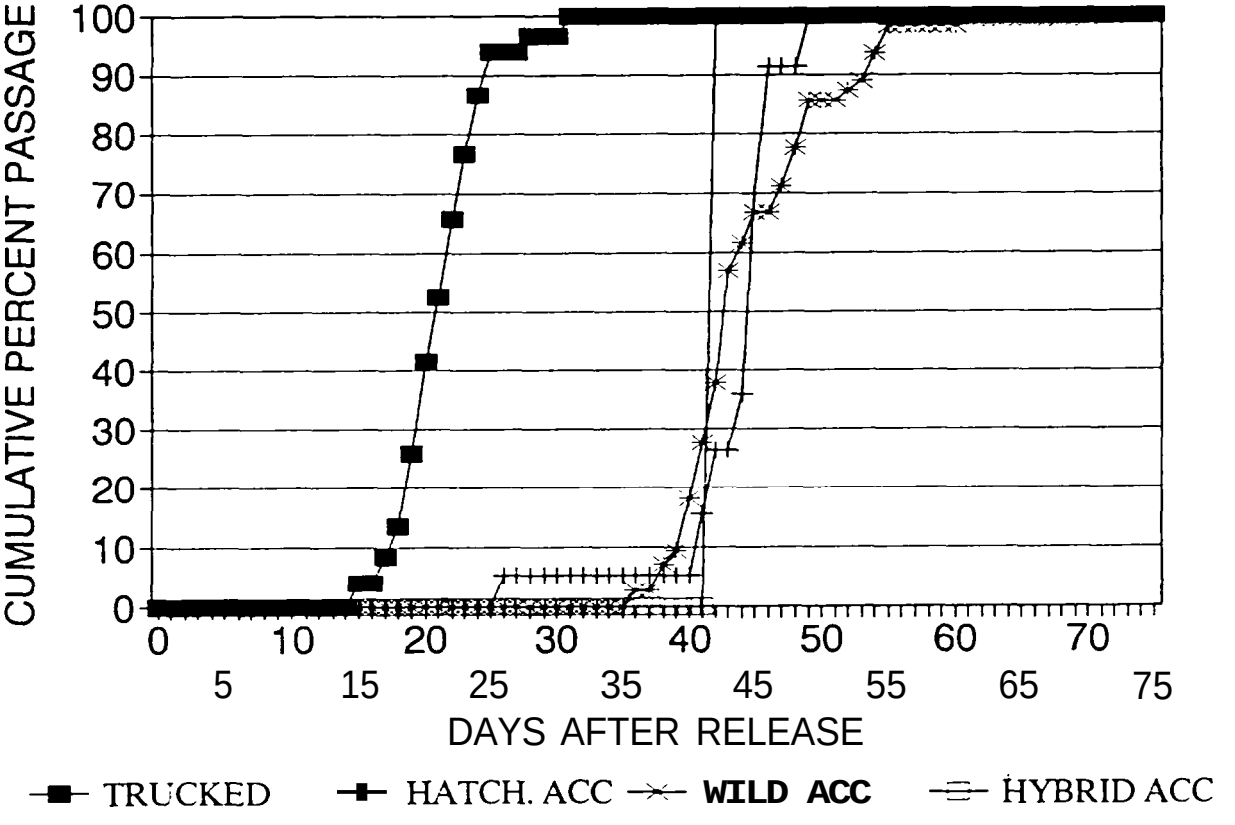


Figure 89. McNary passage, 1987, of experimental fish released as smolts in 1987.

Size of Exwrimental Fish

The length, weight and condition factor of all experimental fish in 1986 and 1987 was summarized in Table 60, in a previous section. From the table, it is apparent that few of these factors vary appreciably among groups, either at release or as observed at Prosser. However, one tantalizing observation concerns the condition factor of wild and hybrid fish versus "pure" hatchery fish. In both 1986 and 1987, wild and hybrid fish either maintained or increased condition from April to May. By contrast, the condition of both hatchery groups dropped substantially from April to May. If this difference is real, it may indicate one of the few benefits solely attributable to "good genes."

