STATUS OF SPRING CHINOOK SALMON IN THE MID-COLUMBIA REGION

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April 24, 1995

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SUMMARY

Introduction

This report, prepared at the request of the three public utility districts of the mid-Columbia region, provides information on the biology and numerical status of spring chinook in the mid-Columbia segment of the Columbia River, upstream from the Yakima River mouth. It emphasizes stock characteristics, hatchery operations, genetic makeup, passage through the migration corridor between natal areas and the sea, and ecology at sea.

Distribution

Wild spring chinook in the Wenatchee River spawn in Nason Creek, and in the Chiwawa, Little Wenatchee, upper main Wenatchee, and White rivers. A group of fish strongly influenced by Carson stock spawns in Icicle Creek, and provides brood stock for Leavenworth National Fish Hatchery (NFH).

Entiat spring chinook spawn in the upper main Entiat River. The brood stock for Entiat NFH is strongly influenced by Carson stock.

Methow wild spring chinook spawn in the Twisp, Chewack, and upper Methow rivers and their tributaries. Winthrop NFH brood stock is strongly infused by Carson spring chinook. Spring chinook do not use the Okanogan River, although they formerly did. No reliable information indicates that spring chinook ever used the Similkameen River.

All wild spring chinook in the mid-Columbia region derived from mixed brood stock from trapping at Rock Island Dam, 1939-1943, part of the Grand Coulee Fish Maintenance Project (GCFMP). The mixed gene pool included spring chinook from the Wenatchee, Entiat, Methow, and upper Columbia River tributaries upstream from the site of Grand Coulee Dam. Mixed adults and juveniles were placed in tributaries and mainstem areas of the Wenatchee, Entiat, and Methow rivers.

Abundance

Escapements to areas upstream from Rock Island Dam were about 3,000 spring chinook in 1935-1938. They rose by the mid-1980s to 27,000, then declined somewhat. Escapement in 1994 (2,041 adults) and predicted escapement for 1995, are very low. Redd counts in spawning index areas used

by wild spring chinook in the mid-Columbia region dId not evidence a decline in the period 1958-1994. Adjustment of redd counts results in an estimate of wild fish abundance about 81.5% that of the Rock Island count of spring chinook. Escapement has been maintained at the cost of in-river harvest in zones 1-6. Harvest rates before 1960 ranged from 40% to 85%. Since 1974, the in-river harvest rate has been less than 10%. Ocean harvest is negligible for mid-Columbia spring chinook.

Life history

Spring chinook of the mid-Columbia reach peak abundance in the lower Columbia River in April and May. Fifty percent of the spring chinook run passes Rock Island Dam in mid-May. Passage at Wells Dam occurs slightly later. Assessment of the nadir of arrivals at Rock Island Dam suggests that PUD cut-off date for spring chinook is later than it should be.

Spring chinook spawn from late July to September, peaking about mid-August. Mid-Columbia spring chinook migrate to sea after one winter of life post-emergence. Most return from the sea four years after their parents did, and after two winters at sea, at about 60 cm hypural length. Twenty to forty percent of adult spring chinook spend three winters at sea and return at larger size. Precocious males, or jacks, return after one winter at sea. Some males mature sexually in fresh water without migrating to the sea, and probably contribute to egg fertilization.

Sex ratios at Leavenworth, Entiat, and Winthrop fish hatcheries range from 1.27 to 1.87 females per male. Although more females than males are collected on wild spawning grounds, we believe the actual effective ratio is closer to 1:1 because it is more difficult to collect males there. We discuss reasons in the text.

Fecundity in females taken in the Chiwawa River is estimated at 5,980; in the Methow River at 5,100. In the latter stream, four-year-old females averaged 4,200 eggs; five-year-old fish averaged 5,400 eggs.

Hatchery operations

Past hatchery introductions include fish from several non-indigenous sources. Within the mid- and upper-Columbia stocks, mixed Wenatchee, Entiat, Methow, and upper Columbia (upstream from Grand Coulee Dam) spring chinook were delivered to tributaries as adults and/or juveniles, forming the basis for adaptation beginning in the 1940s. Upriver spring chinook trapped at Bonneville Dam also provided core broodstock at Leavenworth, Entiat, and Winthrop federal hatcheries. We describe facilities, practices, and problems at the three federal hatcheries.

Two state hatcheries, Rock Island Fish Hatchery Complex and Methow Fish Hatchery Complex, produce smolts with genetic composition particular to the Chiwawa, Methow, Twisp, and Chewack rivers, to supplement natural production. We describe facilities, practices, and some potential problems of these facilities.

Genetics

Analysis of available genetic information indicates that spring and summer/fall chinook differ substantially. Each group belongs to a different distinct evolutionary lineage within the Columbia River. Non-overlapping allele frequencies at many loci contributed to the distinction of these two groups.

Some genetic distinctions among the spring-run fish became apparent based on pairwise genetic distance measurements from three subsets of allele frequency data coupled with direct examinations of the allelic data. Based on the cumulative evidence, the White River populations particularly appear to have diverged, and a natural grouping among wild populations of the Methow River basin may exist. The closely-related Leavenworth and Winthrop hatchery populations were most similar to wild populations of Nason Creek and the Chiwawa River.

Several groups of non-indigenous spring chinook have been introduced to the mid-Columbia region, apart from mixing caused by the GCFMP. Included were McKenzie, Spring Creek, Eagle Creek, Cowlitz, Simpson, and Elokomin stocks. We found no evidence that these introductions have infused wild gene pools in the Chewack, Twisp, upper Methow, Chiwawa, Little Wenatchee, or White rivers, or Nason Creek.

Carson stock spring chinook, a mix developed from upriver spring chinook trapped at Bonneville Dam, appear to be the ancestral source of the Leavenworth, Winthrop, and Entiat hatcheries. Although the relationship of fish of Carson ancestry to wild spring chinook populations is presently unclear, we hypothesize a distinction between the wild demes and the Carson-derived hatchery stocks. Additional sample collections and analyses are needed to verify or reject the hypothesis, and to further define degrees of uniqueness. We discuss direct and indirect genetic effects of hatchery spring chinook on wild fish.

Evolutionarily Significant Unit (ESU)

Plottings of common allele frequencies for two loci indicate a persisting genetic distinction between the spring chinook of the Snake River and mid-Columbia region. These differences, coupled with geographic isolation and distinct habitats contrasting the Snake River and the Columbia River upstream from Rock Island Dam, suggest sufficient genetic, geographical and ecological isolation to prevent expansion of the Snake River ESU to the Columbia River upstream from

Rock Island Dam. Leavenworth Hatchery (and Carson) fish had predominantly mid-Columbia origins. This suggests either initial numerical superiority or adaptive advantage of mid-Columbia fish sh in derivation of the Carson stock. Consequently, the hatchery component cannot presently be excluded from being part of an ESU (or ESUs) of spring chinook salmon upstream from Rock Island Dam. The GCFMP and hatchery activities complicate ESU status among these populations.

All spring-run chinook populations upstream from Rock Island are tentatively considered members of a common ESU. Some evidence supporting the possible existence of isolated population segments of wild fish collected from the White River and within the Methow River drainage suggests the possibility of separate ESUs. Any existing divergence is very recent, having occurred since the relocation and confinement imposed through the implementation of the GCFMP between 1939 - 1943. Further potential erosion of indigenous gene pools relates to the extensive use of hatchery supplementation in this area. Existing enhancement programs for wild demes are designed to reduce the possibility of such erosion. Stocks originating from mixed origin Carson fish gradually adapted to upstream hatcheries, ultimately resulting in the complete use of returning fish as brood stock. To minimize the possibility of loss of indigenous gene pools through hybridization or displacement, these cultured fish should not be outplanted in areas where potential native populations exist.

Habitat quality

Although habitat quality in spawning and rearing areas for spring chinook in the mid-Columbia region has not suffered functional degradation in most areas, water withdrawal is a serious local concern. Much of the upper Methow River lies upstream from irrigation return flows, and in a permeable glacial deposit. Thus it tends to be a losing stream where the stream surface lies above the adjacent roundwater table. Not influenced by irrigation, some reaches of the upper Methow are alternately watered and dewatered. In the Methow basin, irrigation is known to dewater portions of Gold Creek, Benson Creek, and Beaver Creek. Flow is much reduced by irrigation in the Twisp River, Wolf Creek, Goat Creek, and Early Winters Creek. Irrigation withdrawals would be especially severe in effect in drought years. Most irrigation withdrawals in the Wenatchee River take water downstream from spring chinook rearing areas. They probably have little effect upon carrying capacity of the Wenatchee River basin for spring chinook.

We note that juvenile spring chinook use large woody debris extensively for rearing in the Chiwawa River. The Chewack River may offer opportunities for placement of debris for habitat modification.

Spawning, incubation, and rearing

We found no evidence that prespawning losses higher than 20% were the norm in the mid-Columbia region for spring chinook. Survival from egg deposition to emergence has not been studied in spring chinook in the mid-Columbia. In studies outside the region it has ranged from 9 to 90%. Egg-to-parr survival has been variously estimated at 5.7-32% in mid-Columbia tributaries.

Juveniles may move downstream varying distances as fry, parr, and pre-smolts. We describe habitat used by rearing juveniles, feeding, and growth.

Egg to smolt stage

Egg to smolt survival estimates vary widely. In the mid-Columbia, they have ranged from 1.35% to 10.1%. Survival estimates for spring chinook from emergence to smolt stage are complicated by propensity of parr to move out of rearing areas in fall. We discuss competition and predation in the rearing stage.

Timing of smolt movement in main Columbia River

Since 1985, the average 10th, 50th, and 90th percentile passage at Rock Island Dam was April 21, May 10, and June 3, respectively. Run timing of yearling chinook at Rock Island Dam is strongly related to the release of fish from Leavenworth NFH, which reach the dam generally two days after release. Most of the chinook sampled at Rock Island Dam are of hatchery origin, but based on sampling of migrants from the tributaries, we believe that the naturally-produced migrants have a run timing similar to that of the hatchery component of the run.

Peak movement of yearling chinook at Priest Rapids Dam usually occurs in mid-May. Movement at McNary Dam peaks about mid-May. The peak moves to about the third week of May at John Day Dam, and to the last week of May at Bonneville Dam. More than half of the daily movement of spring chinook past dams occurs at night. Most spring chinook move higher in the water column when they enter turbine intakes than subyearling summer/fall chinook and sockeye, but lower than steelhead or coho.

Dam and reservoir passage

As they migrate downstream in the main Columbia River, spring chinook smolts incur some level of "passage mortality" as they pass through the dam by spillway, turbine flow, or any existing bypass system. These losses involve direct physical injury due to mechanical and hydraulic conditions at the dam, and indirect mortality associated with predation on either stunned/injured, or concentrated streams of smolts. "Reservoir mortality" results from conditions smolts encounter while traversing the pool created by the project. The principal mortality mechanism appears to be predation by other fish species. Additionally, river water can become over-saturated with dissolved gas, if spillage at some sites is excessive in volume and duration. This condition can result in both juvenile and adult mortality.

At three of the five mid-Columia dams, the proportion of fish passed through the spillway exceeds the proportion of the water spilled; Wells, Rock Island, and Wanapum dams. There are no species-specific estimates at any site. At Priest Rapids and Rocky Reach dams, the proportion of fish that passes through the spillway is less than the proportion of water spilled. Smolt survival over spillways is estimated to be high at dams throughout the Columbia River, near 98 to 99%.

Flow and travel time

We observed a strong relationship between yearling chinook travel time and release date (a surrogate for degree of smoltification) in spring chinook released from hatcheries in the mid-Columbia region, but no relation with flow. For active migrants intercepted and PIT-tagged at Rock Island Dam we also found release date to be the strongest predictor, with flow explaining a slight to negligible amount of the observed variation in travel time. This contrasts with our findings for steelhead, where flow was the strong predictor variable.

However, analyses of the Fish Passage Center (FPC) indicate that both variables are good predictors for smolts tagged at Rock Island Dam. If one wishes to adopt the generalized flow response indicated in two models of the FPC, then increasing mid-Columbia flow from 120 to 200 kcfs would be predicted to decrease median travel time about four days from 13.2 to 9.6 d, or an average of less than one day per 20 kcfs.

Reach survival of spring chinook smolts

Over the three years 1985-1987, survival estimates obtained by the Fish Passage Center averaged 45% from release near Pateros to the control release site downstream from Priest Rapids Dam. Similar studies were undertaken by the mid-Columbia PUDs in 1980, 1982, and 1983. In those respective years, survival from Pateros to Priest Rapids tailrace was estimated at 33-40%, 44%, and 45%. Using segment-specific survival estimates, the investigators calculated the survival per project (dam and pool combined). In 1982, they reported 87% survival for Wells, Rocky Reach, and Rock Island dams, and 83 % for Wanapum and Priest Rapids dams. In 1983, they reported 84% and 87% for those same projects respectively. Overall, in both years the average survival per project was approximately 85%, if we assume mortalities were evenly distributed across all projects. Those estimates may or may not represent survival of wild migrants.

We modeled the relative change in survival that may occur if some broad mainstem mitigation measures are implemented in the mid-Columbia reach. Our CRiSP modeling predicts that the installation of proposed bypass systems at four mid-Columbia dams will improve smolt survival moderately, but likely not enough to appreciably improve overall stock productivity. CRiSP predicts spill is ineffectual due to offsetting gains and losses associated with improved passage survival and gas saturation, respectively. Only empirical estimates of system survival under various spill levels can verify or refute the hypothesis.

The model analysis suggests that transporting fish from all four mid-Columbia sites may provide substantial gains in survival to a point downstream from Bonneville Dam, far exceeding those offered by any other alternative. The option to transport should be empirically evaluated.

Marine movements and distribution

Chinook movements at sea are more complicated than those of sockeye and pink salmon. Although the majority of chinook appear to remain along the continental shelf more than other species, occasional catches well offshore have been made. Stream-annulus chinook from the Columbia River move northward along the continental shelf in the first few months of ocean life.

Limited information suggests that biomass of chinook, like coho, is greatest along the continental shelf. However, low recovery rates of spring chinook from the mid-Columbia region in ocean troll fisheries, and other information, suggests that these fish may spend more time in far-offshore waters than do ocean-type chinook.

Ocean productivity

Productivity of marine rearing areas fluctuates on an interdecadal scale. The mid-1980s produced relatively large returns of chinook salmon, steelhead, and sockeye in many regional stocks, including spring chinook in the mid-Columbia.

The size and strength of Aleutian low pressure areas appear to influence ocean productivity for salmon. Because the various salmon species feed on similar foods and use areas of the sea in common, ocean carrying capacity probably is limited. Some workers have suggested that enhancement efforts should be geared to that capacity.

El Niño events that bring warm water to the northwestern coastline reduce upwelling in areas used by juvenile salmon after they reach the sea. They also bring dense populations of predators, like Pacific mackerel, inshore. Predation may have been responsible for failure of the smolt runs that reached the mouth of the Columbia River in 1992 and 1993 (adult runs of 1994 and predicted for 1995).

From a high in the mid-1950s, chinook runs from southeastern Alaska to California declined steadily from almost 6 million to under 4 million in the early 1960s. Runs then steadily rose to nearly 6 million again in the mid-1970s. Those numbers include both ocean- and stream-type chinook. More recently, stream-type chinook runs reached a high in the late 1980s.

Fluctuations in marine survival make it infeasible to compare year to year adult returns as indicating habitat conditions in fresh water, including those in the migration corridor.

Harvest

Ocean harvest rate amounted to about 0.6% for mid-Columbia spring chinook 1978-1993. Of all ocean commercial and sport recoveries, 85% were in Canada, 6% in Oregon, and 9% in Washington.

In-river harvest has been curtailed greatly since the 1960s, and in recent years has been less than 6% post-1978. Sport fishing in tributaries is closed, except in terminal fisheries like that in Icicle Creek on adults of hatchery origin. Indian fishing occurs in some years in Icicle Creek. Some, or considerable, loss of pre-smolts occurs in trout fisheries, varying with severity of handling.

Upstream movement of adults

In the ten years 1985-1994, peak spring chinook movement occurred at Rock Island Dam in the week ending May 12, about two weeks earlier than during the period before most mainstem dam construction.

Adult movement rates decline with increased river flow, and delay at dams generally increases with increased spill. Radio-tracking indicates modest amounts of fallback through or over dams after fish pass over fishways. We discuss straying in mid-Columbia tributaries, noting recoveries of tags from other streams. Interdam loss rates in spring chinook appear to lie between 2% and 6%.

Causes of decline

The mid-Columbia tributaries formerly produced substantially more spring chinook as adults returning to the Columbia River before extensive main-stem dam construction and development of upstream storage. We estimate a productivity reduction of at least 43% from the 1950s to the 1980s. The current ratio of recruits/spawner (R/S ratio) leaves much less room for harvest, on average, than was the case in the 1950s.

Marine mammal predation on mid-Columbia spring chinook likely is similar to that for Snake River spring chinook, although no data are available for the former stocks. The latter bear a high incidence of wounding and scarring from harbor seals. Total loss is unknown for mid-Columbia spring chinook.

We found no evidence to indicate that interspecific competition from exotic or indigenous fish species reduces productivity of spring chinook in the mid-Columbia region.

Pathogens certainly kill spring chinook. There is no reason to believe that they are responsible for run declines in wild spring chinook.

Gas bubble trauma can stress or kill spring chinook adults and juveniles. Expert teams have recommended a total dissolved gas cap of 110% saturation. Some evidence suggests that chinook may suffer no mortality if gas remains below a mean of 115% saturation.

Mitigation options

Streamflow augmentation in the Methow River may offer possible habitat enhancement. Large woody debris placement may improve rearing conditions for spring chinook juveniles in some locations, e.g., the Chewack River.

Our modeling indicates that only modest gains are possible with installation of conventional turbine intake screens and bypasses. It suggests substantial improvements in survival if fish are transported from mid-Columbia projects to a point downstream from Bonneville Dam. Spill, constrained by a total dissolved gas cap, offers a fish routing that we believe to be benign. Our modeling does not indicate that flow augmentation offers substantial improvements in survival in the mid-Columbia.

Predator control may produce worthwhile gains in smolt survival. Very large predator populations exist downstream from most or all Columbia River dams. Bypass outfalls, if they are installed, must be designed to foil predators.

Surface vertical slot bypasses or collectors, based on the system at Wells Dam, which has had a high fish passage efficiency, appear to have merit. Application of the concept to other mid-Columbia dams requires prototype testing.

Hatchery operations should aim at producing a smolt with high readiness to migrate. This may require light and temperature manipulation and, perhaps, later release timing. The latter would appear most appropriate if transportation from mid-Columbia dams is employed to speed arrival in the estuary and avoid lower Columbia River projects.

Research needs

1. Instream flow needs of spring chinook juveniles and adults require study,

especially in the Methow River basin.

2. Study of groundwater hydrology and interactions between ground water and irrigation in the Methow basin.

3. Inventory of water rights available, especially in the Methow basin, under a willing-seller, willing-buyer format.

4. List priority areas for instream flow augmentation, if such augmentation is found to be needed.

5. Geomorphology, hydraulics, and gradient of the Chewack River may permit use of large woody debris addition to provide habitat for juvenile chinook. That possibility should be examined for physical feasibility.

6. Upon establishment of feasibility in #5, pilot study should evaluate efficacy of providing large woody debris in the Chewack River for habitat enhancement.

7. Supplement evaluations of genetic makeup of wild spring chinook populations. These would help decision-makers determine how to lump or split the ESUs upstream from Rock Island Dam.

8. Study reach-specific survival with PIT tags, obtaining data crucial to best management of the hydropower system to protect migrating spring chinook. Those studies will require placement of a PIT tag detection system at John Day Dam, in combination with a diverter at McNary Dam.

9. Investigate vertical slot surface collectors.

10. Research on predator behavior is needed in the region. Information from those studies will help delineate means of delivering smolts to tailrace areas that will thwart predators.

9. Transportation deserves expanded study in the region. The studies conducted at Priest Rapids Dam in the period 1984-1986 were flawed in several ways, and cannot be relied upon as managers decide how best to mitigate for dam-related mortality.

10. Hatchery evaluation studies now underway in connection with fish culture programs of Chelan and Douglas PUDs should be continued to fruition.

11. Mid-Columbia enhancement programs should be evaluated as part of the seamless fabric of ocean ecology. Agency and PUD personnel must come to grips with the broad ecological problems of ocean carrying capacity, interspecific interactions, global temperature changes, and ocean fishing on mixed stocks.

Figure legends

Figure 1. Locations of probable spring chinook spawning areas and hatcheries in the Wenatchee and Entiat rivers.

Figure 2. Locations of probable spring chinook spawning areas in the Methow River and Winthrop National Fish Hatchery. Note spelling "Chewuch" in figure is revisionist (our report uses Chewack). Absence of index areas (see Figure 4) downstream from Twisp River suggests little spring chinook spawning in mainstem Methow downstream from Twisp.

Figure 3. Distribution of radio-tagged spring, summer, and fall chinook upstream from Priest Rapids Dam, 1993, from Stuehrenberg et al. (1994).

Figure 4. Spring chinook spawning index reaches in the upper Methow River basin. Note that our text uses long-accepted "Chewack" River spelling.

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Figure 6. Estimated escapement and number of redds observed in the Wenatchee River, 1958-1994, from Peven and Truscott (1995).

Figure 7. Spring chinook redd counts in the four principal tributaries of the Wenatchee River, 1958-1994 (Note: Between 1958 and 1986, surveys were one-time walks of index areas), from Peven and Truscott (1995).

Figure 8. Summary of redd counts upstream from Wells Dam for spring chinook, 1954-1993, from Peven (1992), Scribner et al. (1993), and J. Hubble, YIN, personal communication.

Figure 9. Upriver spring chinook adults harvested, and harvest rate, from WDFW/ODFW (1994).

Figure 10. Relative percentages of stock group contributions to the winter gill net fishery for spring chinook in the Columbia River, 1987-1992, from Miller et al. (1993).

Table titles

Appendices

Appendix 1. Releases of spring chinook in the Wenatchee River basin. Data obtained from Leavenworth NFH, Mullan (1987) and B. Kelly, USFWS, personal communication.

Appendix 2. Releases of spring chinook in the Entiat River basin. Data obtained from Leavenworth NFH, Entiat NFH, Mullan (1987) and B. Kelly, USFWS, personal communication.

Appendix 3. Releases of spring chinook in the Methow River basin. Data obtained from Leavenworth NFH, Winthrop NFH, Mullan (1987) and B. Kelly, USFWS, personal communication.

Appendix 4. Releases of spring chinook into the mainstem Columbia River. Data obtained from Leavenworth NFH, Entiat NFH, Winthrop NFH, Mullan (1987) and B. Kelly, USFWS, personal communication.

Appendix 5. Releases of spring chinook from WDFW supplementation hatcheries. Data obtained from Chelan and Douglas PUD, unpublished data.

Appendix 6. Draft evaluation plan for the Rock Island Hatchery-based Compensation Program, June 1, 1992, from Chelan PUD.

Appendix 7. Methow Basin Spring Chinook Salmon Supplementation Plan. Excerpts from draft of Erho and Bugert Feb. 27, 1995.

Appendix 8. Allele frequencies in populations of Table 19 (this report). Blank spaces for an allele/population indicate no data.

Appendix 9. Estimated travel time for Winthrop, Leavenworth, and Entiat spring chinook releases that were later detected at McNary Dam.

Appendix 10. Estimated travel time for freeze-branded groups from hatchery production releases, 1984-1993, as reported in FPC annual reports.

Appendix 11. Graphs of smolt travel time evaluated against release date (Julian), flow (kcfs), fish length (mm), and temperature (F), for years 1989-1994, from annual reports of the Fish Passage Center.

Appendix 12. Columbia River Salmon Passage Model 1.5, (CRiSP1.5), survival estimates for Winthrop Hatchery spring chinook from release to Priest Rapids Dam and Bonneville Dam tailraces, 1983-1990.

GLOSSARY OF ABBREVIATIONS

ALPI = Aleutian Low Pressure Index
BDA = Bonneville Dam
BF = Furunculosis
BKD = Bacterial kidney disease
BOF = U.S. Bureau of Fisheries (in early to mid 1900s)
CHWA = Chiwawa River
CHEWK = Chewack River
CI = Confidence interval
CRiSP = Columbia River Salmon Passage (model)
CRITFC = Columbia River Intertribal Fish Commission
C&S = Ceremonial and subsistence
CS = *Ceratomyxa shasta*
CWT = Coded wire tag
DCC = Don Chapman Consultants, Inc.
DOE = Washington Department of Ecology
EPA = U.S. Environmental Protection Agency
ERM = *Yersinia ruckeri*
ESU = Evolutionarily significant unit
FGE = fish guidance efficiency, the percentage of fish that enter turbine intakes and are diverted upward into gatewells
FPC = Fish Passage Center
GBT = Gas bubble trauma
GCFMP = Grand Coulee Fish Maintenance Project
IDFG = Idaho Department of Fish and Game
IHN = Infectious hematopoietic necrosis virus
LWEN = Little Wenatchee River
MBSCSP = Methow Basin Spring Chinook Salmon Supplementation Plan
MFHC = Methow Fish Hatchery Complex
MET = Methow River
NASN = Nason Creek
NBS = National Biological Survey
NFH = National Fish Hatchery (U.S. Fish and Wildlife Service)
NMFS = National Marine Fisheries Service
ODFW = Oregon Department of Fish and Wildlife
PSFMC = Pacific States Marine Fisheries Commission
PFMC = Pacific Fishery Management Council

PH = Power house

PIT = Passive integrated transponder

PUD = Public Utility District

RIFHC = Rock Island Fish Hatchery Complex

SOR = System Operation Review

TAC = Technical Advisory Committee in U.S. v. Oregon proceeding

TBR = Transport benefit ratio

TDG = Total dissolved gas

TU = Temperature unit (one degree for one day, expressed as Celsius or Fahrenheit)

TWSP = Twisp River

USACE = U.S. Army Corps of Engineers

USFWS = U.S. Fish and Wildlife Service

WDF = Washington Department of Fisheries, now Washington Department of Fish and Wildlife

WDFG = Washington Department of Fish and Game (in early 1900s)

WDFW = Washington Department of Fish and Wildlife

WDW = Washington Department of Wildlife, now Washington Department of Fish and Wildlife

WHT = White River

YIN = Yakima Indian Nation

Acknowledgments

We thank Chelan, Douglas, and Grant public utility districts for their support of this endeavor.

Inez Hopkins, library specialist for Don Chapman Consultants, Inc., provided invaluable assistance in securing documents, collating citations, and with her enthusiasm. John Stevenson, A. Abbott, and M. Miller assisted with editing the document.

D. Pederson and J. Fryer, of the Columbia River Intertribal Fish Commission, provided age estimates of juveniles and adults, supplemental to published information. We thank J. Hubble, of the Yakima Indian Nation, for various data from the Methow, Wenatchee, and Yakima rivers, H. Bartlett, of the Washington Department of Fish and Wildlife, for data on Methow River chinook salmon, and K. Petersen, N. Eltrich, and L. LaVoy for data on Wenatchee River chinook.

We also thank B. Edwards, D. Davies, B. Walien, and B. Kelly, U.S. Fish and Wildlife Service, for information on the national fish hatcheries, and B. Sullivan, for information on the accelerated smolt program.

A. Abbott helped compile and check hatchery release data, and spent long hours compiling information on temporal changes in mean lengths of adult chinook. S. McCutcheon, of Biomark, Inc., extracted certain PIT-tag data from databases.

N. Mikkelsen and M. Miller compiled literature and created many tables and figures.

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STATUS OF SPRING CHINOOK SALMON IN THE MID-COLUMBIA REGION

INTRODUCTION

This report summarizes information on the biology of spring chinook salmon (*Oncorhynchus tshawytscha*) in the mid-Columbia region.[1] We prepared it at the request of the three mid-Columbia public utility districts (Chelan, Douglas, and Grant County PUDs). We attempt to integrate the array of information, with special reference to the migration corridor. We also emphasize importance of ocean production dynamics. We suggest research efforts in several areas.

We begin with a description of spring chinook and their distribution and abundance in the mid-Columbia region.

DISTRIBUTION AND ABUNDANCE

Spawning populations of spring chinook

Chinook salmon have two main life histories (Healey 1991). One form,

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[1] "Mid-Columbia" in our report means the region from the lower end of the Hanford Reach upstream to Chief Joseph Dam, and tributaries, excluding the Yakima River.

designated stream-type by Gilbert (1913), is typical of northern populations and headwater tributaries of more southern populations. Stream-type chinook spend usually one year (sometimes more) in freshwater as fry or parr before entry into the ocean, they migrate extensively at sea, and return to the natal stream in the spring or summer, several months prior to spawning (Healey 1991). Occasionally, males mature in freshwater without ever migrating to the sea (Robertson 1957; Burck 1965; Mullan et al. 1992a). The second behavioral form is known as ocean-type ("sea type," Gilbert 1913). This life history is common among North American populations south of 56° N (Healey 1991). Ocean type chinook generally migrate to the ocean in their first year of life, spend most of their ocean lives in coastal waters (although they may make extensive migrations), and return to their natal rivers in late summer or early fall (Healey 1991).

In the Columbia River, chinook have been identified as "spring", "summer", or "fall" run fish based on their entry into the river from the ocean (Burner 1951; French and Wahle 1965). This arbitrary division into three segments is biologically incorrect. Thompson (1951) showed that the historical (before Caucasian interference) chinook run entering the Columbia River was a bell-shaped curve from February to November, peaking between June 10-20, and tapering off to tails before and after this time. Early harvest of the most productive segment of the run (those entering in the early summer period) left the spring and fall components as artifacts of overfishing (Beiningen 1976).

Different temperature regimes in natal areas cause the various in run timings that regulate incubation and emergence of fry (Miller and Brannon 1982). In the mid-Columbia region, spring (early-run) salmon spawn in the cooler headwater tributaries from July to mid-September. The later components of the chinook run (summer/fall) spawn in warmer downstream areas in the mainstems of the major tributaries and the mainstem of the Columbia River (Meekin 1963; French and Wahle 1965; Chapman et al. 1982). In essence, a time-window exists for egg deposition in a specific site as water temperatures decrease from upstream to downstream each fall. This time-space dimension was originally filled by successive waves of chinook salmon spawners.

For the above reasons the summer/fall components of the chinook run in the mid-Columbia basin can be referred to as ocean-type[2] and the spring component of the run as stream-type. The National Marine Fisheries Service (NMFS) recognized these distinctions in their grouping of the spring and summer components of the chinook run that enters the Snake River basin under the ESA listings of 1992, where the spring and summer components are stream-type and the fall component is ocean-type.

Matthews and Waples (1991), after review of the relationships of the different runs of chinook in the Snake and upper Columbia[3] rivers state:

> *Life history information thus clearly indicates a strong affinity between summer- and fall-run fish in the upper Columbia, and between spring- and summer-run fish in the Snake River. Genetic data support the hypothesis that these affinities correspond to ancestral relationships.*

So, based on life history patterns, spring chinook in the mid-Columbia basin and spring/summer chinook from the Snake basin are similar. Throughout this report, we refer to the stream-type chinook in the mid-Columbia region as "spring" chinook.

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[2] However, some evidence exists that some summer/fall chinook of the mid-Columbia region can have stream-type scale patterns (Chapman et al. 1994a). It appears that these fish rear in the mainstem Columbia River, not in natal tributaries.

[3] Matthews and Waples (1991) define the lower, mid-, and upper Columbia River as areas of the river below Bonneville Dam (Bonneville Dam), between Bonneville Dam and the confluence of the Snake River, and above the confluence of the Snake River, respectively. In the text of our report, we use *mid-Columbia* in referring to the Columbia River and tributaries upstream from the mouth of the Yakima River.

Spring chinook distribution

Fulton (1968) gives the characteristics of spring chinook spawning streams as *Smaller tributaries and upper reaches of principal tributaries*. He relied heavily on the field work of French and Wahle (1965) for his information on distribution. He combines descriptions of spring and summer chinook distributions in the Wenatchee River basin (Figure 1) as: *Most of main river; portions of Chiwawa, Little Wenatchee, and White rivers; and Nason, Icicle, and Peshastin creeks.* The main river, habitat for summer/fall chinook, is used by spring chinook as a migration corridor and by juveniles (presmolts) for overwintering (Hillman et al. 1989a; 1989b). However, spring chinook spawn and rear in the upper main Wenatchee River upstream from the mouth of the Chiwawa River, overlapping with summer chinook in that area (Peven 1994) (Figure 1). In the Wenatchee River, the primary spawning grounds of spring chinook, in order of importance, are: Chiwawa River, Nason Creek, Little Wenatchee, and White River (Figure 1; Icicle River is not included because it is believed that most of the spawning population from this stream consist of adult returns to the Leavenworth NFH (Peven 1994)).

Fulton (1968) includes *Most of the main* (Entiat) *river* (Figure 1) as habitat for spring and summer chinook, noting that steep gradients of tributaries prevent salmon use. Chapman et al. (1994a) discounted use of the Entiat River by summer/fall chinook.

Chinook use of the Methow River basin (Figure 2) is shown by Fulton (1968) as *Main stream* (Methow) *and large tributaries....Lower portion of main stream* (Twisp River) .... *Main stream* (Chewack River) *to 52 km. above the mouth.* Fulton mentions that the Chewack River has the largest spring chinook run of any single stream above Rocky Reach Dam. Kohn (1988) shows redd locations for spring chinook in the Methow River basin. He notes heavy use of the Twisp River, Chewack, upper Methow River upstream from Wolf Creek, and modest use of Lost River and Early Winters Creek. The primary spawning grounds are, in order of importance: the mainstem Methow, Twisp, Chewack, and Lost rivers (Scribner et al. 1993).

Spawning occurs from late July through September, usually peaking in mid- to late August. Distribution of redds in the Methow and Wenatchee basins in the 1990s has changed little since the 1950s (French and Wahle 1965; Scribner et al. 1993; Peven 1994).

Fulton (1968) reports no use of Okanogan River tributaries by spring chinook. However, Craig and Suomela (1941) contains affidavits that indicate use of Salmon Creek by chinook salmon. Based on the time at which these fish were observed, they were spring chinook. In 1936, spring chinook were observed in the Okanogan River upstream from Lake Osoyoos by Canadian biologists (Gartrell 1936).[4] That observation for May estimated 100-300 adults present "on the spawning grounds." We know of no other years when use of the Okanogan River by spring chinook was noted. WDW (1989) states: *Natural spring chinook production in the Okanogan and Similkameen subbasins is currently not feasible due to extensive habitat alterations in the accessible reaches.* Failure of inclined-plane traps to capture spring chinook smolts during trapping of sockeye smolts in the lower Okanogan River (McGee and Truscott 1982; McGee et al. 1983) empirically supports that judgment. Bryant and Parkhurst (1950) and Fulton (1970) claim spring chinook used Omak Creek, although the affidavits in Craig and Suomela (1941) do not mention such use. Weitkamp and Neuner (1981) captured a handful of chinook juveniles in a floating trap in the Okanogan River in 1981 that were large enough to be spring chinook. The trap was downstream from the confluence of Salmon Creek, and could have resulted from spring chinook that spawned in Salmon Creek. None was captured in 1982-1983.

It has been suggested that spring chinook formerly used the Similkameen River upstream from falls that lay at the present site of Enloe Dam. Chapman et

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[4] Gartrell (1936) contains the only reference that we found to spawning by spring-run salmon in the main Okanogan River. We regard this information cautiously.

al. (1994a) found no evidence that such use occurred. The underlying source for Fulton's (1968) inclusion of the Similkameen River upstream from the site of Enloe Dam as anadromous salmon habitat was WDF (1938). Perusal of that source does not support the Fulton observation. WDF (1938) describes existence of potential spawning habitat in the area upstream from Enloe Dam, but provides no documentation of historical use of the area by salmon or steelhead (*O. mykiss*). Cox and Russell (1942) state:

> *From testimony of a Mr. McGrath at Nighthawk, who had been in that country over 40 years, we learned that before any power dam was built* (Enloe Dam)*, the 15' to 20' natural falls already mentioned prevented salmon ascending any farther. He had often fished the river at Nighthawk but had never heard of a salmon being seen or caught above the natural falls. He stated that the Indians came in to fish at these falls each summer.....Therefore, we conclude that this power dam did not interfere with any salmon runs....*

Stuehrenberg et al. (1994) tracked radio-tagged spring and summer/fall chinook to destinations in mid-Columbia tributaries. Of the fish that passed Priest Rapids Dam (PRD), over 85% were last detected in tributaries (Figure 3). Among spring chinook, about 58% went to the Wenatchee River, about 9% to the Entiat River, 17% to the Methow, and 2% to the Okanogan River.[5] An additional 10% were last tracked in the main Columbia River, with tributary destination unknown.

A total of 742 spring chinook were radio-tagged and released. Average flows during the spring migration were 124 kcfs, and water was spilled at mid-Columbia dams to assist smolt migrations. Stuehrenberg et al. (1994) found no

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[5] This finding would appear to conflict with other data that indicate no use of the Okanogan River by spring chinook. However, radio-tagged fish tracked by Stuehrenberg et al. (1994) were classed as spring or summer chinook on the basis of arbitrary cutoff dates for run timing at John Day Dam. Cutoff dates do not completely define groups. Inevitably, some fish classed as spring chinook would be summer/fall fish.

distinct separation in timing of different stocks of spring chinook destined for the Wenatchee, Entiat, Methow, and Okanogan rivers (the fish tagged as spring chinook that entered the latter river (n = 7 tributary arrivals) may have been part of the overlapping, early-arriving summer/fall chinook).

Spring chinook preferred the left-bank fish ladder at Priest Rapids and Wanapum dams (93.9% and 96.7%, respectively), but the right-bank ladder at Rock Island Dam (74.6%) and Rocky Reach Dam (100%). They used left- and right-bank ladders equally at Wells Dam (Stuehrenberg et al. 1994). Most tagged fish arrived at dams in daytime and most movements in and out of ladders occurred in daytime.

Meekin (1993) and Scribner et al. (1993) tabulated distribution of spring chinook redds in the Methow River basin 1987-1993 (Table 1). About half of the redds were usually counted in the index areas (Figure 4) used to establish trends in spawner abundance. From 13-22% of the redds lay upstream from the upper index area boundaries, and 34-55% lay downstream from the lower boundaries. Presence of a weir for broodstock collection in the Twisp River may have caused more spawning than usual downstream from the weir in 1992 (Meekin 1993) and perhaps in 1993 (Scribner et al. 1993).

The upper Methow, Chewack,[6] and Twisp rivers accounted for a mean of 37.5%, 26.3%, and 26.0% of the redds counted in the Methow River basin 1987-1993. The remaining redds lay in the Lost River (8.4%), Early Winters Creek (1.2%, Gold Creek (0.3%), and Lake Creek (0.4%) (Scribner et al. 1993).

Spring chinook abundance

The numbers of spring chinook that entered the Columbia River averaged less than 102,000 in the first eight years after Bonneville Dam (1938) made it possible to estimate escapements at that point (Figure 5). Only after the mid-1970s did numbers again reach such low abundance.

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[6] Revisionist spelling "Chewuch."

In the mid-Columbia region, spring chinook counting at Rock Island Dam began in 1935. Numbers in the period 1935-38 were less than 3,000 fish (Figure 5). Counts rose somewhat erratically to a high point of about 27,000 in the mid-1980s, a period of high ocean productivity, then declined for six years. Escapements in 1992 and 1993 were larger, then dropped sharply in 1994. Hatchery inputs have occurred since the onset of the Grand Coulee Fish Maintenance Project (GCFMP) in 1939. As we note elsewhere, the 1994 adult run was very poor, and the run predicted for 1995 is even smaller, apparently the result of low ocean survival.