Smolt-to-Adult Survival

The experiments designed to determine the best brood stock source were unsuccessful for the reasons mentioned earlier in this section. In the 1987 release year, there was the mixture of coded-wire tags in the hatchery x hatchery (HxH) acclimation pond release group and the trucked hatchery release group so that no evaluation of survival from smolt to adult could be calculated for that group. The results from the 1984 brood year (1986 release) and the partial data on the hatchery x wild (HxW) and wild x wild (WxW) releases of the 1985 brood year groups are presented in Table 67.

As can be observed from the limited data available, the survival from smolt at release was generally poor for these groups, especially the 1986 smolt releases. The 1987 smolts, however, do have survival rates from smolt-at-Prosser to returning adult that approximate the survival estimated for wild fish in the same time frame. These estimates are likely to improve as the 1990 catch data for the Columbia River becomes available.

Also of interest in these limited results is the indication that the WxW crosses do not do better than the HxH and HxW release groups. There is some indication that wild fish do not do as well in hatcheries as cultured stocks that have evolved to adapt to the hatchery environment. Thus, genetics alone is not the answer to improving post-release survival of hatchery reared fish. This is another indication that hatchery facilities and operations must be examined and revised to address increasing the survival of the hatchery product in the natural environment after release rather than measuring success just in total numbers of smolts that survive to release from the facility. The genetics aspect, while perhaps not increasing the post-release survival of these fish, is undoubtedly important in the reproductive success and long-term fitness of the locally adapted populations of salmon in various subbasins. Again this aspect of the supplementation question was not addressed in this project. It definitely does need to be addressed in future research efforts.

Table 67. Survival from smolt-at-release, and smolt-at-Prosser, to returning adult to the Columbia and the Yakima for the HxH, HxW, and WxW brood stock release groups.

Brood Year	Treatment	Survival to Yakima from smolt at		Survival to Columbia from smolt at	
		Release	Prosser	Release	Prosser
1984	HxH	.04%	.21%	.05%	.29%
	HxW	.02%	.12%	.04%	.20%
	WXW	.01%	.06%	.02%	.07%
1985	HxH	N/A			
	HxW	.09%	3.06%	.10%	3.60%
	WXW	.11%	1.00%	.11%	1.03%

C) Recommendations

The results of the eight years of research on spring chinook salmon in the Yakima Subbasin indicated that the following critical uncertainties exist and should be addressed with further research efforts in the future.

1) Determination of the locations, causes, and magnitude of smolts lost during their inriver migrations through the subbasin.

   Researchers repeatedly observed smolt losses of 50% to 80% from upriver release points to Prosser Dam. Preliminary studies have indicated that serious losses occur below Wapatox, Sunnyside and Prosser dams, and these areas should be investigated. Investigations should not, however, be limited to these reaches, but should include the entire mainstem Yakima and Naches rivers.

   A smolt survival study should not be limited to predation. Non-predatory losses could include residualization, disease, water quality (temperature, dissolved oxygen, toxins), entrainment in Phase-II diversions and physical stranding.

2) Quantification of the relationship between instream flow and smolt production.

   This relationship must be defined for spring flows in reaches above major rearing areas, for winter flows and water surface elevations in suspected overwintering areas, and for summer flows in major rearing areas.

3) Development and/or refinement of habitat-based carrying capacity estimators.

   All available estimators entail fairly bold assumptions, including the estimate based on weighted usable area (IFIM). These assumptions **must** be checked and revised as necessary.

4) Determination of the physical and\or behavioral differences between hatchery and wild smolts that could account for the magnitude of difference in their survival rates from smolt to adult.

   hlodification of hatchery practices could result if it is found that differences in survival can be attributed to physical or behavior changes produced by hatchery rearing.