In the Wenatchee River, estimated escapement and redds have fluctuated widely since 1958, the earliest date for which systematic data were available (Figure 6). The escapement trend was upward from 1958 to the present, in spite of the poor run of 1994. The estimated abundance of spring chinook redds varied, fluctuating widely about a mean of about 500 redds. When we examine redd counts in individual tributaries (Chiwawa, Little Wenatchee, and White rivers, and Nason Creek), the fluctuations in counts appear of even greater amplitude (Figure 7). Nonetheless, we see no evidence of long-term declines in estimated redd abundance 1958-1994. For spring chinook spawning areas upstream from Wells Dam, redd counts also fluctuated widely 1954-1994, but without evidencing long-term declines in numbers (Figure 8).

It is important to remember that the long-term relative stability in mid-Columbia spring chinook has been supported by drastic reductions in harvest of upriver spring chinook in zones 1-6. The harvest rate in zones 1-6, which had ranged from 40-85% before the 1960s (Figure 9), trended downward until 1974, and thereafter averaged less than 10%. Numerical harvest, which peaked, in the post-Bonneville Dam era, in the 1950s, also trended downward to 1974, and thereafter remained at negligible numbers (Figure 9).

In the period 1987-1992, the winter gill net fishery, the only surviving non-Indian inriver harvest directed at spring chinook, consisted mostly of Willamette River spring chinook (82%), Columbia River spring chinook (mid-Columbia origin)

(11%), and lower Columbia and Snake River spring chinook (each 4%) (Figure 10) (Miller et al. 1993). The 11% contribution by mid-Columbia River spring chinook does not equate to harvest rate. We plotted the trend in contribution of mid-Columbia spring chinook to the winter fishery in Figure 11. Clearly, the rate has declined over the six years examined by Miller et al. (1993).

Both harvest rate and numerical harvest of spring chinook probably peaked in the last 15 years of the 1800s. Numbers of spring chinook in the upriver run in the late 1930s and 1940s were probably depressed by decades of overfishing. Runs increased in the 1950s, partly in response to somewhat reduced harvest rates. Favorable ocean productivity may also have been involved.

Redd-based spring chinook abundance

In the foregoing section, we discuss escapements as estimated from dam counts and by trends in redd abundance. LaVoy (1995) calculated wild spring chinook numbers based on redd counts. He calculated a single count expansion factor based on Wenatchee River surveys by the Yakima Indian Nation (YIN) staff and Chelan PUD in 1987-1988. In those years, the YIN counted redds several times, while Chelan PUD counted redds at the estimated peak of redd abundance in index areas. The multiplier equaled 1.496. Thus, assuming that work in 1987-1988 can be applied to previous years, one would multiply the annual peak-period redd count by about 1.5 to obtain a cumulative season redd total.

LaVoy (1995) believes spring chinook index counts are reliable because surveyors walk or float through the index areas when visibility is good. He considers counting efficiency high for spring chinook redds. He used highest redd counts in the Wenatchee, Entiat, and Methow rivers for years previous to 1987, expanded them for a non-index to index ratio, and by the 1.496 single/cumulative redd count. He also adjusted for a ratio of 2.2 fish per redd, based on LaVoy (1994).

We provide LaVoy's (1995) tables as our tables 2-5. As summarized in our

Table 5, LaVoy (1995) estimated total wild fish from the redd expansion, then adjusted the number for 5% interdam loss (see section in our report on interdam loss rates. The 5% figure appears reasonable, although it may be slightly high). For the period 1975-1994, the redd expansion method for all populations of wild fish, added to estimated numbers of hatchery fish (corrected for sport fishing) yielded numbers of spring chinook that averaged 81.5% of the actual Rock Island Dam count, after a 5% adjustment for interdam loss. We suggest that the loss of 18.5% of spring chinook between dam passage and completion of spawning is not unusual, and can be termed pre-spawning mortality (see report section on pre-spawning mortality). However, several expansion factors and adjustments are involved in the derivation of the final estimate of hatchery and wild spring chinook based on hatchery arrivals and redd numbers. They could lead to either over- or under-estimation of the loss rate.

Management manipulations

Grand Coulee Fish Maintenance Project:

Construction of the Grand Coulee Dam in the Columbia River without fish passage facilities led to fish maintenance programs of the GCFMP that centered around trapping at Rock Island Dam. During the GCFMP, all salmon and steelhead that reached Rock Island Dam were trapped there and mixed. Trapped and transported spring chinook of mixed origins were allowed to spawn naturally in Nason Creek upstream from a rack 0.25 miles upstream from the creek mouth.

We tabulate numbers of spring chinook delivered to Nason Creek in Table 6 . Releases ranged from 3,957 in 1939 to 1,014 in 1942. Of carcasses examined, the percent that had spawned ranged from 37% to 86%. The data in Table 6, together with the count of spring chinook at Rock Island Dam, enable us to calculate the percentage of fish potentially available for artificial culture: 7%, 27%, 22%, 25%, and 84% in the 1939, 1940, 1941, 1942, and 1943 brood years, respectively (Table 7). The Fish and Hanavan (1948) record of fate of spring chinook is incomplete. It does not account for adults counted but neither delivered to Nason Creek nor to hatchery facilities. That number amounts to 241 to 623 fish (mean of 364 adults) in the five-year period 1939-1943 (Table 7).

Trapping at Rock Island Dam extended over five brood years, 1939 through 1943. The last brood to spawn naturally in natal streams was that of 1938.[7] Below we summarize the activities of the GCFMP with respect to spring chinook salmon. The information below was obtained from Fish and Hanavan (1948), and Appendix 1 of our report.

Brood Year **Description**

1938 - normal spawning, juveniles go to sea 1940.

1939 - mixed-stock adult spring chinook released in Nason Creek.

1940 - 306 females artificially spawned. Records of fate of the progeny were combined with records of summer chinook, of which 1,062 females were spawned artificially. About 135,000 parr released to Icicle Creek in October, 1941. About 640,000 parr released to the Entiat River and 182,000 in the Methow River in 1941.

1941 - About 239,400 spring chinook fry of McKenzie River (Oregon) origin, and 444,000 fry from Entiat NFH were released to Icicle Creek (Appendix 1).

1942 - About 30,000 fingerlings, products of adults trapped at Rock Island

[7] Some spring chinook native to Nason Creek could have been among the fish released there upstream from the rack 1939-1943, although their contribution may have been small because spring chinook counts at Tumwater Dam in 1935-37 were very low (Craig and Suomela 1941). In addition, some resident age 2+ male spring chinook in Nason Creek may have contributed to fertilization of eggs of females that spawned in Nason Creek in the 1939, 1940, and 1941 broods.

Dam, released in the Methow River in August. About 118,000 parr released to Icicle Creek in October 1943. Appendix 1 shows 591,000 parr released to the Entiat River in March, 1943. The brood year of these parr is in some doubt.

1943 - About 1 million fry/fingerlings released to Wenatchee River tributaries, 591,000 to the Entiat River, and 654,000 to the Methow River.

1944 - Four females and 11 males entered holding ponds at Winthrop; only two males entered the Leavenworth facility. Just 3,600 fry were released to Methow River (Appendix 1).

1945 - Eighteen females and 77 males spawned at Winthrop; 49,700 fry released in Methow River March 1946, and 549,000 fry released in Methow River in February 1947 (these juveniles probably reared at other mid-Columbia hatcheries, as the egg potential of 18 females would not support a release of that magnitude).

1946 - Of 300 fish that entered Entiat holding pond, 128 were spawned and progeny transferred to Winthrop. Of 487 adults that entered Winthrop pond, 69 were spawned. Fingerlings released totaled 804,000 in February, 1948 to the Wenatchee, 913,000 in February 1948 to the Methow River (Appendix 1).

1947 - Of 459 adults returning to Leavenworth, 414 were spawned. Appendix 1 804,330 fingerlings released to Icicle Creek in the February, 1948. Of 363 adults that entered Winthrop pond, 348 were spawned and 912,889 fingerlings released to Methow River in February, 1948.

Introductions of non-indigenous spring chinook:

In addition to the non-indigenous introductions noted in the preceding subsection on the GCFMP, managers have injected several other exogenous groups of spring chinook. These are described later, in the sections on artificial propagation and genetics.

LIFE HISTORY FEATURES

Adult migration timing

Mainstem Columbia River:

Adult spring chinook destined for areas upstream from Bonneville Dam (upriver runs) enter the Columbia River beginning in March and reach peak abundance (in the lower river) in April and early May (WDF and ODFW 1994). Fifty percent of the spring chinook run passes Priest Rapids and Rock Island dams by mid-May, while most pass Wells Dam somewhat later (Figure 12; Howell et al. 1985; Chelan and Douglas PUD, unpublished data). Chinook that pass Rock Island Dam are considered "spring-run" fish from the beginning of counting (mid-April) through approximately the third week of June (French and Wahle 1965; Mullan 1987).

We assessed the timing of spring chinook passing Rock Island Dam to determine if the current separation timing between spring and summer chinook is appropriate. The Chelan PUD (which manages the counting at the dam) uses June 23 as the cut-off date between spring and summer chinook passing the dam. This cut-off date is based on the average separation date determined by Meekin (1963), which was reconfirmed by Mullan (1987). The Army Corps of Engineers uses June 17 as a cut-off date, which conforms to their estimates of fish passage from dams downstream of Rock Island.

We examined the daily counts of chinook passing Rock Island Dam to determine the nadir in the chinook counts (Figure 13). We found that in 60% of the years examined, the nadir in the counts appeared prior to either the Army Corps of Engineers or PUD cut-off date. In 20% of the years, the nadir was later than the PUD cut-off, while in 15% of the years the nadir appeared between the two cut-off dates. The average date of the nadir in the counts was June 16, suggesting that the Corps of Engineers cut-off date may be more appropriate than the cut-off date used by the PUDs.

We examined what differences may occur when using the nadir in the counts (Table 8). We found that using the Corps of Engineers cut-off date accounted for an error of 0.48%, while using the PUD cut-off date incorrectly separated the two races 5.5% of the time.

While in years past the June 23 separation date at Rock Island appeared appropriate (Meekin 1963; French and Wahle 1965; Mullan 1987), the run timing in recent years leads us to suggest that an earlier separation date may be more appropriate (see section on adult upstream migration) to represent the categorization of stream- and ocean-type chinook that ascend Rock Island Dam. We suggest that run timing separation dates be standardized among all agencies, with the Corps of Engineers separation date being more appropriate (based on the nadir).

Tributaries:

Spring chinook enter the mainstem portions of tributaries from late April through July, and hold in deeper pools and under cover until onset of spawning. They may spawn near holding areas or move upstream into smaller tributaries. Spawning occurs from late July through September, usually peaking in mid- to late August (Figure 14).

Age structure

Juveniles:

Juvenile spring chinook generally spend one year in fresh water before they enter the sea (Mullan 1987; Healey 1991). French and Wahle (1959) sampled downstream migrating chinook captured at Tumwater Dam in 1955. Of the fish sampled in April and May, two size groups were sampled. Twenty-one percent (n=3,318) were categorized as fry (some may have been summer chinook that spawned upstream from the sampling site). French and Wahle (1959) read scales from 79 juveniles that were of the larger size group. Seventy-eight of the scales indicated the fish were in their second year of life (1.)[8], while the remaining one was in the third year of life (2.). Healey (1991) reports that some populations in more northern rivers produce smolts that spend an additional year in fresh water, but the vast majority of stream-type chinook spend no more than one winter in fresh water before they enter the sea.

Fryer et al. (1992) summarized age information of spring chinook sampled at Bonneville Dam from 1987 through 1991. They found no adult scales with two stream annuli (2.x), although in every year there were some fish estimated to have entered the ocean in their first year of life (0.x; probably from the Snake River basin). Adults sampled in the mid-Columbia tributaries have shown no 0.x or 2.x life histories (Figure 15).

Adults:

Most Columbia River adult spring chinook spend two years in the ocean before migrating back to their natal streams (Mullan 1987; Fryer et al. 1992).

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[8] For age estimations, we use the "European Method" for describing age, where two digits are used, separated by a period. The first digit represents the number of winters the fish has spent in freshwater, and the second digit the number of winters in saltwater. We also use the total age (e.g., a fish designated as 1.2 is four-years-old).

Adults sampled from mid-Columbia tributaries predominantly spend two years in the ocean, and are four years old (1.2) (Table 9; Figure 15). Both females and males are predominantly four years old. The estimates of age of adult spring chinook sampled in the mid-Columbia comport well with those for fish sampled at Bonneville Dam and other Columbia basin tributaries (Figure 16). These data suggest that over 50% of spring chinook in the Columbia River basin spend one year in fresh water and two in salt water. About 20-40% spend an extra year in saltwater before returning to the river. Most stream-type chinook throughout their geographic range average approximately four years of age, except those from the Yukon River, Alaska (Figure 17).

The comparison of age composition within the Columbia Basin in Figure 16 suggests that populations that travel farther upstream have a higher percentage of older fish in the sample. While Figure 17 shows a weak latitudinal cline for age, Figure 16 suggests an elevational one within the Columbia Basin (also see section on fecundity).

As previously mentioned, individuals that never migrated to the sea make up some portion of the spawning population (Healey 1991; Mullan et al. 1992a). The state of sexual maturation of male chinook is considered precocious when it occurs any time before normal maturation in the ocean (Mullan et al. 1992b). Thus, we consider male chinook to be precocious if they mature at the end of their first or second summer, regardless if they lived their second summer in fresh or salt water. Mullan et al. (1992b) indicate that precocious maturation of male spring chinook is common in the mid-Columbia basin and is characteristic of both hatchery and wild stocks. Generally the largest males show evidence of early maturity (Rich 1920). This may be why large numbers of hatchery fish mature precociously.

The proportion of males that mature precociously is mostly unknown. Mullan et al. (1992) examined 20,000 wild juvenile chinook in tributaries of the mid-Columbia River during 1983-1988 and found that precocious males made up about 1% of the sample. Examination of 3,443 juveniles from the Lemhi River, Idaho, showed that precocious development existed in 2.6% of the sample (Gebhards 1960). Burck (1993) believes that precocious males in Lookingglass Creek, a Grande Ronde tributary in Oregon, *...could amount to several percent of the total production of juveniles for a brood year.* His trap catch peaked in the last week of August or the first week of September, and amounted to 158 to 575 fish in the years 1964-1968. We do not know what fraction of the male population consisted of precocious males in the above studies. Actual percentages of precocious males in the male populations would be considerably higher, as the samples in their studies consisted of both juvenile males and females. In the McCloud River, California, Rich (1920) found that precocious males constituted 10-12% of the male population. These studies consider only males that mature in freshwater. If we include jacks (age-2 males that return after 1 year in the ocean), the percentage of males that mature precociously would be much greater than 10%.

Precocious males tend to have a higher mortality rate than non-maturing juveniles. For example, Mullan et al. (1992b) found that precocious males made up a greater percentage of the fish that died at the Leavenworth National Fish Hatchery. This may be one reason why females consistently outnumber males about 3:2 in adult returns to the mid-Columbia Basin, even though sex ratios of juveniles favor males. Precocious males also tend to be less nomadic than other juveniles. In Icicle Creek, Mullan et al. (1992b) report that males generally remained in the test area, while females migrated. They also suggest that precocious males were quite numerous in the test area.

The extent that precocious males contribute to reproduction is unknown. In the mid-Columbia Basin, males that mature in freshwater during their first or second summer may contribute to reproduction, and may contribute more than jacks under certain conditions. For example, Leman (1968) and Mullan et al. (1992b) observed only precocious males attending large female chinook in small headwater streams that were accessible only at high water. In Marsh Creek and Elk Creek, Idaho, precocious males occurred most frequently where there was active spawning (Gebhards 1960). These fish usually lay within the depression of the redd with an adult female, or male and female pair. Gebhards (1960) reports seeing between 4 and 30 precocious males within redds. Apparently these fish frequent spawning areas to reproduce, not to forage on eggs. Gebhards (1960) analyzed the stomach contents of several precocious males and found that only 5% had consumed eggs. Furthermore, most (85.1%) of the dead precocious males that he found were partly or completely spent.

It is unknown if precocious males die after maturing in freshwater. Mullan et al. (1992) suggest that most precocial age 0. males survive whereas most precocial 1. males die. Robertson (1957) found that 56 of 60 age-0 precocious parr lived for five months in a hatchery and had renewed spermatogenesis. Gebhards (1960) concluded, from indirect evidence, that most age-0 precocious males survived, while yearling precocious males died. Rich (1920) also claims that some precocious males recover, but Burck (1967) found that, of 259 yearling precocious males that he held in a downstream migrant trap, all died. This could have been because of poor holding conditions. Unlike precocious males that mature in freshwater, jacks die after maturation.

Although jacks are less common among spring chinook (<13%) than among summer/fall chinook (>35%) in the mid-Columbia basin (Mullan 1987), they probably contribute to reproduction in the basin. Reproduction of jacks has been considered inferior to the larger, older males, but Gross (1984) indicates that jacks successfully reproduce and that their strategy appears to be evolutionarily stable. Thus, jacks have the potential for obtaining equal reproductive success. Unlike larger, older males that win proximity to females through fighting with competitors, jacks reproduce successfully by sneaking (Gross 1991). Because of their cryptic coloration and small body size, the sneaking tactic offers jacks a successful alternative for fertilizing eggs. This tactic works well if debris or shallow areas are available as refuges. If these refuges are limited or occupied by other precocious males, than jacks must compete with older males for proximity to females. Having a small body size, jacks are not suited for fighting with older males, and are usually forced to the far end of the hierarchy from where fertilization success will be very low (Gross 1991). Under these conditions, small males that mature precociously in freshwater may have a reproductive advantage over jacks because they can hide in refuges close to females that are too small for jacks.

The mechanism that dictates the life history tactic of chinook is not well understood (Gross 1991). The tactic, probably determined in the fry stage, is apparently related to body size, since larger, faster growing juveniles tend to mature precociously and smaller, slower growing males mature at an older age. Juvenile size is determined by many variables, such as genotype, egg size, time of hatching, water flow, water temperature, territory quality, stream productivity, predation pressure, and population density. Changes in these variables may therefore affect the life-history of chinook. In addition, hatcheries can increase the number of precocious males by accelerating the growth rates of chinook (Mullan et al. 1992b). Lastly, selective harvest of larger chinook can increase the occurrence of precocious males. This can have two effects (Gross 1991): (1) a decline of larger, older males on the breeding grounds (frees jacks to employ either fighting or sneaking tactics), and (2) selective harvest of large chinook provides an immediate increase in the probability that jacks, relative to larger males, survive to breed. Thus, selective removal of individuals that adopt the late-maturing life-history tactic should result in an evolutionary response toward more jacks (Ricker 1981; Gross 1991).

We believe that precocious males may play a significant role in reproduction in the mid-Columbia Basin, spawning successfully not only as "sneakers" in the presence of older males, but as the sole male present in some areas and in some years when spawner numbers are very low. They probably play a greater role in spawning in years like 1994, when numbers of spawners are so low that adult females are widely dispersed.

Length at age

Juveniles:

Fish and Hanavan (1948) sampled juvenile chinook emigrating from the "upper" and "lower" Wenatchee River during 1940 and 1941. The only yearlings they found were in the samples collected in May and June in the "lower" river. The yearlings sampled in May and June (June yearlings were grouped in the May samples) averaged 127 mm (assumed fork length). Yearlings sampled at Tumwater Dam in 1955 by French and Wahle (1959) averaged 95 mm in April and May (Figure 18; note no sampling in June because of high water). Petersen (WDFW, personal communication) measured yearling spring chinook that emigrated from the Chiwawa River in 1994 and found average size increased from 87 to 98 mm between March and June (Figure 19). Hubble (YIN, personal communication), found juvenile chinook averaging 100 and 101 mm in April and May, respectively, in the Chewack River in 1993 (Figure 20).

In the 1950s, Edson (1958) found that juvenile chinook salmon collected in the water cooling screens at Rock Island Dam averaged between 90 and 110 mm in April and May (Figure 21). In the 1970s, yearling juvenile chinook sampled in April and May averaged 120 mm (Figure 22)[9]. There appears to be some discrepancy between the size of juveniles sampled from the water cooling screens from the 1950s and the 1970s (Figure 21), but this may be due to sample error (more units were sampled in 1956, 1957 than during the 1970s), to an increased proportion of hatchery smolts released at relatively large size, or possibly differences in run timing that may have developed (see Downstream Migration section). In April and May, 1993, yearling chinook collected at the second

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[9] Juvenile chinook in the 30-40 mm range are probably from late-run chinook that spawned in the mainstem of the Columbia River upstream from Rock Island Dam (Edson 1958; French and Wahle 1965).

powerhouse bypass trap (for both naturally- and hatchery-produced individuals)[10] averaged 138 mm FL.

Subyearlings measured by Fish and Hanavan (1948) had average lengths that ranged from 37 mm (April 1941 - upper Wenatchee) to 137 mm (November 1940 - lower Wenatchee). French and Wahle (1959) found subyearling average lengths that ranged between 41 mm in April and 79 mm in October (Figure 18). Petersen collected too few subyearlings in the early spring to obtain average lengths, but some fish ranged in the 30-40 mm length class in March and May (Figure 19). Beginning in June, subyearlings began showing up in larger numbers , and lengths averaged 54 mm in 1994 (Figure 19). By October, 1994, subyearlings averaged 88 mm. These fish lengths were somewhat longer than those measured by French and Wahle at Tumwater Dam in 1955 (Figure 18), but comport well with lengths measured in the fall from the Chewack River (Figure 20). Causes of the observed differences in length between years and streams could include: 1) year-to-year variation in size, 2) samples including fish from other tributaries that may have growth rates different from those of juveniles from the Chiwawa River, or, 3) fish were growing before their capture at Tumwater Dam.

Lengths of juveniles measured in the Chiwawa River comport well with lengths of juvenile chinook measured in the Chewack River in 1993 (Figure 20), and the Naches River (Yakima basin) in 1985 (Figure 23), and in Lookingglass Creek in Oregon (Burck 1993). In all four drainages, larger migrants were observed in the spring, then smaller migrants were observed from July through the fall. In general, juvenile spring chinook sampled in the Naches River appeared larger for a given month than juveniles sampled in the Chiwawa or Chewack rivers (with exceptions noted for September on the Chiwawa and April and May on the Chewack; Figures 19-21). This difference in average length might be explained by year-to-year variation of the samples, or differences in food productivity in the

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[10] The length data were obtained from PIT-tag files (D. Marvin, Fish Passage Center, personal communication), and were designated as "unknown" for origin. Most of these fish are probably of hatchery origin.

different systems, or the fact that the Naches site is farther downstream from the spawning areas than the Chiwawa or Chewack river sampling sites, giving the migrants more opportunity to feed and grow before being captured.

Adults:

Over half of the adults return to the mid-Columbia basin in their fourth year (Table 9) (see above), averaging around 60 cm hypural length (Table 10, Figure 24). There appears to be little difference in the average length per age group between streams for both sexes, and females are approximately the same average size per age group as males, within streams (Table 10, Figures 24,25). Mullan (1987) observed that males were larger for a given age group for fish returning to the Leavenworth NFH, but the data collected on the spawning grounds between 1986 and 1993 do not show this (Figures 24,25). There may be more sampling bias in fish sampled on the spawning grounds than the possibly more random sample collected at the hatchery.

For all fish sampled, length averaged 66 and 67 cm, for females and males, respectively (Figure 25). These distributions are different from those measured in the 1950s by French and Wahle (1965) (Figure 25). The average length for females was exactly the same between the late 1950s and more recent samples, but the males measured in the late 1950s were smaller than males in the more recent samples (Figure 25). This discrepancy may be due to sampling bias, or the differences in the number of jacks present on the spawning grounds. Most of the jacks collected by French and Wahle were from the Twisp River in 1957 and the Chewack River in 1958. The years 1957 and 1958 were years of very high jack counts for spring and summer chinook salmon at Rock Island Dam.[11] It is curious that French and Wahle were able to capture so many jacks, since we are unable to

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[11] We mention summer chinook jacks because the arbitrary date at which fish are designated "spring" or "summer" would bias the number of fish being categorized as either. In 1957, the summer chinook jack count was almost 7,000 and the spring chinook jack count was nearly 3,000, both very high numbers compared to the historic record at Rock Island Dam. The spring chinook jack count has not been over 1,000 fish since 1977.

do so from the spawning grounds in recent years (C. Peven, personal communication).

Sex ratios

Mullan (1987) presented data compiled from Howell et al. (1985) on the number of returning male and female hatchery spring chinook in the mid-Columbia. From those data, we calculated the sex ratios for Leavenworth, Entiat, and Winthrop populations. The range (female to male) for the three stocks was 1.27:1 to 1.86:1. These estimates are similar to data compiled within the mid-Columbia for wild fish collected during carcass surveys for the periods of 1957-1960, and 1986-1993. For the period of 1957-1960, the ratio was 1.55:1. For the period of 1986-1993, the ratio was 1.07:1. Although these estimates are fairly close, it is likely that the actual ratio for the wild fish collected on the spawning ground is closer to 1:1. This is because there is a greater likelihood of recovering females on the spawning ground than males (Chapman et al. 1994a). Data from the Yakima River basin between 1980 and 1992 comport well with Mullan's observation (J. Hubble, YIN, personal communication). French and Wahle (1965) found mostly females on the spawning grounds in the late 1950s, as has been the case in recent years (Figure 25). Year-to-year returns may vary. Males can outnumber females on the spawning grounds (from Howell et al. 1985), but overall, it appears that the reverse is true.

Fecundity

Fecundity from wild spring chinook salmon has been measured in recent years in the mid-Columbia basin as part of newly developed hatchery supplementation programs (see Hatchery Operations section). In the Chiwawa River, the estimated fecundity has ranged from 4,600 - 5,980 between 1990 and

1994.[12] In the Methow River basin, fecundity (hand counted) has averaged 5,100 (range: 2,600-8,100) between 1992 and 1994 (Table 11). In the Methow River, four-year-old females averaged 4,200 eggs, while five-year-old fish averaged 5,400 eggs (Table 12). Differences in length explained 44% of the variation in eggs per female measured from the Methow River basin (Figure 26).

Healey and Heard (1984) found that length usually explained less than 50% of the variation observed in fecundity of chinook. Variation in age, seasonal runs, and life history (ocean- or stream-type) were not significant predictors of differences in fecundity. In the majority of populations that Healey and Heard (1984) examined, variation between years was significant, but not large, and when annual variation was taken into account, the variation in fecundity only increased from 34 to 45%. They conclude: *clearly, a great deal of variation in fecundity within populations remains to be explained.*

Rounsefell (1957) felt that there was a relationship between the number of eggs per female and latitude, with populations from lower latitudes having more eggs for a given length than more northerly populations. Healey and Heard (1984) disagreed with Rounsefell (1957), and concluded that the trend toward higher fecundity increased at higher latitudes (Figure 27). We found that fecundity also appeared to increase in populations that were farther upstream from the mouth of the Columbia River (Figure 27). This relationship could be an evolutionary response to the probable higher mortality of migrants (both upstream and downstream) that would accrue going to and coming from the ocean. It could also be explained by differences in sampling techniques or years sampled. Healey and Heard (1984) speculated:

> . . *the differences in elevation reflect local adaptation to spawning*

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[12] Fecundity estimates for years 1989 and 1992 were not used in this report because fish were gaffed off the spawning grounds, and a large portion of the females were partially spent. The fecundity reported for 1994 (5,979) was hand-counted and should be viewed as the best estimate, although it was derived from only six fish (K. Petersen, personal communication).

and rearing conditions. Most of the high-fecundity populations, for example, are stream-type chinook and for these populations high fecundity may be necessary to offset high prereproductive mortality and older age of maturity.

ARTIFICIAL PROPAGATION OF SPRING CHINOOK IN THE MID-COLUMBIA

Early hatcheries

The first hatcheries that released stream-type chinook in the mid-Columbia Basin began operation in 1899 on the Wenatchee River (Chiwakum Creek), and near the confluence of the Twisp River on the Methow River (WDFG 1899). These hatcheries were built to replenish the salmon (primarily chinook, and coho) runs, which had virtually been eliminated by the 1890s (Gilbert and Evermann 1895; WDFG 1898). In 1899 and 1900, hatcheries were also built on the Little Spokane and Colville rivers, but very few eggs were obtained, and the hatcheries were closed for salmon production after only one season (WDFG 1902). The Wenatchee facility was closed from 1904 to 1913 because of severe weather, logistics of the location, but primarily because it lacked adequate brood stock. From WDFG (1904),

> *The Wenatchee hatchery is another one of the hatcheries that is closed this season. . . had it been located below the Tumwater Canyon, further down the river, it would have been less expensive to operate and enable us to secure the early run of Chinook salmon and fulfill the purposes for which it was originally intended, but located where it is at present, we can only get an inferior run of Silversides* [coho] . . .

The biggest problems encountered in the early years of the hatcheries were lack of fish for broodstock, and because of irrigation diversions that entrained large numbers of juveniles (both naturally- and artificially produced). From WDFG (1904):

One of the greatest menaces to the successful operation of fish hatcheries east of the mountains and one of the most perplexing problems this Department has to contend with, is the irrigation ditches. . . the inlets to these ditches are large and a great many young salmon that have been hatched and cared for by this Department at a considerable expense, on being turned out of the hatcheries will make their way into these ditches, or will be drawn therein by the suction and carried out into the fields and lost. Two years ago I made a trip through Eastern Washington for the express purpose of investigating these conditions, and in many ditches that I visited I found thousands of young salmon that had entered the irrigation ditches and died; in some instances I could have gathered up pails full within a radius of 20 feet.

Most of the fish planted from the Wenatchee and Methow facilities in the first few years of production were probably coho (WDFG 1904-1920; Craig and Suomela 1941). For the first few years, species were not differentiated, with almost 8 million fry planted per year from the Wenatchee facility and up to 3 million per year from the Methow (Table 13). Beginning in 1904, when species were differentiated, by far the majority of fish released were coho. After the Wenatchee hatchery was moved downstream near the town of Leavenworth in 1914, chinook production began again, with supplementation of eggs from other hatcheries as far away as the Willamette and McKenzie rivers of Oregon (WDFG 1914; Craig and Suomela 1941; Table 13). From Craig and Suomela (1941),

The records of the hatchery operations at both above Tumwater Canyon *and Leavenworth indicate that it was not found possible at either location to secure either early run chinook or any other variety of that species in significant numbers. Also, numerous shipments were made to the Leavenworth station from streams on the lower Columbia and from outside the state. Some of the eggs were undoubtedly from the early run chinooks of the Willamette River system. However, other shipments, such as those made from Little White Salmon River by the U. S. Bureau of Fisheries, and probably some of those made by other Washington hatcheries on the lower Columbia, could have supplied only extremely late fall running chinooks. Therefore, it appears evident that the Washington State fisheries authorities have from time to time made attempts to introduce exotic populations of salmon to the Wenatchee River . . . and that they carried on this program for many years before the Grand Coulee fish salvage activities made necessary the transfer of strange runs of fish to that river.*

Very few chinook were released from the Methow hatchery (Craig and Suomela 1941). Egg take between the years 1908 - 1912 ranged from 5,000 - 68,000 (average 24,100, Table 13). In 1915, the hatchery was moved downstream near the mouth of the river at Pateros. The hatchery was moved for two main reasons: it lacked brood stocks other than coho, and the new location lay downstream from the irrigation intakes (WDFG 1917). From WDFG (1917),

Two years of operation of the new hatchery have demonstrated the wisdom of the change. Not only are we now securing more silverside salmon spawn at the new location than we did at the old, but our new location has developed to be the best hatchery in the state for the taking of Steelhead salmon eggs. Also, we have been able here to secure Spring Chinook salmon eggs . . ., and from Craig and Suomela,

> *. . . however, chinooks were never obtained in any quantity. . . some eggs were transferred to Methow from other locations. Even chum salmon eggs were shipped there in 1916 and 1917. . . In many cases there is no indication as to where the transferred chinook eggs were taken, but some were obtained from the U. S. Bureau of Fisheries hatcheries on the lower Columbia and probably some of the Washington hatcheries from that section also contributed late run stock to the Methow River. It is very questionable whether any of these fish were able to return to the Methow River, since the distance they would have to migrate is much greater than that to which the original stock was accustomed. However, these records indicate that the Washington State Fisheries authorities made attempts to introduce strange runs of salmon to the Methow as well as to the Wenatchee.*

In 1917, 1.5 million eggs were received at the Methow Hatchery from unknown origin. In the late 1920s, eggs were received from exotic hatcheries, but appear to be mostly late-run chinook (Craig and Suomela 1941).

The release of fry from the early hatcheries on the Wenatchee and Methow rivers probably contributed little to adult returns. Steward and Bjornn (1990) concluded that if the habitat is under-seeded (which it appears that the Wenatchee and Methow rivers may have been at the time), then fry stocking may increase production of adult fish. But they also review literature suggesting that unfed fry survived at lower rates than fed fry. We have no way to determine if fry released from the early hatcheries of the mid-Columbia were fed or not, but we presume not. The time of year the fry were released also appears to affect survival (Steward and Bjornn 1990). Again, we have no way to determine when the fry were released from the early hatcheries. If the time of release of the hatchery fish placed them in the stream before wild fish appeared, the hatchery fish may have had a negative impact on the few wild fish that remained in the mid-Columbia streams during the years of the early hatchery operations (Steward and Bjornn 1990).

Federal hatchery programs

The hatcheries built as part of the GCFMP began operation in the early 1940s at Leavenworth (Icicle Creek, a tributary of the Wenatchee River), Entiat, and Winthrop (Methow River). The Leavenworth facility was built as the main hatchery site, and the Entiat and Winthrop hatcheries as substations. These hatcheries were built as part of the program to relocate populations of salmon and steelhead that formerly ascended the Columbia River upstream from the Grand Coulee Dam site.

Leavenworth National Fish Hatchery (NFH):

Leavenworth NFH is located on Icicle Creek, a tributary of the Wenatchee River near the town of Leavenworth. Leavenworth NFH has released chinook since 1941. Between 1946 and 1968, spring chinook were released in only three years, and have been released every year since 1971 (Appendix 1).

History: The Leavenworth NFH was authorized by the GCFMP on April 3, 1937 and re-authorized by the Mitchell Act on May 11, 1938 (USFWS 1986a). It began operation in 1941. The initial plan for the operation of the Leavenworth Hatchery Complex (Leavenworth, Entiat and Winthrop NFHs) called for the collection of adult salmon and steelhead at Rock Island Dam and transport to the hatchery for holding and spawning. Eggs and juveniles would subsequently be shipped to the satellite facilities. The hatchery was constructed between 1938 and 1940. Sockeye (*O. nerka*), chinook, and steelhead were the species of emphasis, and later coho were added. Sockeye production ended in the 1960s because of low survival, and disease problems (USFWS 1986a). Coho production also ended in the 1960s.

In the mid-1970s, the mid-Columbia Rehabilitation Committee decided that the three NFHs in the mid-Columbia would designate spring chinook as the priority species of production (USFWS 1986a). The USFWS's Regional Resource Plan also focuses on spring chinook as the priority species in the mid-Columbia and lists the following strategies for artificial propagation (from USFWS 1986a):

> *Aid in increasing the number of hatchery-reared smolts produced in the National Fish Hatchery System.*
>
> > *Modify hatchery operations to optimize production and survival.*
> >
> > *Plan, design and construct new propagation capacity.*
>
> *Contribute to the Columbia River Fish Commission (CRFC) 15-year objective of sustaining a 2.1 million naturally produced adult salmon and steelhead population through judicious stocking of hatchery fish.*

From the above strategies, it was decided that the Leavenworth NFH complex would be operated primarily for spring chinook. USFWS (1986a) states that the "current" production goal of 2.75 million smolts was to be raised to 4.1 million fish that *will be a combination of smolts for release in the Icicle Creek and pre-smolts for release in other streams designated for outplants of fish.* This increase in production was to be caused by an increase in 12 cfs of water from the existing irrigation district. The increase did not occur, and the production goal (actually 2.2 million) was reduced beginning with the 1992 brood to 1.6 million in an effort to increase the quality of fish released from Leavenworth (D. Davies, USFWS, personal communication).

Chinook broodstock origin for the hatchery has varied. Most of the broodstock in the early 1940s came from the fishways of Rock Island Dam. In 1942, spring chinook from the McKenzie River, Oregon, were released in Icicle Creek. Spring chinook released from Leavenworth NFH in the 1940s and 1950s were primarily collected from Icicle Creek (Appendix 1). In 1967 and 1968, fish from Spring and Eagle Creek NFHs (30 miles upstream from Bonneville Dam, and on the Clackamas R., respectively) were released in Icicle Creek. Beginning in 1971, until 1983, most of the fish released in Icicle Creek were from the Carson NFH (Wind R.), Little White Salmon NFH (Little White Salmon R.), and Cowlitz WDFW hatchery (Peven 1992; Appendix 1). Carson fish were also released in 1986, but since 1981, most of the fish released from Leavenworth are from broodstock collected there (Appendix 1). Most of the early releases of fish from Leavenworth NFH were fry and parr (> 300 fish per pound, and between 30-300 fish per pound, respectively). Since the 1960s, all releases have been smolts (<30 fish/lb).

Goals and objectives: Objectives originally established for the Leavenworth Hatchery Complex, as part of the GCFMP were (from Calkins et al. 1939):

1) *. . . to bring, by stream rehabilitation and supplemental planting, the fish populations in the 677 miles of tributary streams between Grand Coulee Dam and Rock Island Dam, up to figures commensurate with the earlier undisturbed conditions and with the natural food supply in the streams.*
2) *. . . to produce in addition, by the combination of artificial spawning, feeding, rearing and planting in these streams, a supplemental downstream migration equivalent to that normally produced by the 1,245 miles of streams and tributaries above Grand Coulee Dam.*

Current objectives of the USFWS hatcheries are outlined in USFWS (1986a, b). In the USFWS Statement of Roles and Responsibilities, the broad role of the hatcheries are,

. . . to seek and provide for mitigation of fishery resource impairment due to

Federal water-related developments . . . the Fishery Resource Program goal, in fulfilling its mitigative responsibilities, is to ensure that established and future fishery resource mitigation requirements are fully and effectively discharged. Implicit in this goal is the replacement of fishery resource losses caused by specific Federal projects . . . and another responsibility of the Leavenworth Hatchery . . . is to restore depleted Pacific salmon and steelhead stocks of national significance in accord with statutory mandates such as the Pacific Northwest Electric Power Planning and Conservation Act, Mitchell Act, Salmon and Steelhead Conservation Act, Pacific Salmon Treaty Act of 1985 and Indian Treaties and related Court decisions.

Shelldrake (1993) updated the objectives of the mid-Columbia NFHs:

1) *Hatchery production* [specific to each facility].

2) *Minimize interaction with other fish populations through proper rearing and release strategies.*

3) *Maintain stock integrity and genetic diversity of each unique stock through proper management of genetic resources.*

4) *Maximize survival at all life stages using disease control and disease prevention techniques. Prevent introduction, spread or amplification of fish pathogens.*

5) *Conduct environmental monitoring to ensure that hatchery operations comply with water quality standards and to assist in managing fish health.*

6) *Communicate effectively with other salmon producers and managers in the Columbia River Basin.*

Facility description: The hatchery is located on Icicle Creek, 2.8 miles from its mouth on the Wenatchee River. There are two adult salmon/steelhead holding ponds, 38 Foster-Lucas ponds, three banks of fifteen 8ft by 80 ft standard raceways, 54 indoor fiberglass rearing tanks, and 40 concrete deep troughs.

The primary water source for the hatchery is Icicle Creek. The water right for the hatchery allows for 42 cubic feet per second (cfs) to be used for the hatchery. During low flows in the summer, the hatchery water supply is supplemented from water from Snow and Nada lakes (up to 16,000 acre feet; these lakes are part of the upper Icicle Creek watershed). The hatchery also has seven wells which have the capability to pump 6,700 gallons per minute (gpm) under the water right with the Washington State Department of Ecology (DOE). The water from the wells are used for egg incubation and early rearing (USFWS 1986a; B. Thorsen, personal communication).