5) Determination of whether reproductive success or long-term fitness of the locally adapted Yakima Subbasin spring chinook stocks would be affected from supplementation using local brood stocks.

Preliminary results indicated that local brood stock does not automatically produce a hatchery-reared smolt that has superior survival from smolt to adult over hatchery brood stock. However, the reproductive success or long-term fitness of the local stocks may suffer if hatchery brood stock is used in future supplementation efforts.

6) Determination of the relationship between duration of in-basin outmigration and subsequent adult returns.

7) Determination of the "outmigrant-to-adult" return rate for spring chinook passing Prosser in the late fall and winter.

As about one-fourth of brood year outmigration has been observed in the winter, this is an issue of some importance. It would also be useful to know whether the magnitude of winter movement is related to egg deposition and/or rearing density in suspected overwintering areas.

LITERATURE CITED

Anonymous. 1974. Yakima-Kittitas resource conservation and development plan. USDA, Soil Conservation Service, Spokane, Washington.

Anonymous. 1985. Yakima River basin water enhancement project Phase-II status report. Report to the regional director, Pacific Northwest Region, Bureau of Reclamation and the director, Department of Ecology, State of Washington.

Bartoo, N.W. 1977. Population parameter estimates and energy budgets for peamouth, northern squawfish and yellow perch in Lake Washington. Doctoral Dissertation. University of Washington, Seattle, Washington.

Beamsderfer, R.C. and B.E. Rieman. 1988. Predation by resident fish on juvenile salmonids in a mainstem Columbia reservoir: Part III. Abundance and distribution of northern squawfish, walleye and smallmouth bass. In T.P. Poe and B.E. Rieman, editors. Predation by resident fish on juvenile salmonids in John Day Reservoir 1983-86. Final Report (Contracts DEAI79-82P34796 and DE-AI79-828BP35097) to Bonneville Power Administration, Portland, Oregon.

Bjornn, T.C. 1971. Trout and salmon movements in two Idaho streams as related to temperature, food, streamflow, cover and population density. Transactions of the American Fisheries Society 100:423-438.

Bjornn, T.C. 1978. Survival, production and yield of trout and chinook salmon in the Lemhi River, Idaho. Bulletin 27, College of Forestry, Wildlife and Range Sciences, University of Idaho, Moscow, Idaho.

Boucher, P.R. 1982. Sediment transport by irrigation return flows in four small drainages within the DID-18 drainage of the Sulphur Creek Basin, Yakima County, Washington, April 1979-October 1981. U.S. Geological Survey, Water Resources Investigations, Report 83-4 167.

Bryant, F.G. and Z.E. Parkhurst. 1950. Survey of the Columbia River and its tributaries - Part IV. Special Scientific Report: Fisheries No. 37. U.S. Fish and Wildlife Service, September 1950.

Cederholm, C.J., L.M. Reid and E.O. Salo. 1981. Cumulative effects of logging road sediment on salmonid populations in the Clearwater River, Jefferson County, Wash. Pages 38-74 In Proceedings from the conference Salmon Spawning Gravel: A Renewable Resource in the Pacific Northwest? Rep. 39. State of Washington Water Research Center, Pullman.

Crase, F.T. 1985. Estimating actual fish production in the Yakima River Basin, Washington. Division of Planning, Pacific Northwest Region, Bureau of Reclamation, Boise, Idaho.

Easterbrooks, J. 1990. Unpublished memorandum.

Easterbrooks, J.A. and S. Kessler. 1984. Supplemental data, information and biological justification in support of Amendment US/704(e)(l)-5 -- Construction of an Adult Fish Passage Facility at Salmon Falls, Little Naches River (Yakima River Basin) and Amendment US/704(d)91-15 -- Little Naches River Channel Rehabilitation. Testimonial Report for Northwest Power Planning Council meeting, July 26, 1984 (unpublished).

Eddy, B.R. 1987. Wapatox Canal fish screening facility efficiency study: 1986 data report. Report to Pacific Power and Light, 920 S.W. Sixth Ave., Portland, Oregon. January 11, 1987.