Culture practices: Adult chinook return to the hatchery beginning in late April - early May. The escapement goal of the hatchery (number of adults needed to meet the production goal) is 1,500.[13] Spawning begins in mid-August and continues into the first week of September, and egg incubation and initial rearing take place in the indoor facility. Feeding usually starts in December, and fish are placed in the outdoor raceways in February. After release of yearlings takes place, fish density in the raceways is reduced further in May (D. Davies, USFWS, personal communication). Fish are reared in the outdoor raceways until release the following April.

The adult pre-spawning survival goal is 98% and has averaged 94% (89-96%) in the last five years (Shelldrake 1993). The hatchery goal for green-egg to fry and fry to smolt survival is 95% and has averaged 91% (89-92%) for egg-fry, and 93.4% (90-96%) for fry-smolt. The size of smolts upon release has averaged 17.1 (16-18.2) fish/lb, which is the goal for the hatchery (16-18; Shelldrake 1993).

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[13] Additional fish may be collected in years when it is believed that Entiat and Winthrop stations will not meet escapement levels needed for their production.

Hatchery production: Since 1971, when the current smolt program began, annual releases of spring chinook from the Leavenworth NFH have averaged 973,000 fish (Appendix 1 (not including fry and parr releases)). In keeping with the original design for the hatchery complex, some of the fish raised at Leavenworth in the 1940s were transferred to the Entiat and Winthrop hatcheries, fish are still shipped to the Winthrop station, and rarely to the Entiat station (Appendix 1). The current annual production goal is 1.6 million chinook smolts at approximately 18 fish per pound (or less).

Adult returns: For brood years 1940 to 1943, chinook were released from the three NFH stations to

> *. . determine whether a better return could be expected by 1) rearing chinook salmon in hatcheries to 1-year of age or 2) by rearing them to 1 ½ years of age* (Fulton and Pearson 1981).

Out of the eight experiments listed by Fulton and Pearson 1981), only one experiment used spring chinook (actually, the experiment mixed "summer" (collected after June 30), and "late spring"), so it is difficult to determine adult returns for spring chinook. What might be gleaned from the experiments is that fish that were raised to smolt size (assumed by the number of months reared since no size information is given) and released in the spring returned at higher numbers than fish released in the fall.

One experiment released spring chinook from the McKenzie River, Oregon into Icicle Creek in October 1942 to see how transplanted fish would perform. Both ventral fins and the anal fin were removed, probably reducing survival of these fish (Weber and Wahle 1969). Only one of the 45 fish recovered was found in Icicle Creek, others were recovered in the lower river fisheries for a total recovery of 0.089% of the fish released (50,435). Fulton and Pearson (1981) do remark that some of the fish recovered in the lower river fisheries were recovered *well above the mouth of the Willamette River* (into which the McKenzie River flows).

We compared the number of smolts[14] released to the number of adults returning to the Wenatchee, Entiat, and Methow rivers. For fish returning to the Wenatchee River, the smolt-to-adult survival averaged 0.45% (range: 0.14 - 0.99%, corrected for interdam loss, and incidental in-river and ocean harvest) between release year 1978 and 1990 (Table 14). Shelldrake (1993) lists the smolt-to-adult survival goal as 0.5%, which he shows as the five year average (range 0.12-0.92%). Mullan et al. (1992b) report the mean smolt-to-adult survival of fish from Leavenworth NFH from 1976 - 1988 as 0.55% (range: 0.21-0.70%). They conclude,

> *The universal presence of bacterial kidney disease (BKD) in hatchery stocks is a prime suspect for the poor returns of chinook salmon. Equally obvious is that the behavior of chinook salmon in hatcheries is conditioned differently from that of wild fish. Large age-0 and yearling chinook salmon smolts released to Icicle Creek were not cover-oriented, remained at the water surface and drifted downstream in the thalweg regardless of season or time of day, and had no apparent social structure, and were hyperactive . . . Recently hatched fry released to Icicle Creek, by contrast quickly removed themselves from the strong currents and mimicked the behavior of naturally produced chinook . . . Behavior and BKD in hatchery chinook is related . . .*

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[14] We did not account for fry or parr releases in our estimates, or fish released in the fall or winter. While it is probable that these fish have made some contribution to the returning adults, we were unsure how to represent post release mortality (i.e., how many of the fish actually migrated downstream). Considering this, the estimates of smolt-to-adult survival that we have derived should be considered biased upward.

While the return per release of adult chinook may be low, hatchery fish have still made up the majority of returning fish to the Wenatchee River in most years since the 1960s (Figures 28-30). Hatchery fish have made up greater than 50% of the run in practically every year since 1980. The percentage of hatchery fish in the spring chinook run in the Wenatchee River appears to be increasing in recent years (Figure 29), probably as a result of increased smolt-to-adult survival in the early 1990s (Figure 31), although we assume that the survival of smolts will show a commensurate drop in years 1992-1994 once all adults are accounted for.

The origin of the present returns to the Leavenworth NFH is the constant infusion of spring chinook from Carson NFH in the 1970s and 1980s (see Genetics section; also Appendix 1). These fish descended from fish trapped at Bonneville Dam in the mid 1950s (Ricker 1972). Shelldrake (1993) lists (in order of preference) wild Wenatchee River stock, upper mid-Columbia stock, or Carson stock as acceptable broodstock for the Leavenworth facility in years of extremely low returns.

Fish health and disease history: Health monitoring and treatments are outlined in Shelldrake (1993).

At time of spawning, hatchery brood stock is checked for infections of viruses, bacteria, and parasites. Of the known pathogens, infectious hematopoietic necrosis virus (IHN), BKD, *Yersinia ruckeri* (ERM), *Aeromonas salmonicida* (Furunculosis or BF), and the parasite *Ceratomixa shasta* (CS) are commonly isolated (Morrison 1995). Isolations from 1988 through 1994 were:

Year	Entiat	Leavenworth	Winthrop
1988	BKD, CS	BKD, IHN, CS	BKD, BF, IHN, CS
1989	BKD, ERM, IHN, CS	BKD, ERM, IHN, CS	BKD, CS
1990	BKD, ERM, CS	BKD, ERM, BF, CS	BKD, ERM, CS
1991	BKD, CS	BKD, ERM, IHN, CS	BKD, CS
1992	BKD, CS	BKD, BF, IHN, CS	BKD, CS
1993	BKD, CS	BKD, CS	BKD, CS
1994	BKD, CS	BKD, CS	BKD

The frequency and severity of disease incidence in juvenile salmon at the National Fish Hatcheries varies from year to year (Morrison 1995). At Entiat NFH, BKD is the primary infectious disease. Although IHN was isolated from juveniles in 1988 and 1991, no mortality was associated. In 1990, coldwater disease (CWD) caused a low to moderate mortality. At Leavenworth NFH, BKD is always found in juveniles, but mortality attributable to the disease is infrequent. The parasite ICH is a threat when water warms in late summer, and in 1989, ERM caused moderate mortality in a few ponds (Morrison 1995). At Winthrop NFH, the most serious infections are BKD and ICH infestations. We tabulate pre-release BKD infection

Entiat NFH:

Located on the Entiat River, this substation began operation in 1941. The Entiat hatchery released spring chinook as part of the GCFMP sporadically between 1943 and 1951, and then again for a few years in the mid-1960s, and since 1976 (Peven 1992).

Broodstock origin for fish released from the Entiat NFH has varied over the years. Between 1976 and 1984, eggs from broodstock of the Cowlitz, Carson, and Little White Salmon hatcheries were raised and released from Entiat (Appendix 2). Occasionally fish eggs are received from Winthrop Hatchery too (Appendix 2).

Overall, since 1984, most of the fish raised at the hatchery are from fish returning there. The production goal was reduced beginning with the 1992 brood to 800,000 (half as yearlings released in April, the other half as subyearlings released in May; Shelldrake 1993) in an effort to increase the quality of fish released (B. Edwards, USFWS, personal communication).

The history, goals and objectives of the Entiat NFH are the same as the Leavenworth NFH (see above).

Facility description: The hatchery, 6.7 miles upstream from the confluence with the Columbia River has one adult holding pond (75 x 150 x 8 ft), 30 raceways (8 x 80 ft), two steel rearing tanks, 36 circular rearing tanks, 16 rectangular tanks, 16 concrete troughs, 16 Heath type incubators, and two fiberglass distribution tanks (USFWS 1986b).

The primary water source for the hatchery is the Entiat River. The water right for the hatchery allows for 22.5 cfs. Four wells also provide 1,800 gpm of water, and Packwood (Limekiln) Spring supplies a continuous flow of 600 gpm (USFWS 1986b). From USFWS (1986b),

> *The spring and well water sources are of great importance to the success of the hatchery because they provide a supply of disease-free, silt-free and relatively constant temperature water to the hatchery. Constant temperature water is utilized to temper Entiat River water which varies from slush ice during the winter months to 70°F plus water during the summer months.*

Culture practices: Adult chinook return to the hatchery beginning in late April, early May. The current escapement goal for Entiat is 650 fish (five-year mean = 593 (437-687); Shelldrake 1993). Spawning begins in late August and lasts into September. Eggs are incubated in the Heath type trays and are usually on feed by late November, early December (B. Edwards, USFWS, personal communication). Fish are reared for their first 11 months on ground water, and their final 5 months on a combination of ground and river water. For the first 11 months of rearing, fish are all reared in old 8 x 80 ft concrete raceways, and then two thirds are transferred to 16 x 20 ft holding ponds, and one-third stay in the raceways. All fish are released directly into the Entiat River from the raceways and ponds at a goal of 18 fish/lb for yearlings (B. Edwards, personal communication).

Since 1991, releases of pre-smolts and age-0 fish have been made (at about 80 fish/lb). The release in 1995 will be the last of this five year study to determine if reduced density increases the quality of the fish released, although Shelldrake (1993) lists the subyearling releases as a production goal. Entiat River water also causes a problem with the parasite *Myxobilus* spp. (see below).

Adult pre-spawning survival has been below the goal of 95% in recent years. Shelldrake (1993) shows the five-year average as 75% (range 67-97%). Green-egg-to-fry and fry-to-smolt survival has averaged 90 and 88.9%, respectively, somewhat below the 95% goal.

Hatchery production: Stream-type chinook have been released from the Entiat NFH since 1941 (Appendix 2). Since 1976, when the present smolt program began, annual releases of smolts have averaged 386,000. Since 1991, an average of 368,000 pre-smolts have been released (smolt releases averaged 479,000 during that same time period) (Appendix 2). The current smolt production goal of 800,000 fish has not been met in recent years because of lack of pathogen-free water (B. Edwards, personal communication).

Adult returns: We estimate that the average smolt-to-adult survival between 1980 and 1990 was 0.14% (range: 0.04-.21%) (Table 16; corrected for harvest and inter-dam loss). The yearly smolt-to-adult survival is much lower than at Leavenworth, and in some years, lower than at Winthrop NFH (Figure 31). Shelldrake lists the survival goal of this hatchery as 0.5%. Mullan et al. (1992b) report the mean smolt-to-adult survival of fish released from the Entiat NFH as

0.16% (range: 0.07-0.27%). As in the Wenatchee River, hatchery fish appear to make up a large percentage of the total number of fish returning to the Entiat River in most years (Figure 29). While the percentage of hatchery fish appears to be increasing somewhat in the Entiat River, the relationship is not as strong as in the Wenatchee River (Figure 29), which may be a function of the poorer smolt-to-adult survival (Figure 31). The differences in smolt-to-adult survival for fish released from the Entiat NFH compared to the Leavenworth NFH is probably a function of an additional dam (Rocky Reach) passed, higher incidence of BKD, and the occurrence of *Myxobilus*, and, possibly other cultural differences between the two facilities, mostly water quality related. New release strategies (lower rearing densities) have resulted in higher-quality fish being released, and may increase smolt-to-adult survivals to levels closer to those at Leavenworth NFH. Shelldrake (1993) indicates that in years of low returns, wild Entiat stock and then Leavenworth stock could be used as broodstock supplements.

Fish health and disease: See this section title under "Leavenworth NFH." Bacterial kidney disease and infection of fish with *Myxobilus* spp., a parasitic protozoan that infects the brain stem of juvenile fish, are constant fish health problems at Entiat. Since 1991, the occurrence of *Myxobilus* and bacterial kidney disease have been reduced because of the earlier releases of pre-smolts. The use of ground water has decreased the daily percent mortality 90% (B. Edwards, personal communication). Health monitoring and treatments are outlined in Shelldrake (1993).

Winthrop NFH:

Located on the Methow River, this substation of the Leavenworth NFH complex began operation in 1941. The Winthrop Hatchery released stream-type chinook every year from 1941 through 1962. Releases of spring chinook ceased until 1976, when the current program began, and have since been ongoing (Appendix 3). Production at Winthrop was recently reduced from over 1 million fish to 800,000 (B. Walien, USFWS, personal communication).

Broodstock origin for fish released from the Winthrop NFH has varied over the years. The first four years of releases were from broodstock collected at Rock Island Dam as part of the GCFMP (see above). Eggs from the Cowlitz, Little White, Carson, Klickitat, and Leavenworth hatcheries have been raised and released from Winthrop since the current program began in 1976 (Appendix 3). Eggs are also collected from returning adults, but numbers of adults returning are so low that the production goal is rarely met (see below). The history, goals and objectives of the Winthrop NFH are the same as the Leavenworth NFH (see above).

Facility description: Located on the Methow River, at rivermile 50.4, this facility has two new 40 by 80 ft adult holding ponds, two older holding ponds (54 x 160 ft, and 54 x 236 ft), sixteen 17 x 76 ft. Foster-Lucas ponds, sixteen 12 x 102 ft, and 30 8 x 80 ft raceways. Inside the hatchery building there are 8 (16 tray) incubators, thirty-five 3 x 16 ft fiberglass tanks, and four 16.5 x 16 concrete starting troughs (USFWS 1986c).

The primary water source for the hatchery is the Methow River. The water right allows for withdrawals up to 50 cfs. Spring Branch Springs provides up to 10 cfs, and a groundwater infiltration gallery and well provide 1,500 gpm, with a maximum of 2,400 ac. ft. per year (USFWS 1986c). The springs and infiltration galleries provide warmer water during the winter months.

Culture practices: Adult chinook return to the hatchery in May and June. Spawning begins in late August and continues through September, and sometimes into October. The escapement goal of 900 (Shelldrake shows 800 as the goal) is rarely met (five-year average = 300 (64-942)), which is why in some years, the majority of fish released are from broodstock collected at Leavenworth (Appendix 3). Pre-spawning mortality of adults has been reduced since a new holding facility was built. Pre-spawn survival was 60-65% (goal = 95%, five-year average 66% (64-78)), but has been close to 96% in the last two years (B. Walien, USFWS, personal communication). Eggs incubate in hatch tanks, and fish are held in these tanks as long as possible. Fish are moved outside to Foster-Lucas ponds and placed in raceways after smolts of the previous brood are released in April. They are raised in the raceways until release the following April. Green-egg-to-fry and fry-to-smolt survival has averaged 84.8 (72-93%) and 89.2% (82-94%), respectively over the last five years, below the goal of 95% (Shelldrake 1993)

Hatchery production: Since the current smolt program began in 1976, an average of 387,000 smolts has been released (Appendix 3). The current production goal is 800,000 smolts at 16-22 fish/lb (five year average of 17.6 (17.2-19)).

Adult returns: We estimate the average smolt-to-adult survival as 0.12% for years 1980 - 1990 (Table 17; range: 0.01 - 0.29%, corrected for inter-dam loss and incidental harvest). Shelldrake (1993) lists the goal at Winthrop as 0.5%. Mullan et al. (1992b) report the mean smolt-to-adult survival of spring chinook released from Winthrop as 0.20% from 1976 to 1988 (range: 0.02-0.28%). The percentage of hatchery fish returning to the Methow River has declined from 1980 to 1994 (Figure 28). Hatchery fish have never made up more than 50% of the returning population. However, the number of hatchery fish returning to the Methow River can be substantial in some years. Winthrop fish have two additional dams to pass compared to Leavenworth fish (one compared to Entiat fish). Relatively poorer survival in recent years cannot be explained by this reason alone, especially considering the operating bypass system at Wells Dam, which we assume has increased survival to some degree.

We postulate that Winthrop fish survived at higher rates than Entiat fish in the mid-1980s because of poor health of the Entiat fish, and that lower survival since the mid-1980s reflects increased health problems of Winthrop fish. Winthrop NFH has the highest occurrence of BKD of the three NFHs (B. Walien, USFWS, personal communication). Certainly, the additional dams increase the mortality of the Winthrop fish (compared to Leavenworth and Entiat), but Winthrop fish would never survive at higher rates than Entiat fish if dam mortality were the outstanding factor involved.

The origin of the present returns to the Winthrop NFH are from the constant infusion of spring chinook from Carson, Little White, and Leavenworth NFHs in the 1970s and 1980s (see Genetics section; also Appendix 3). Shelldrake (1993) lists wild Methow River stock or Leavenworth stock as acceptable broodstock for the Winthrop facility in years of extremely low returns.

Fish health and disease: See this section under Leavenworth NFH description. Health monitoring and treatments are outlined in Shelldrake (1993).

Epilogue for federal hatcheries:

Survival of spring chinook from the national fish hatcheries of the mid-Columbia River has been very low. Until recently, little regard was given as to what broodstock was used and infusions of lower river stocks still occur. Carcass surveys of spawning grounds suggests little straying of hatchery fish, but this is not surprising, given the low number of fish returning. Disease, especially BKD, is believed to be a major factor in the survival of the fish released from the mid-Columbia NFHs (Howell et al. 1985). Factors that affect other hatchery and wild stocks also affect fish released from these hatcheries and should be considered (see other sections of this report for details). Hatchery releases of smolts (fry and parr releases not considered, but they are represented in Appendix 1-4) from the mid-Columbia have increased significantly over the last 40 years (Figure 32; Table 18). Decreased size and increased age at maturity of many populations of salmonids along the entire Pacific rim suggest that the ocean may be food-limited in some years. The continued increases in hatchery releases may be exacerbating poor survival when ocean food production is low.

We compared the performance of the Rapid River Hatchery (IDFG) to the Leavenworth NFH for similar years (Figure 33). For both hatcheries, there appears to be little relationship between the numbers of fish released and subsequent adult returns (Figures 34-35). Leavenworth Hatchery has increased the number of smolts released in recent years, while Rapid River releases remained virtually the same. However, adult return trends differ markedly, with Leavenworth showing an increase and Rapid River decreasing (Figure 33). Comparing the performance of Rapid River before and after full development of the Lower Snake and Columbia rivers, we find similar results in the trend of adults returning (Figure 36). The development of the lower Snake River has certainly played a role in the reduction in smolt-to-adult survival. When releases began at Rapid River in 1964, only Ice Harbor Dam was present on the lower Snake River. It appears (Figure 36) that smolt-to-adult survival dropped dramatically after the completions of John Day (1968) and Lower Monument (1969), Little Goose (1970), and finally Lower Granite in 1975. In most years, but not all, survival of Leavenworth releases is higher than for releases at Rapid River (Figure 37). Differential harvest (unlikely) either in the ocean or lower river may account for some of the differences, or differences in the health of the fish upon release. While the construction of mainstem hydroelectric projects reduced smolt survival, it is not the only problem affecting survival (see other sections).

The fish cultural practices of the USFWS appear to be in transition. Objectives listed by Shelldrake (1993) differ from those mentioned by USFWS (1986a,b,c), giving genetics and broodstock origin more emphasis. Other innovative studies have been conducted by Leavenworth NFH in recent years (using cover over ponds and not hand-feeding fish) that may eventually lead to higher-quality smolts.

State hatchery programs

The state of Washington (WDFW) operates two hatcheries that raise stream-type chinook in the mid-Columbia region. These programs compensate for losses of spring chinook at mainstem hydroelectric projects. The two state spring chinook programs are based on the concept of supplementation, which we discuss in further detail below.

Goals and objectives:

The goal of the state hatcheries is to use artificial production to replace adult production lost due to smolt mortality at mainstem hydroelectric projects, while not reducing the natural production or long-term fitness of salmonid stocks in the area (WDF 1993). Specific goals of the WDFW hatcheries (WDF 1993) are:

1) *Hatchery production* [in terms of number of fish released from each site],
2) *minimize interactions with other fish populations through rearing and release strategies,*
3) *maintain stock integrity and genetic diversity of each population or unique stock through proper management of genetic resources.*
4) *maximize survival at all life stages using disease control and disease prevention techniques. Prevent introduction, spread or amplification of fish pathogens,*
5) *conduct environmental monitoring to ensure that the hatchery operations comply with water quality standards and to assist in managing fish health,*
6) *communicate effectively with other salmon producers and managers in the Columbia River basin, and with implementors of local and regional flow and spill programs, and*
7) *develop a Conservation Plan and conduct a comprehensive monitoring/evaluation program to determine that the program meets mitigation obligations, estimate survival to adult, evaluate effects of the program on local naturally producing populations, and evaluate*

downstream migration rates in regards to size and timing of fish released.

Rock Island Fish Hatchery Complex:

History: The Rock Island Fish Hatchery Complex (RIFHC) began operation in 1989 as mitigation for salmonids lost as a result of operation of Rock Island Dam. The facility was constructed by, and operates under funding from, Chelan PUD. The spring chinook production goal is 672,000 fish at 12 fish/lb (WDF 1993).

The Rock Island Settlement Agreement (by which the RIFHC was authorized) includes provision for evaluation of the Rock Island Hatchery program, both in terms of meeting its production requirements and its effects on natural production of the salmon populations supplemented by the program. Portions of the evaluation plan can be found in Appendix 6. The evaluation plan includes genetic monitoring of the hatchery and naturally produced fish, migration timing and survival studies of the hatchery releases, and studies to evaluate interaction between hatchery and naturally produced fish. Genetic monitoring and coded wire tagging studies began with the first brood year (1989), prior to development of the evaluation plan.

Facility description: The RIFHC has one main incubation and rearing hatchery (Eastbank) and five satellite rearing/acclimation facilities, and four broodstock trapping sites. The main hatchery, Eastbank, has two adult holding ponds, with one designated for Chiwawa River chinook, 70 half-stacks of vertical incubators equipped with a chilled water supply (4.5 gpm per half-stack), eight 3,750 cu. ft. raceways and five 22,200 cu. ft. raceways. Eastbank has four wells that supply 53 cfs. This water varies in temperature from a low of 46° F in May to a high of 57° F in December. Rearing space at Eastbank was designed to maintain maximum loading densities below the criteria of Piper et al. (1982), as modified by Wood (Chelan PUD and CH2MHILL 1988).

The Chiwawa rearing ponds are sized so that loading densities will not exceed 6 lbs fish per gpm flow and 0.75 lbs fish per cu. ft. of usable rearing space. The Chiwawa facility has two 50 x 150 x 5 ft ponds with a usable rearing area of 37,500 cubic ft.

Culture practices: The RIFHC is designed to supplement the natural production of spring chinook in the Chiwawa River. Naturally-produced fish (only) are collected for broodstock at a weir constructed for this purpose adjacent to the Chiwawa River acclimation pond site (Figure 1). Broodstock collection protocols have been developed that limit collection of naturally produced adults for the hatchery program at no more than 30% of the run ascending the Chiwawa (Peck 1993). The current adult collection goal is 400 adults.

Broodstock collected at the weir are transported on a daily basis to the main facility (Eastbank), located immediately upstream from Rocky Reach Dam on the main stem Columbia River. Adults are spawned from mid-August through September, and the eggs incubate in chilled water, which retards egg and alevin development. Chilled water is used so the fish will not have to be placed on a maintenance diet in the fall. From Chelan PUD and CH2MHILL (1988),

> *The growth rate of chinook salmon is rapid with the high nutritive value of hatchery feeds and at moderate water temperatures, such as the 52 degrees F. groundwater supply at the Eastbank Hatchery. Typically, chinook hatcheries with similar conditions must resort to feeding of maintenance diets to hold growth in check, yet still produce very large smolts. Problems associated with excessive growth in the hatchery environment include: 1) fall smolting response with associated disease problems (i.e. tail rot) and stress; 2) health and nutritional problems that may be exacerbated by overwinter feeding of maintenance diet; 3) increased number of precocious*

males with smolts larger than 10/lb; and 4) the requirement of a much larger volume of rearing space and water supply due to the higher poundage of fish on station. The complex of Eastbank hatchery and satellite rearing stations is designed to avoid the problem of chinook overgrowth in the hatchery environment by use of chilled incubation water and cold water rearing at satellite stations of spring chinook . . .

The juveniles are reared in raceways at the main facility until they are about 20 fish/lb in September, then transferred to the Chiwawa rearing ponds. The fish are raised through the winter on Chiwawa River water unless ice precludes the use of this source, at which time water from the main Wenatchee River is used. Smolts are volitionally released from the ponds beginning in April the following year.

Hatchery production: Since 1989, an average of 50 adults has been collected (range: 13-106). This is far short of the 400 adults needed to make the production goal of 672,000 smolts. In 1989, the weir was not complete and all of the adults were gaffed off the spawning grounds and spawned immediately. A floating PVC picket weir was completed in time for the 1990 brood, but did not function properly, either in 1990 or 1991. The effectiveness of the weir depended on river discharge (fish were able to pass around it in higher flows; S. Hays, Chelan PUD, personal communication). In 1992, the floating weir washed out in an early spring freshet, and broodstock was collected by gaff from the spawning grounds again. A custom-built, hydraulically-operated weir was constructed and in place for the 1993 adult migration. This weir effectively blocked fish from sneaking upstream, but did not have the proper attraction to the trap, and fish of Chiwawa River origin were observed in the Wenatchee River and other tributaries upstream from the Chiwawa (Peven 1994). In 1994, the weir was operated intermittently because of concern for the few fish that were expected to return (S. Hays, personal communication). Chelan PUD had planned a radio tracking experiment, including tagging fish at Tumwater Dam and evaluating their experience at the weir, but only three fish were tagged, with one encountering the weir in its upright (as opposed to flattened to allow water, debris, and adult salmon to pass without impedance) position (no delay was observed; Peven and Truscott 1995).

Fish have been released at the Chiwawa facility since 1991 (Appendix 5). An average of 61,000 fish have been released (range: 43,000-85,113; Appendix 5), far short of the production goal of 672,000.

For the three years that data are available, pre-spawning survival has ranged from 74 - 100% (for 1990, 1991, and 1993). Survival from fertilization to release has average 86.2% (range: 77-95%), much higher than the current protocol of 75% (K. Petersen, WDFW, personal communication).

Adult returns: The first adult returns from the Chiwawa occurred in 1993 with age-4 fish returning from the 1989 brood year. The majority of adults returning to the Chiwawa in 1993 appear to have been diverted to other spawning areas (see above). LaVoy (1994) used an expansion based on the release group marking rate and then by a carcass sampling rate for each tributary where CWTs were recovered. He estimated that 136 Chiwawa River 1989 brood chinook returned in 1993. An additional 17 fish were estimated to have been caught in non-treaty troll, treaty C&S, and Wenatchee sport fisheries (LaVoy 1995). In 1994, LaVoy (1995) estimated that 10 fish returned to the Wenatchee River from the 1989 brood year (1 at the weir, and 9 on the spawning grounds). Two fish were collected at the Chiwawa weir in 1991, and these "mini-jacks" have been removed from our estimate. The total number of adults accounted for as returning to the Wenatchee River thus is 154 (non-treaty troll and treaty fisheries removed). Correcting for inter-dam loss (5%), and incidental in-river (5.5%; treaty and non-treaty estimates from LaVoy) and ocean harvest (less than 5%; this report), the smolt-to-adult survival for the 1989 brood was about 0.56%, which is greater than the corrected Leavenworth NFH survival of 0.44% for 1989 (Table 14). Although this smolt-to-adult survival may increase after the 1995 returns of six-year-old fish (projections are for a much reduced run to the entire Columbia River and we do not expect many, if any, six-year-old fish to return), the survival for the one year is more than double that expressed as the goal of the hatchery (0.26%; Peck 1993)[15].

Fish health and disease: No major disease epizootics have occurred, except for bacterial kidney disease (BKD). Because of BKD, juveniles were not marked from the 1992 brood that were released in 1994. Tail erosion after transfer to the rearing/acclimation ponds has been a common cause of mortality. No pathogen has been identified as the cause. Health monitoring and disease treatment are outlined in Peck (1993).

Methow Fish Hatchery Complex:

History: The Methow Fish Hatchery Complex (MFHC) was built to compensate for losses of smolts caused by the operation of Wells Dam (Erho and Bugert 1995). The facility was constructed by, and operates, under funding from Douglas PUD. Eggs are collected at weirs on the Methow, Twisp, and Chewack rivers and incubated discretely at the central facility near the town of Winthrop. Smolts (246,000 for each facility) are released from acclimation ponds on the Twisp, Chewack, and Methow (central facility) rivers (Peck 1993; Bartlett and Bugert 1994).

One of the guiding principles of the Methow Basin Spring Chinook Salmon Supplementation Plan (MBSCSP) is to increase natural production of the three principal stocks from the main stem Methow, Chewack, and Twisp rivers. With this in mind, the general supplementation plan has established separate strategies for each of the three streams. Each stock will have specific escapement goals,

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[15] The smolt-to-adult survival goal of the hatchery is measured at Rock Island Dam (Hatchery Evaluation Plan). Not expanding the return to the river for inter-dam loss (but adding lower river fisheries) gives us a smolt-to-adult survival of 0.38% ((136 + 17 + 10)/42707). This rate is still higher than the goal of the hatchery for the one brood.

designed to provide a basis for evaluating the progress of achieving the original intent of the program. From Erho and Bugert (1995),

> ***Methow River:*** *Collaboration between Winthrop FH and Methow FH is of paramount importance for the MBSCSP. Gene flow between the two hatcheries will inevitably occur. To be consistent with this situation, all spring chinook salmon that spawn in the mainstem Methow River upstream of the Chewuch* (Chewack) *River confluence will be managed as one genome. To be successful, this management strategy requires three conditions: 1) no spring chinook salmon from outside this reach will be imported to either hatchery for propagation and released into the Methow River (exogenous salmon may be reared at the hatcheries if they are acclimated and released into their natal stream), 2) all salmon released from either hatchery into the Methow Basin will be externally marked, and 3) salmon that spawn in the Lost River will be included in this population.*
>
> ***Chewuch River:*** *The Fishery Parties recognize the opportunity to implement innovative fish cultural practices at Methow FH, yet also are acutely aware of the need to ensure high survival of the supplemented populations. The Chewuch River population will therefore be the designated stock used for innovative hatchery management. In general terms, the Chewuch stock may be considered an experimental "treatment" stream, compared to the Twisp River population, which will serve as the "reference". Alternative fish culture may include such practices as life skills training (Olla and Davis 1989, Suboski and Templeton 1989), side channel rearing (Budhabhatti and Maughan 1994), and autumn pre-smolt releases (Bjornn 1978, Bilby and Bisson 1987), or other prototypical hatchery strategies.*
>
> ***Twisp River:*** *The Twisp River stock will be managed in a manner that*

ensures the highest survival of both natural and hatchery salmon in that river. Low risk production strategies will be implemented in all stages of the program. The Evaluation Plan will place an emphasis on long-term genetic and demographic monitoring of the Twisp population, to evaluate the stability of a small semelparous population. An estimate of minimum viable population (MVP; Shaffer 1981, 1990, Lacava and Hughes 1984) size will be derived, either through empirical or heuristic analysis (Kapuscinski and Lannan 1986). The escapement goal for the Twisp River will then be based upon the estimated MVP.

The Wells Settlement Agreement (by which MFHC was authorized) includes provision for evaluation of the MBSCSP, both in terms of meeting its production requirements under Phase I, and its effects on natural production. A copy of the draft evaluation plan is attached in Appendix 7. This evaluation plan includes genetic monitoring of hatchery and naturally produced fish, migration timing and survival studies of hatchery releases, and studies to evaluate interaction between hatchery- and naturally produced fish.

Facility description: The MFHC consists of a central facility on the Methow River, near the town of Winthrop, and two satellite facilities on the Chewack and Twisp rivers.

The main facility is located on the Methow River, approximately 45 miles upstream of the confluence with the Columbia River. This facility has three canopy-covered 8 x 78 x 4 ft adult holding ponds, 12 canopy-covered juvenile raceways of the same dimensions as the adult ponds, and 24 indoor 3 x 59 x 4.5 ft start tanks. In addition, there are three separate incubation rooms with 15 single stack (eight trays per stack) vertical incubators and one 107 x 59 x 4.5 ft acclimation pond, which releases into the Methow River (Bartlett and Bugert 1994).

The main water source for the Methow facility is from four wells that provide almost 10 cfs. An additional water right of 18 cfs of Methow River water is provided, with 11 cfs guaranteed (the additional 7 cfs is shared with Winthrop NFH in the spring; Bartlett and Bugert 1994).

Almost six miles upstream of the confluence of the Methow River is the Chewack River acclimation site. The site has one large acclimation pond, which measures 107 x 70 x 4.5 ft. The water source of the acclimation pond is the Chewack River, which is supplied by gravity feed from the Chewack Canal Company's irrigation ditch. The maximum flow to the pond is 5.6 cfs (Bartlett and Bugert 1994). Adult trapping for the Chewack fish occurs at Fulton Dam, approximately 4.5 miles downstream of the acclimation pond (1.5 miles upstream of the confluence with the Methow River).

The Twisp River acclimation site is approximately 5 miles upstream of the confluence with the Methow River. The facility has one acclimation pond which measures 107 x 59 x 4.5 ft. The water source of the pond is the Twisp River from the Valley Power irrigation canal, with a maximum flow of 5.6 cfs. The adult collection trap is located adjacent to the acclimation pond (Bartlett and Bugert 1994).

Culture practices: The MFHC is designed to supplement the natural production of spring chinook in the Methow River basin. Naturally produced spring chinook (only) are collected from traps on the Chewack (Fulton Dam), Twisp (at the acclimation site), and Methow (presently Foghorn Diversion Dam, but the future site is undecided) rivers. The broodstock protocol will be developed on a yearly basis (Erho and Bugert 1995). To achieve the goal of 246,000 fish per site, a total of 714 naturally produced adults is needed (WDF 1993). No more than 30% of the run will be collected (Peck 1993).

Broodstock collected at the various locations are transported immediately to the main facility near Winthrop. Adults spawning begins in mid-August, and continues through September. Juveniles are reared at the main facility, with final acclimation occurring at the sites of release. Fish are transferred to the final rearing sites in March (Bartlett and Bugert 1994). Smolts are permitted to migrate volitionally, beginning in April. For the 1992 brood, pre-spawning survival of adults was 85 and 80% for the Chewack and Twisp, respectively (no Methow stock was collected). Survivals from green-egg-to-fry were 88.2 and 94.2% for the Chewack and Twisp rivers, respectively, and fry-to-smolt survival was 94.2% for both stocks.

Hatchery production: In 1992, 50 spring chinook were collected for broodstock in the Twisp (30) and Chewack (20) rivers. No broodstock was taken for the Methow population (Bartlett and Bugert 1994). In 1993, 110 adults were collected from the Chewack River, 99 from the Methow River, and 40 from the Twisp River. In 1994, 12, 17, and 5 adults were collected from the Chewack, Methow, and Twisp rivers, respectively (H. Bartlett, WDFW, personal communication).

Since 1992 was the first brood year for this facility, there has been only one release to date. Approximately 76,000 (41,000 released to the Chewack, and 36,000 released to the Twisp) fish were released from the MFHC in 1994 (Appendix 5). Because the hatchery first released fish in 1994, there is no adult return information available yet.

Fish health and disease: No major fish health problems occurred during the rearing of the 1992 brood (Bartlett and Bugert 1994). Fish health monitoring and disease treatment are outlined in Peck (1993).

GENETIC CHARACTERISTICS

Introduction

Recent petitions for ESA listings of various populations of both anadromous and resident salmonids native to upstream drainages of the Columbia and Snake Rivers (e.g., Rohlf 1993) prompted a recent general review of the status of summer/fall chinook salmon upstream from Rock Island Dam (Chapman et al. 1994a). This assessment stimulated genetic considerations of these fish (Utter 1993, Utter et al. in press) that included data from spring runs to this area.

This report section is motivated by a current need for a primary focus on the genetic status of spring-run fish. Less extensive genetic data of earlier studies but from a broader sampling range complement the information and conclusions reached in Utter et al. (in press). The status of these populations as evolutionarily significant units (ESUs) and the specific needs for additional genetic information are discussed.

Background

Details of sampling (Table 19) focus on locations upstream from Rock Island Dam (Figure 38). Samples of juveniles and adults were from the named locations except for collections 15 and 16, which were hatchery-reared progeny of Chiwawa River adults.

Most of the biochemical genetic data were derived from three sources:

(1) Schreck et al. (1986),
(2) Hershberger et al. (1988), and
(3) Utter et al. (in press).

A combined analysis involving all of the pertinent information from each of these sources was precluded because of their differing sets of polymorphic loci and alleles. Because of continuing technical developments in this field through the present (discussed in Shaklee and Phelps 1991), a chronological increase has occurred regarding the detail and discriminatory capabilities of the reported information. However, earlier data sets remained valuable for temporal comparisons of compatible data within common locations, and for data from locations not sampled in later studies.

This problem was resolved by first assembling a data set containing the informational (i.e., polymorphic) data from (3). Compatible data from pertinent collections in (2) were then added, requiring pooling of variant alleles for some loci of (3) and (2) (Table 20) to permit calculation of genetic distances (Nei 1972). Different recordings of allele frequencies for sMDH-B1,2* in (2) and (3) required conversion of data from (2) (where all variation was assigned to a single disomic locus) to that of (3) (where variation was assumed to occur at a tetrasomic locus; i.e., the sum of two disomic loci). The conversion decreased the frequency of variant alleles of (2) by a factor of 0.5. Finally, data from (1) that were compatible with the combined information from (3) and (2) were added. Sampling locations and details (Figure 38, Table 19) included 27 collections. Analyses from different subsets of these total data (Appendix 8) were the basis for the conclusions of this report.

Data were analyzed through Biosys-1 (Swofford and Selander 1989) to calculate heterozygosities and genetic distances (Nei 1972), and to perform unweighted pair-group method (UPGM) cluster analyses (Sneath and Sokal 1973). Each cluster analysis is based on genetic distances derived from different sets of polymorphic loci; thus they are relative values useful only for comparative purposes within a specific set of analyses.

Analyses and interpretations

Three cluster analyses using data of sources (2) and (3) cumulatively provide some insights that vary according to the collections included and the amount of genetic information used. Figure 39, based on the compatible data for 16 polymorphic loci of both sources, provides the most extensive comparison among spring-run populations (18 collections). Figure 40 is limited to the seven spring-run collections examined in (3), and derived from additional discriminating information contained in (3) that was excluded from Figure 39. Figure 41 is based on the total unmerged information of (3). The following descriptions include interpretations from these analyses, plus additional observations from the allele frequency data of (1) included in Appendix 8.

Spring-run vs. summer/fall-run collections

The analyses that jointly examine both of these recognized major groups clearly reflect their genetic distinctness. In Figure 39, the 18 spring-run and 3 summer/fall-run collections diverged at a relative genetic distance of about 0.045. Non-overlapping allele frequencies at many loci contributed to the distinction of these two groups; most notable was PGK-2* with frequencies of the *100 allele about 0.100 for spring-run and near to or greater than 0.600 for summer/fall-run fish. Other loci where mean frequency differences of the common allele averaged .20 or greater between the two groups included two loci, AH* and sIDHP-2*, where the common allele was virtually invariant or "fixed" in the spring-run group, and sIDHP-1* with the reverse situation. Other group-distinguishing loci included LDH-C*, MPI*, sSOD-1*, and PEP-B1*. A similarly large separation is apparent in Figure 41 between the two major groups based on the full set of 33 polymorphic loci analyzed in (3).