Eddy, B.R. 1988. Wapatox Canal fish screen facility passage effectiveness evaluation 1986-1987. Pacific Power and Light Environmental Services, August 1988.

Envirosphere. 1985. An assessment of the potential entrainment of juvenile salmonids into hydropower/irrigation canals of the Yakima River during winter. Final Report prepared for the Yakima Indian Nation Fisheries Resources Management and the U.S. Department of Energy, Bonneville Power Administration, Division of Fish and Wildlife. September, 1985. Envirosphere Co., 10900 NE 8th St., Bellevue, WA, 98004, September 1985.

Fast, D.E., J. Hubble and B. Watson. 1985. Yakima River spring chinook enhancement study. 1985 Annual Report to Bonneville Power Administration. Project 82-16.

Fast, D.E., J. Hubble and B. Watson. 1986. Yakima River spring chinook enhancement study. 1986 Annual Report to Bonneville Power Administration. Project 82-16.

Fast, D.E., J. Hubble and B. Watson. 1987. Yakima River spring chinook enhancement study. 1987 Annual Report to Bonneville Power Administration. Project 82-16.

Hallowed, J.J. 1984. A study of fall chinook (Oncorhvnchus tshawvtscha) in Marion Drain on the Yakima Indian Reservation. Yakima Indian Nation Information Report 84-7.

Hosey and Associates and Fish Management Consultants. 1990. Evaluation of effectiveness of fish protection facilities: Evaluation of the Chandler, Columbia, Roza and Easton screening facilities. Completion Report. Prepared for Bureau of Reclamation, Contract 7-CS-10-07720. Prepared by Hosey and Associates Engineering Company and Fish Management Consultants, September 1990.

Hubble, J.D., D.E. Fast, T.B. Scribner, W.R. Sharp and M.V. Johnston. 1990. Yakima/Klickitat natural production and enhancement program. 1990 Annual Report to Bonneville Power Administration. Project 88-120.

Johnson, A., D. Norton and B. Yake. 1986. Occurrence and significance of DDT compounds and other contaminants in fish, water, and sediment from the Yakima River Basin. Washington Department of Ecology, Water Quality Investigations Section, Olympia, Washington. Report 86-5.

Koski, K.V. 1966. The survival of coho (Oncorhvnchus kisutch) from egg deposition to emergence in three Oregon coastal streams. M.S. Thesis, Oregon State University, Corvallis, OR. 84 pp.

Lindland, R.L. 1973. Squawfish control in Cascade Reservoir. Federal Aid Project F-53-R-8 Job 2a, Idaho Fish and Game Department, Boise, Idaho.

Lindsay, R.B., J.S. Ziller and R.K. Schroeder. 1982. An ecological and fish cultural study of Deschutes River salmonids. Oregon Department of Fish and Wildlife, Fish Research Project F-88-R-13, Annual Progress Report, Portland, Oregon.

Lindsay, R.B., W.J. Knox, M.W. Flesher, B.J. Smith, E.A. Olsen, and L.S. Lutz. 1985. Study of wild spring chinook salmon in the John Day River System: 1985 Final Report. Bonneville Power Administration Division of Fish and Wildlife Contract DE-A179-83BP39796, Project 79-4, February 1986.

Lotspeich, F.B., and F.H. Everest. 1981. A new method for reporting and interpreting textural composition of spawning gravel. U.S. Forest Service. Pac. N.W. For. and Range Exp. Sta. Note PNW-369, 11 pp.

Major, R.L. and J.L. Mighell. 1969. Egg to migrant survival of spring chinook (Oncorhvnchus tshawvtscha) in the Yakima River, Washington. Washington Fishery Bulletin 67(2):347-359.

Mongillo, P. and L. Falconer. 1980. Yakima fisheries enhancement study final report. Washington Department of Game, Yakima, Washington. October 1980.