Genetic subdivisions among spring-run collections

Each of the three cluster analyses suggests the existence of some degree of genetic distinctness among the spring-run fish. In Figure 38, collections of wild fish from the Entiat River (18) and White River (9) diverged at respective distances of 0.01 and 0.007 from two less distinct groups of collections joining at a distance of .005. Discriminating allele frequencies for these two single outlying collections occurred at the MPI* and sSOD* loci; additional individual differences at sIDHP-2* (18) and sIDHP-1* (9) distinguished each collection from one another and from the two less-differentiated clusters. These two clusters were comprised of wild fish of the Methow drainage dominating one of the groups, and wild collections from the Wenatchee drainage and the Winthrop and Leavenworth Hatcheries represented in the other. Interpretation of Figure 39 was complicated by the presence of one group of Chiwawa River juveniles (15) amidst the wild Methow drainage fish, and the contrast in clustering of the two White River collections (9 and 10).

The clusterings of Figure 40, though based on complementary data, suggest some distinctions similar to those of the same seven collections included in Figure 39. Collections of the Chiwawa River (15) and the White River (9) diverged from the remaining five collections. Both Chiwawa juvenile collections (15 and 16) differ in opposite directions from the adult collection at mMDH-2*; the most distinct collection on the basis of these five loci (15) is further characterized by a relatively high frequency of the variant allele at mAH-4*. The White River fish (9) are distinguished by high frequencies of the common allele of mMDH-2* and the variant allele of TPI-2.2*. The topography in Figure 40 for these seven collections is similar to that of Figure 40 based on the information from the larger data set of (3).

Genetic conclusions for spring-run collections

The much smaller magnitude of difference among the spring-run collections than between these and the summer/fall-run fish requires a more cautious approach to deriving genetic conclusions about apparent relationships within this group. At this level, distinctions may be based on one or more possibilities other than a real genetic divergence; including non-random sampling, year-class variation, and problems in recording raw data. The following tentative conclusions were derived with such alternative possibilities in mind, drawing in additional information from source (1) where appropriate.

The most obvious distinctions among the spring-run fish are the outlying collections in each of the dendrograms. The outlying Entiat collection (18) in Figure 38 contrasts with the Entiat collection (26) reported in source (1) which does not suggest a distinction of this group within other spring-run fish (Appendix 8). Allele frequencies for MPI* of collection (18) are the primary source of its divergence, whereas MPI* allele frequencies for collection (26) lie well within the range of other spring-run collections of this region. The data for (26) are considered more representative in view of the extensive history of translocation and hatchery influence (discussed below) in this basin. The data for collection (18) record seven sampling areas over a three-mile stretch (Table 16). Nevertheless, most of the fish could have been progeny of a few matings taken at a single area, and the aberrant data a reflection of the inevitable biases arising from such a "bottleneck". This explanation is proposed pending confirmation through subsequent sampling.

A similar explanation is suggested for the consistent divergence of juvenile collection (15) from the other collections of Chiwawa River fish (14, 16, 17). The juvenile progeny of Chiwawa River adults were sampled during hatchery rearing for collection (15). The observed differences are primarily attributed to one or more possible sources of bias (Marshall and Young 1994) including limited numbers of parents, differential family survival, and non-random sampling of juveniles. The spring chinook salmon of the Chiwawa River, then, like those of the Entiat River, are not considered strongly diverged from other groups upstream from Rock Island Dam.

White River collection (9) diverges from the clusters comprising most of the spring-run populations in Figures 39-41. This group differs from the White River juvenile collection (10), which is more typical of other spring chinook populations of this region (noting the correction of allele frequency data for PGK-2* in Table

20). The outlying collection (9) and the conformance of (10) with most spring-run fish cannot be as readily explained as the above-noted inconsistencies. The collection of adult fish (9) is considered less vulnerable to potential sampling biases affecting juveniles. However, attempts to minimize these biases (Table 20), coupled with the concurrence of allelic data with other regional groups, preclude an easy dismissal of collection (10) data as artifactual. The independent distinction of collection (9) with data not available for (10) (Figure 40, Appendix 8) favors consideration of the adult collection as representative of this drainage, but indicates a need for testing this conclusion with further sampling. Chinook of the White River are therefore tentatively considered a divergent group from other spring-run fish of this region.

Finally, a somewhat divergent group of Methow River wild fish is suggested in Figure 39, based on the collections from the Twisp River (3 and 4), the Chewack River (5), and the Lost River (6), aggregating within a common cluster (where the inclusion of Chiwawa R. collection (15) is disregarded as an artifact based on previous discussion). Non-overlapping allele frequencies with hatchery fish of this drainage (collections 1 and 2) at three loci (IDH-3*, PGK-2*, SOD-1*) are consistent with the distinction of these populations. Data for the latter two loci were also reported for the collection of wild juvenile fish from the Methow River collection (27) (Appendix 8) reported in source (1) where low PGK-2*100 frequencies comported with collections (3 - 6), but SOD-1* frequencies overlapped with those of collections (1) and (2). The magnitude of these distinctions is slight. Further sampling is needed to determine whether persisting wild spring chinook populations exist that are distinguishable from hatchery-maintained populations of the Methow drainage, and other wild spring-run populations of this region.

Influences of management activities

This section addresses management activities over the past 60 years that have had actual or potential influences on the genetic structure of spring-run chinook salmon populations upstream from Rock Island Dam. This information is reviewed in Utter et al. (in press) and much of this section is taken directly from this source.

Two related activities drastically changed the population structure of mid-Columbia River chinook salmon during the 1930s and 1940s. The impoundment of Grand Coulee Dam in 1939 permanently blocked access of anadromous salmonids to over 1,000 miles of upstream spawning and rearing habitat. In compensation for this loss, the GCFMP intercepted upstream migratory salmonids at Rock Island Dam from 1939 through 1943 for relocation in tributaries downstream from Grand Coulee Dam. Details of these events relating to spring chinook salmon were outlined earlier in our report. These interceptions, translocations and admixtures permanently transfigured the populations of anadromous salmonids upstream from Rock Island Dam, providing a foundation for the present population structures.

The extreme modifications on population structures initiated by the GCFMP have been complicated by subsequent cultural activities persisting through the present. The most obvious manipulations involve introductions of fish from regions beyond the mid-Columbia River. A review of such introductions (Table 21, Appendix 1) indicates a continual influx of exogenous populations of diverse geographic and ancestral origins.

The most persistent and extensive of these introductions involves the Carson Hatchery, on the Wind River (enters the Columbia River on the Washington side of the Bonneville Dam pool). This population was derived from spring-run fish destined for the Snake and the mid-Columbia region and intercepted at Bonneville Dam starting in 1955 (Ricker 1972). The spring-run fish of the adjacent Little White Salmon River Hatchery were derived at least in part from Carson fish (Howell et al. 1985).

A dependency of both the Leavenworth and Entiat hatcheries on Carson fish through the 1970s into the 1981 brood year ultimately gave way to full hatchery production from spring-run salmon returning to the respective hatcheries (Peven 1992b). Presumably, the current brood stocks of both hatcheries reflect a virtually 100% Carson Hatchery ancestry. The contributions of these massive releases and other exogenous releases to the wild populations of these drainages (Mullan 1987) are unknown.

The exogenous summer/fall fish recorded in Table 21 are introduced from a more extensive geographic range than the spring-run fish, the Simpson Hatchery being within the drainage of the Chehalis River of the Washington Coast. However, exogenous spring-run fish introduced from the Willamette and Cowlitz drainages are separated by the greatest genetic distance from the indigenous chinook populations upstream from Rock Island Dam (Utter et al. 1989).

The above account of the GCFMP and of subsequent hatchery activities on chinook salmon populations of the mid-Columbia River are but a brief synopsis of the overall and continuing influence of these activities (cf. an earlier section of our report, Chapman et al. 1994a, Mullan 1987 and references therein for comprehensive background information). Nevertheless, the material presented is sufficient to document profound actual and potential effects on these populations. The following section considers some of these effects.

Synthesis from genetic and historical information

Joint consideration of the genetic and historical information provides additional insights into the current status of spring-run chinook salmon populations upstream from Rock Island Dam. The major points from these preceding sections include:

- spring-run populations are genetically distinct from summer/fall fish;
- the strongest evidence for genetic isolation within the spring-run fish

came from adult collections of the White River, and the existence of isolated wild populations was suggested within the Methow drainage;

- both of these possibilities require verification with further sampling;
- the basis for all current distributions upstream from Rock Island Dam lies in relocations and mixing of populations over five consecutive years under the GCFMP;
- releases of cultured fish under the GCFMP included possible crosses between late spawning spring-run and early spawning summer/fall fish;
- extensive subsequent releases have included origins from gene pools beyond the mid-Columbia River;

What further conclusions can be derived from this combined information? First, there are no detectable residual effects from the mixed spring-summer releases under the GCFMP. No intermediate groups are evident in Figures 39-41 to suggest persistence of a hybridized spring-run x summer/fall ancestry. Inspection of the allelic data of the presumed distinct White River spring-run population indicates a recent (i.e., post GCFMP) divergence from pure spring-run ancestry; no alleles or allele frequencies are apparent that tend toward the summer/fall group.

Similarly, most of the populations represented in the exogenous releases (Table 21, Figure 41) appear to have left no detectable descendants. Each population derived from or beyond the lower Columbia River (McKenzie, Spring Creek, Eagle Creek, Cowlitz, Simpson, Elokomin) represents lineages distinct from either of the resident groups produced upstream from Rock Island Dam (Utter et al. 1989). Presumably, these fish and the above-noted hybrid progeny were poorly adapted to the habitats of their release and failed to make a permanent contribution to the mid-Columbia River gene pools.

The lower river populations that derived from mixed upriver ancestry tell a different story. The continued infusion of Carson-derived spring-run fish ultimately resulted in self-sustaining mid-Columbia River hatchery populations, and is discussed in greater detail in a subsequent section of this report.

There seems little doubt that chinook salmon populations can adapt quickly to new environments. Quinn et al. (1995) discuss the rapid apparent adaptation of chinook salmon liberated in New Zealand about 1905. They point out that if the differences (freshwater age, marine age, length at age, weight at length, fecundity at length, and timing of migration and spawning) are caused by genetic divergence, such rapid evolution would provide a new perspective on the stock concept in salmon. Populations would be seen as more plastic than commonly believed. Research now underway with New Zealand salmon reared under controlled conditions will reveal whether the noted differences are genetic or environmental responses.

Genetic effects of hatchery fish on wild spring chinook

Waples (1991a) described the potential for hatchery salmonids to interact with wild fish, arguing that it has increased in recent decades. He listed three issues: (1) direct genetic effects caused by hybridization and introgression; (2) indirect genetic effects largely due to altered selection regimes or reduced population size caused by competition, predation, disease, or other factors; and (3) genetic changes to hatchery stocks through selection, drift, or stock transfers, which magnify consequences of various management options.

Direct genetic effects:

Homing permits local adaptation. If hatchery fish, such as Leavenworth or Winthrop hatchery fish with extensive Carson Hatchery background, strayed extensively into tributaries used by wild spring chinook, one might expect hybridization to occur with detectable consequences. No direct evidence exists that such hybridization has occurred in Wenatchee or Methow tributaries used by wild chinook in spite of similar allele frequencies of Leavenworth Hatchery fish and wild stocks of the Chiwawa River and Nason Creek. Chapman et al. (1991) extensively reviewed information on homing in spring chinook. They noted that carcass checks in the mid-Columbia region revealed very limited Leavenworth Hatchery strays among tags sampled in 967 carcasses examined within Wenatchee River tributaries (excluding Icicle Creek) or in the Entiat and Methow rivers. Many hatchery tags were recovered from Icicle Creek, into which Leavenworth Hatchery fish are released. Quinn and Fresh (1984) reported that straying was higher in older spring chinook, reaching over 3% in fish five years old, but for all combined ages equaled only about 1.4%. They also found that straying rate was higher in small escapements than in large ones. Straying was 3.8% for an escapement of about 4,500, 2.3% for an escapement of 6,134, and 1.6% and 0.3% for respective escapements of 12,384 and 18,069.

Peven (1992b) surveyed spawning grounds in the Wenatchee River basin in 1992. He reported counting of 528 spring chinook redds, of which 93% were in principal tributaries and 7% in the upper Wenatchee River. He assumed that the 491 redds found in tributaries other than Icicle Creek were created by wild/natural spawners, although redd counters found one carcass with the adipose fin clipped from each of the Little Wenatchee, Chiwawa, and upper Wenatchee rivers. Pacific States Fishery Management Council (PSFMC) (1993) records release of 2,086,716 unmarked spring chinook yearlings of brood year 1988, and 183,989 fish with coded wire tags and adipose clips. In addition, 298,462 zero-age subyearlings, all marked with wire tags and adipose clips, were released from the same brood year. All marked fish were released in Icicle Creek. If we assume that strays into natural spawning areas would consist mostly of fish from Leavenworth Hatchery releases, and not from hatcheries in other mid-Columbia tributaries or other basins, then three carcasses with adipose clips could represent as many as 13 hatchery strays [(2,086,716 unmarked/482,451 marked) x 3 = 12.9 fish]. If the strays consisted only of adults from the zero-age release, which were all marked, then three marked carcasses represents only three fish. In summary, if we assume 2.4 adults per redd (Mullan 1990), 1,178 adults escaped to the principal tributaries used by Wenatchee River wild spring chinook. The stray rate probably equaled about 1% if all strays came from Leavenworth Hatchery releases. We would expect no negative effects of Leavenworth Hatchery strays on wild gene pools in the spring chinook spawning areas of the Wenatchee River.

Information is very limited on negative effects of hybridization of wild and hatchery chinook. Williams (1990) reported that declines in chinook salmon redds in hatchery-supplemented streams have exceeded those in unsupplemented streams. Nickelson et al. (1986) reported declines in coho (*O. kisutch*) populations where hatchery coho were used to supplement natural production. As Waples (1991a) points out, such declines are doubly damaging if wild runs are "mined" to produce hatchery fish with lower survival than progeny of wild adults.

Indirect genetic effects:

Large numbers of hatchery fish, mixed with wild ones, can lead to excessive harvest on the wild run component. Where excessive escapement of hatchery fish occurs, even a small percentage of straying can lead to a high fraction of hatchery fish in wild production areas. Hatchery fish of Carson origin, released in the main Grande Ronde River, strayed to, or colonized, wild fish sanctuary areas in the Wenaha and Minam rivers, and made up over 70% of spawners in those areas in at least two years (Grande Ronde subbasin plan, ODFW et al. 1989).

Waples (1991a) noted that large numbers of hatchery fish, which migrate in a relatively short time period and with a numerical spike, led managers to deliver water budget flows to assist downstream passage of those large numbers, rather than rationing water to meet the needs of the protracted movement of wild stocks (Chapman et al. 1991; Achord et al. 1995). The indirect genetic effect may have been to increase migration mortality of wild fish, if one assumes that smolt survival increases because of water budget flows.

Elsewhere in our report, we discuss another indirect effect of hatchery fish on genetics. Ocean carrying capacity may be limited and density-related interactions may occur at sea (Beamish and Bouillon 1993). To the extent that hatchery-produced fish reduce carrying capacity of ocean rearing areas for wild fish, an indirect genetic effect can occur.

Any factor that affects abundance of wild populations can also alter selective pressures and cause directional genetic change in wild stocks (Waples 1991a). Examples include selective fishing pressure caused by propensity of wild Snake River chinook to stay at sea more often for three years instead of two years (Chapman et al. 1991). In the mid-Columbia region, hatchery and wild spring chinook do not differ materially in number of years that they spend at sea. Longer time at sea could expose wild fish to relatively more incidental catch and hooking-related mortality, as well as natural mortality. Gill nets may tend to take larger fish, selecting against three-ocean wild fish. Both fisheries would appear to be minor in potential effect at present harvest rates.

Genetic changes in hatchery stocks:

Waples (1991a) cited Utter et al. (1989) and Waples et al. (1990) as demonstrating no trend toward reduced heterozygosities in hatchery chinook salmon in comparison with wild chinook in the same region. Waples and Teel (1990) and Waples and Smouse (1990) found unexpectedly high allele frequency changes and gametic disequilibrium in hatchery, but not wild, chinook stocks from the Oregon coast. Those authors suggested that the explanation lay in the low effective number of breeders (N_b) < 50). Waples (1991a) suggests that a figure in this range is possible for many of the hatcheries included in the study by Waples and Teel (1990).

Evolutionarily significant units

The U.S. Endangered Species Act (ESA) as amended in 1978 mandates protection of "distinct population segments" of vertebrates as well as of recognized species and subspecies. The concept of the evolutionarily significant unit (ESU) provides a logical and biologically sound framework for defining such intraspecific segments (Waples 1991b). To be considered as an ESU, populations must (1) be substantially reproductively isolated from other conspecific populations units, and (2) must represent an important component in the evolutionary legacy of the species.

Basic questions to be considered in defining an ESU include:

- Is the population genetically distinct from other conspecific populations?
- Does the population occupy unique habitat?
- Is the population uniquely adaptated to its environment?
- If the population became extinct, would this event represent a significant loss to the ecological/genetic diversity of the species?

Waples (1991b; 1991c) further suggested that ESUs should correspond to larger, more comprehensive units unless there is clear evidence that evolutionarily important differences exist between smaller population segments. These questions and criteria guide considerations of chinook salmon populations of the mid-Columbia Region as possible ESUs.

The clear genetic isolation of spring-run and summer/fall chinook upstream from Rock Island Dam qualifies them for separate consideration as ESUs. Although the exogenous ancestry within the hatchery component may preclude this segment of spring-run fish from ESU status (Hard et al. 1992), Waples (1991c) cautions that some interbreeding may be allowable for ESU status, noting: *The key question to consider is whether stock mixing has compromised the* *evolutionarily important adaptations that distinguished the original population.*

Another pertinent question is whether or not spring-run chinook upstream from Rock Island Dam are (or ever were) genetically distinguishable from Snake River spring/summer chinook. The two groups are certainly closely related (Figure 42). The ESU status presently granted to the Snake River group (Matthews and Waples 1991) might conceivably be extended to populations upstream from Rock Island Dam, but only if one considers that Carson Hatchery spring chinooks form a discrete ESU.

Comparisons of allele frequencies of these two groups indicate overlapping among collections for comparable data at many loci (Appendix 8, Waples et al. 1993). Nevertheless, plottings of common allele frequencies for two loci, <u>sSOD-1*</u> and <u>sIDHP-1*</u> (Figure 43), indicate a persisting genetic distinction between the groups. These differences, coupled with geographic isolation and distinct habitats contrasting the Snake River and the Columbia River upstream from Rock Island Dam (Chapman et al. 1991, Utter et al. 1982) suggest sufficient genetic, geographical and ecological isolation to prevent expansion of the Snake River ESU to the Columbia River upstream from Rock Island Dam.

In addition, the genetic differences of Figure 43 comport with Leavenworth Hatchery (and Carson) fish having predominantly mid-Columbia origins, suggesting either initial numerical superiority or adaptive advantage of these fish in derivation of the Carson stock. Consequently, the hatchery component cannot presently be excluded from being part of an ESU (or ESUs) of spring chinook salmon upstream from Rock Island Dam. The ESU status among these populations is complicated by the GCFMP and hatchery activities. Certainly the wild Methow and White River fish might qualify as separate ESUs if further data verify their existence as a distinct population segments. For the moment, this question remains open.

Adaptations within apparently homogenous groups:

ESUs, being based on distinctions from other intraspecific groups, provide a sound biological basis for proscribing admixtures beyond their boundaries because of the likelihood of the existence of strongly contrasting adaptations independently evolved in different groups. However, definition of an ESU by no means implies a single panmictic unit (Waples 1991b). An apparently homogeneous group may very well warrant subdivision upon accumulation of additional positive data (cf. Utter et al. 1992). The greatest value in identifying any ESUs of spring chinook salmon upstream from Rock Island Dam is therefore to identify and protect their component groups to prevent breakdown of their adaptations.

The failure to distinguish temporal or geographic differences among the sampled groups does not "prove" the absence of such differences. This possibility is illustrated through the data presented for the presently considered spring-run populations that would form a much more homogenous grouping if the White River population had not been sampled. The possibility of White River, Methow drainage and other as yet unsampled remnant geographic isolates being components of one or more ESUs within this region remains to be determined.