Park, D.L. 1985. A review of smolt transportation to bypass dams on the Snake and Columbia rivers. Report of research financed by U.S. Army Corps of Engineers (Contract DACW68-84-H-0034) and Coastal Zone and Estuarine Studies Division, Northwest and Alaska Fisheries Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, 2725 Montlake Boulevard East, Seattle, Washington. February 1985.

Patton, B.G., R.B. Thompson, W.G. Gronlund. 1970. Distribution and abundance of fish in the Yakima River, Wash., April 1957 to May 1958. U.S. Fish and Wildlife Service Special Scientific Report -- Fisheries No. 603, Washington, D.C., June 1970.

Payne, T.R. 1982. Instream flow assessment: Yakima River between Sunnyside Dam and Zillah Wasteway. December 1982.

Piper, R.G., I-B. McElwain, L.E. Orme, J.P. McCraren, L.G. Fowler and J.R. Leonard. 1982. Fish hatchery management. USDI, Fish and Wildlife Service, Washington, D.C. 1982.

Reimers, P.E. and R.E. Loeffel. 1967. The length of residence of juvenile fall chinook in selected Columbia River tributaries. Research Briefs, Fish Commission of Oregon, Volume 13, Number 1.

Ricker, W. 1975. Computation and interpretation of biological statistics of fish populations. Bull. of the Fish. Res. Board of Canada:191.

Shirazi, M.A. and W.K. Seim. 1979. A stream systems evaluation -- an emphasis on spawning habitat for salmonids. EPA Rep. 600/3-79-109. Corvallis Environmental Research Laboratory and the U.S. Environmental Protection Agency, Corvallis, Oregon.

Smoker, W.A. 1956. Evaluation of the potential salmon and steelhead production of the Yakima River to the commercial and recreational fisheries. Report to the Washington Department of Fisheries. 19pp.

Stainbrook, C., T.A. Luther and L.E. Pitt, Jr. 1985. Habitat quality and baseline data annual report. The Confederated Tribes and Bands of the Warm Springs Indian Reservation.

Stemple, J.M. 1985. Conversion of weighted usable area to potential fish production in the Yakima Basin. U.S. Fish and Wildlife Service, Olympia, Washington, Moses Lake Suboffice. June 1985.

Suboski, M.D. and J.J. Templeton. 1988. Acquisition and social communication of stimulus recognition by fish. Behavioral Processes 16:213-244.

Taggart, J.V. 1976. The survival from egg deposition to emergence in coho salmon in the Clearwater River, Jefferson County, Washington. M.S. Thesis, Univ. of Washington.

Tappel, P.D., and T.C. Bjomn. 1983. A new method of relating size of spawning gravel to salmonid embryo survival. North Amer. Joum. Fish Mgmt.

Vigg, S. 1988. Functional response of northern squawfish predation to salmonid prey densities in McNary tailrace, Columbia River. In T.P. Poe and B.E. Rieman, editors. Predation by resident fish on juvenile salmonids in John Day Reservoir 1983-86. Final Report (Contracts DE-AI79-82P34796 and DE-AI79-828BP35097) to Bonneville Power Administration, Portland, Oregon.

Wasserman, L. and J. Hubble. 1983. Yakima River spring chinook enhancement study. 1983 Annual Report to Bonneville Power Administration. Project 82-16.

Wasserman, L., J. Hubble and B. Watson. 1984. Yakima River spring chinook enhancement study. 1984 Annual Report to Bonneville Power Administration. Project 82-16.

Wasserman, L., J. Hubble and B. Watson. 1985. Yakima River spring chinook enhancement study. 1985 Annual Report to Bonneville Power Administration. Project 82-16. 115 pp

Yakima Indian Nation, Washington Department of Fisheries, and Washington Department of Wildlife. 1990. Yakima River subbasin salmon and steelhead production plan. Presented to the Northwest Power Planning Council, Portland, Oregon. September 1, 1990.