Evidence for actual or apparent hybridizations between groups alone is insufficient to document a breakdown of between-group distinctions. Obviously the spring-run and the summer/fall chinook populations above Rock Island Dam retained their respective identities in spite of extensive opportunities for natural hybridization and possibly inadvertent hybridizations through cultural activities between the groups under the GCFMP. As noted above, the reduced fitness of the hybrid fish presumably precluded their ability to measurably contribute to subsequent generations in competition with non-hybridized native fish.

Persistence or evolution of adaptive distinctions in the absence of conspicuous genetic differentiation is well documented (e.g., Gharrett and Smoker 1993). Such differences are possible because of the more rapid evolutionary time scale for genetic divergence of strongly adaptive characters (e.g., run timing) in contrast with more neutral characters such as the multiple polymorphic protein-coding loci used in this study (cf. Utter et al. 1993). Thus, adaptively distinct, geographically isolated groups certainly exist that are not strongly differentiated by the genetic markers of this study such as those remnant wild chinook populations considered above within the Snake River and upstream from Rock Island Dam; because of the GCFMP, any such adaptations within the latter area would have occurred after 1939.

Release data for spring-run chinook from the Leavenworth Hatchery (Appendix 1) provide direct evidence for this kind of rapid adaptation without measurable genetic differentiation. Populations of the Carson and Little White Salmon hatcheries, originating from interceptions of spring-run fish destined for the mid-Columbia and Snake rivers, were released from the Leavenworth Hatchery into Icicle Creek from 1971 through 1982. The initial dependency on these sources gradually subsided as numbers of returning releases gradually increased to the point where they have constituted the entire brood stock after 1983. Adaptation to this upstream hatchery environment apparently occurred over approximately three generations in the absence of divergence of allele frequencies of multiple polymorphic loci (Utter et al. 1989; Matthews and Waples 1991b). Improved adaptations of transplanted chinook salmon over successive generations have been previously reported for chinook salmon (Ricker 1972). Similarly, divergence of a single-source seeding of chinook salmon in New Zealand into diverse habitats and life history patterns (Quinn and Unwin 1993) attests to the evolutionary flexibility of the species given such opportunity.

Conclusions and recommendations regarding genetics

We use population genetic data from three different sources to estimate the degree of genetic divergence among spring-run chinook salmon upstream from Rock Island Dam. These fish are genetically distinct from summer/fall chinook salmon occurring in the same area, and from spring/summer chinook salmon of the Snake River, although they are closely related to the latter group.

All spring-run chinook populations upstream from Rock Island Dam are tentatively considered members of a common ESU. Some evidence supporting the possible existence of isolated population segments of wild fish collected from the White River and within the Methow River drainage suggests the possibility of separate ESUs, pending verification of their distinctness with additional data.

Any existing divergence is very recent, having occurred since the relocation and confinement imposed through the implementation of the GCFMP between 1939 - 1943. Further potential erosion of indigenous gene pools relates to the extensive use of hatchery supplementation in this area. Stocks originating from mixed origin Carson fish gradually adapted to upstream hatcheries, ultimately resulting in the complete use of returning fish as brood stock. To minimize the possibility of loss of indigenous gene pools through hybridization or displacement, these cultured fish should not be outplanted in areas where potential native populations exist. Present policies accord with this prohibition, as enhancement programs for Chiwawa and Methow River wild fish use naturally-produced adults as brood stock from specific tributaries, and return pre-smolts to tributaries of parental origin.

HABITAT SETTING

Chapman et al. (1994a) reviewed Mullan et al. (1992b), WDW et al. (1989), Mullan et al. (1986), WDF et al. (1990), and other documents, summarizing the geology, land form, climate, and vegetation characteristics of the mid-Columbia region. We will not repeat those summaries here. Because the emphasis in Chapman et al. (1994a) was on the condition of stream habitat in the middle and lower reaches of the main tributaries used by summer/fall chinook, Chapman et al. (1994b) augmented habitat information with some elaboration of detail on tributaries used by summer steelhead. That augmented information also applies to habitat of spring chinook.

Mullan et al. (1992b) state:

> *Despite some abuse from recent activities of humans, there appears to be little or no net loss of the functional features of mid-Columbia River tributaries......Water quality of the Wenatchee, Entiat, and Methow rivers is essentially pristine.*

They conclude:

> *Man-made dams and irrigation have reduced anadromous salmonid habitat by 12% for the Wenatchee, 3% for the Methow, and not at all for the Entiat River.*
>
> *Mining, grazing, logging, and road construction are not widespread problems for salmonids in the Wenatchee, Entiat, and Methow river drainages. Wildfires have been a problem, but occurred naturally before humans became a major factor in the ecosystems. Sediment now delivered to the Wenatchee, Entiat, and Methow rivers from human activities is about 10% above natural background levels. Sediment delivery is too small and stream gradients too high for negative impact on salmonid habitat.*
>
> *Stream channels are stable, and retain annual peak flows within their banks during most run-off. Extreme floods limit riparian vegetation.*
>
> *About 16%, 28%, and 21% of the mean monthly flow is diverted for irrigation in August, September, and October in the Wenatchee River (RM 21.5). Similar values for the Entiat River (RM 0.3) are 5%, 9%, and 8%, respectively. Annual depletion in river discharge from irrigation on the Methow River varies 28% to 79%*

August to October, depending on reach and return flow. We found no appreciable difference in habitat and salmonid standing crop with irrigation diversion except in grossly dewatered stream reaches...... Turn-of-the-century sawmill, hydroelectric, and unscreened irrigation diversion dams devastated salmon, but these problems have long been corrected. The only dams affecting the Wenatchee, Entiat, and Methow rivers are on the Columbia River.....

We do not mean to minimize the importance of local habitat degradation in mid-Columbia tributaries. Water withdrawal is a serious local concern. Much of the upper Methow River lies upstream from irrigation return flows, and in a permeable glacial deposit. Thus it tends to be a losing stream were the stream surface lies above the groundwater table adjacent. Without the influence of irrigation, some reaches of the upper Methow are alternately watered and dewatered (Mullan et al. 1992b). In the Methow basin, irrigation is known to dewater portions of Gold Creek, Benson Creek, and Beaver Creek. Flow is much reduced by irrigation in the Twisp River, Wolf Creek, Goat Creek, and Early Winters Creek. Irrigation withdrawals would be especially severe in effect in drought years.

Water use in the Okanogan system is the primary cause of seasonal low or intermittent flows. Surface waters were over-appropriated in the early 1900s, with resulting loss of spawning and rearing for chinook in the Chiliwist, Loup Loup, Bonaparte, and Salmon creeks, with the loss of the latter termed "particularly devastating" (WDW et al. 1989). The significance of loss of the first three streams is doubtful, as no record is available that spring chinook ever used those streams (see Craig and Suomela 1941). If any chinook used them, we would expect the fish to have been spring, rather than summer/fall, chinook. Omak Creek, according to Fulton (1968) was lost to spring chinook as a result of irrigation water withdrawals. However, none of the sources cited for his conclusion (WDF 1938; French and Wahle 1960, 1965; and Fish and Hanavan

1948) supports him, although Bryant and Parkhurst (1950) mention limited use of Omak Creek by spring chinook.

Wissmar et al. (1994) mention the effects of mining on Salmon Creek:

> *A prime example of an affected system was Salmon Creek near Okanogan City. Salmon Creek was essentially destroyed by the rapid construction of the Ruby and Conconully town sites and development of claims throughout the drainage. By 1888 about 13 miles northeast of Okanogan City, Ruby City extended a quarter of a mile within and adjacent to the channel of Salmon Creek. The destruction of Salmon Creek has been said to be particularly devastating to spring chinook salmon (WDW et al. 1989).*

McIntosh et al. (1994) examined information on pool volumes that the U.S. Bureau of Fisheries (BOF) had measured in the period 1934-1942. They compared those volumes in certain sites to volumes measured 1990-1992. The BOF surveyed pool volumes at continuous 100-yd intervals, generally from the river or stream mouth to the upstream extent of anadromy. Within each 100-yd unit, the survey assessed channel width, bottom substrate, and counted number of pools by size class. McIntosh et al. (1994) state that the modern survey methods that they used were comparable to the BOF methods. Comparisons were made for areas managed (subjected to multiple use for timber, livestock, agriculture, and mining) and unmanaged (minimally affected by human disturbance, such as wilderness and roadless areas) in the the Methow and Wenatchee river basins. Methods used in the BOF survey are detailed in Rich (1948). In the absence of contact between surveyors of the BOF and those reported by McIntosh et al. (1994), some uncertainty inevitably arises about method comparability with respect to measurements. For instance, Rich (1948) describes how one man surveyed stream segments, with a second man taking a vehicle two or three miles upstream and beginning another solitary survey. Rich also states that widths were determined with a survey tape. It would be impossible for one man to measure widths with a survey tape in mainstem reaches of the Wenatchee and Methow rivers.

Rich (1948) noted that the BOF survey counted "resting pools," which were over six ft deep (also called "good" pools), and pools 2-6 ft deep ("fair" pools). Some room for error may derive from those designations. Furthermore, stream discharge at the time of the survey would partly govern pool depth. Finally, the early and later surveyors may have counted small and tiny "good" pools differently.

In spite of certain reservations that we have about direct comparisons of pool volumes, *counts* of pools over 6 ft deep could be useful in comparing data from the 1930s and 1940s with present conditions. In 146 km of managed watershed areas in the Methow River (Chewack River - 33.9 km; Methow River - 69.7 km; Twisp River - 42.5 km), counts of large pools increased from 4.9 to 7.7/km, a 57% increase. In 33.6 km of managed areas in the Wenatchee River (entirely in Nason Creek), counts increased from 4.9 to 7.7/km, also a 57% increase (McIntosh et al. 1994). In unmanaged reaches of the Methow River, in 30.2 km (Chewack River only), pool counts rose from 1.0 to 3.4/km, a 240% increase. In 80.2 km of unmanaged areas in the Wenatchee River (6.9 km in Jack Creek, 14.2 km in Icicle Creek upstream from the anadromous zone, and 59.1 km in the Chiwawa River), counts rose from 2.5 to 7.5/km. These data apply only to the areas surveyed in the 1930s and 1940s and in 1990-1992. They may not accurately indicate basin-wide changes even if they accurately indicate changes in index areas. Nonetheless, the data suggest that pool frequency in managed and unmanaged areas may have increased over time. If the comparison of McIntosh et al. (1994) is valid, the results comport with Mullan et al. (1992b), who thought the major tributary basins of the mid-Columbia region had generally suffered little function loss as fish habitat (however, Mullan et al. (1992b) directed most of their observations to the Wenatchee and Methow rivers, and did not report conditions in the Okanogan River basin).

Conditions in the Columbia River estuary and lower Columbia River have been reviewed elsewhere (Chapman et al. 1994a, 1994b).

SPAWNING AND INCUBATION

Prespawning mortality

Mullan (1990) divided escapements by spawner/redd ratios of 2.4 to account for prespawning mortality. This procedure implicitly assumes a prespawning loss of about 17%. Mullan's sources for the 2.4 divisor were Kohn (1988) for the Methow River and Hollowed (1983) for the Yakima River. Chapman et al. (1991) estimated much higher prespawning loss (40-50%) in Snake River spring chinook, citing results on the Warm Springs River obtained by Lindsay et al. (1989), Bjornn (1990), Levendofske et al. (1989), and the Salmon River subbasin plan. Lower prespawning loss was estimated in the Rogue River, Oregon. From 1977 to 1981 the loss averaged 12% (range 6-34% for the five years) for wild spring chinook and 36% (range 12-80% for the same years) for hatchery fish (Cramer et al. 1985).

Stuehrenberg et al. (1994) reported that over 85% of radio-tagged spring and summer/fall chinook that passed Priest Rapids Dam were last detected in tributaries. Unfortunately, that estimate of arrivals in tributaries does not integrate all pre-spawning loss after fish arrived in tributaries, and some fish may have arrived in tributaries undetected, as did some radio-tagged fish that entered Ringold Spring Chinook Facility.

Scribner et al. (1993) summarized the percentages of completely-spawned female spring chinook in the Methow River as 89%, 90%, 88%, 95%, 90%, and

92% for the respective years from 1987 through 1992, and 92.6% in 1993. The complement is not mortality, for it includes some partially-spawned carcasses. In 1993, for example, 5.9% of carcasses examined were completely unspawned, and 1.5% were partially spawned with 500 eggs or more remaining.

Scribner et al. (1993) provided a table (their Table 1) that summarizes, for 1987-1993, estimated spring chinook spawners upstream from Wells Dam, the total redd count, and calculated fish per redd. The mean number of fish per redd across the seven years equaled 2.32. If we assume two fish are required per redd, prespawning loss can be calculated as 14% (100(1.0-(2.0/2.3))).

For one year, 1993, we can examine the potential error caused by fallback at Wells Dam. In 1993, Stuehrenberg et al. (1993) report about 3% fallback for spring chinook. In that year, the fish-per-redd statistic was 2.51 (Scribner et al. 1993), calculated as 617 redds for an escapement of 1,546 fish. The true escapement should probably be reduced by 3% to account for fallback, which would lead to an adjusted escapement of 1,500 fish, and adjusted fish/redd of 2.43. Thus, prespawning loss would be about 18%.

In our report section on redd-based estimates of spring chinook abundance, we noted that those estimates, together with abundance of hatchery fish and estimated sport harvest, average about 81.5% of the Rock Island count of spring chinook. Those data would suggest a pre-spawning loss of about 18.5%. We found no evidence in the literature that prespawning losses higher than 20% were the norm in the mid-Columbia region for spring chinook.

Incubation and emergence

Although incubation connects inextricably to spawning habitat, the requirements of embryos during incubation differ from those of spawning adults. Obviously, when a female chinook selects a nest site, she also selects the incubation environment. Successful incubation and emergence, however, depend on many extragravel and intragravel physical, chemical, and hydraulic variables (Chapman 1988). We do not describe those variables in detail, but rather describe what we know about incubation and emergence of spring chinook salmon in the mid-Columbia basin.

As described in Chapman et al. (1994a), the length of time required for chinook eggs to incubate in gravel depends largely on water temperature, but also varies with region, habitat, and season. The colder the temperature, the slower will be the developmental rate of the embryo and the longer the time to hatching. Chinook eggs can incubate and hatch successfully at water temperatures of 4-16°C; however, they can tolerate lower temperatures in the later stages of embryonic development (Combs and Burrows 1957; Combs 1965; Piper et al. 1982). Piper et al. (1982) report that it takes about 750 daily temperature units (1 temperature unit = 1°F above freezing for a period of 24 hrs) for chinook to hatch. No one has assessed the length of time required for naturally-produced spring chinook to hatch in the mid-Columbia basin. Where females select spawning areas with subgravel flows that result from groundwater upwelling, water temperatures in the gravels may change much less than do surface water temperatures throughout the incubation period. In these areas, variation in emergence time would result primarily from differences in time of egg deposition. In areas not influenced by groundwater, hatching times may vary more widely.

The time from hatching to fry emergence also depends on temperature and, to a lesser extent, on dissolved oxygen concentrations, light intensities, and genetic variation (Beacham and Murray 1990; Bjornn and Reiser 1991). Piper et al. (1982) report that about 850 daily temperature units beyond hatching are needed for fry to emerge (1,600 dtu °F from egg to emergence). Fast et al. (1991) report that spring chinook in the Yakima River required on average 1,600 TUs for first emergence. They found that on average 2,259 TUs were required for complete emergence. Brannon (1987) points out that the time of spawning and fry emergence within a population relates directly to the incubation temperature.

He notes that a curvilinear relationship exits between incubation temperature and the rate of development, indicating increased compensation as temperature drops. Thus, within the temperature ranges encountered during incubation in natural spawning grounds, fewer temperature units are required at lower temperatures. Embryos require more thermal units to hatch at higher temperatures. Brannon (1987) also notes that more thermal units are required if oxygen levels in the redd drop toward poor conditions for survival. This compensation reduces the influence of year-to-year variability in temperature cycles, which otherwise would cause a wide range in time of emergence.

Depending upon the temperature regime of the natal stream, eggs hatch in the late fall or early winter. After hatching, alevins remain in the gravel 4-6 weeks or more, until the yolk sac is absorbed (Dill 1969). During this period, alevins are negatively phototactic and positively geotactic and thigmotactic. According to Godin (1981), these characteristics encourage further submergence into the gravel and prevent premature emergence. Dill (1969) notes that alevins tend to remain relatively inactive unless excessive levels of carbon dioxide or metabolic waste force them to disperse. Fast et al. (1991) found that alevins also disperse to avoid desiccation during low flow. As the yolk sac is absorbed, alevins develop positive rheotactic and phototactic responses and begin an upward migration in the gravel (Dill 1969). Godin (1981) reports that gravel size, interstitial spacing, rate of water flow, dissolved gases, and water temperature govern intragravel movement. Chinook fry usually emerge from the gravel at night, probably to avoid predators (Bams 1969).

We found very little information on the time of emergence of spring chinook in the mid-Columbia basin. Tuttle (1948) mentions emergence as early as February 11 in 1947 in Nason Creek. Trapping in the Chiwawa River in 1993 by WDFW indicates that chinook emerge in that system as early as 16 March (Petersen et al. 1993). Smolt trapping in the Chewack River in 1993 by the Yakima Indian Nation indicates that fry emerge before mid-April (Hubble 1993). In

1994 they observed fry in late March in the Chewack River and in early March in the upper Methow River (J. Hubble, personal communication). Although there is an increased compensation at lower incubation temperatures, it is insufficient to prevent chinook from emerging later in colder environments. For example, Mullan et al. (1992a) captured chinook fry in Icicle Creek, a cold incubation environment, in early April 1989. We would expect that chinook also emerge late in Early Winters Creek because of its cold water temperatures.

Egg-to-emergence survival

Chinook eggs are particularly vulnerable to shock injury (Allen and Hassler 1986). Injury can result from gravel movement caused by bottom scouring, mechanical impaction, or superimposed spawning activity. Low dissolved oxygen, high concentrations of toxic chemicals, high water temperatures, infestations of fungi or oligochaetes, predation by insects or fish, dewatering, freezing, and heavy sedimentation also kill eggs. Under poor conditions, egg mortality may be as high as 95% (Gangmark and Bakkala 1960). Under ideal conditions the mortality may be as low as 10% (Briggs 1953). Tuttle (1948) mentions that in Nason Creek in 1947,

> *......nests on the lower part of the stream were destroyed by moving ice jams, and at some stations the gravel bars containing the nests were washed away to a depth of 12 inches or more. It is believed by the writer, that considerable loss of eggs and fry occurs during the time that the ice moves out of the smaller tributary streams in this area.*

Survival from egg to hatching has not been assessed for spring chinook in the mid-Columbia basin. Shelton (1955) investigated the survival-to-hatching of eggs planted at different depths in two sizes of gravel in artificial stream channels with several different percolation rates. He concluded that survival to hatching was greater than 97%, regardless of planting depth or gravel size, provided percolation rate was at least 0.03 cm/s. This is consistent with Gangmark and Bakkala (1960), who report that mortality of eggs increases if percolation rates decrease. They observed mortalities of 2.9% at 0.034 cm/s and about 40% at 0.0042 cm/s. Under more natural conditions, Vronskiy (1972) reported survival of 97% to hatching, while Briggs (1953) estimated survival at 82%. Mean survival rates probably vary among the mid-Columbia River tributaries because of different temperature regimes and siltation rates, but we find no reason to think that they would decrease below about 80%.

No one has assessed the percentage of chinook eggs that survive to emergence in the mid-Columbia Basin. One reason is that estimating survival to emergence of chinook in the basin poses significant problems, because some fish migrate downstream to other rearing areas as fry and others rear for a variable length of time before migrating downstream (Hubble 1993; Petersen et al. 1993; Hillman and Miller 1994). Counts of downstream migrants or counts of chinook fry in rearing areas, therefore, would provide only minimum estimates of the number of fry that emerged. Furthermore, it is quite difficult to assess numbers of female spawners and egg voidance within all spawning tributaries. Even if all redds in the basin could be counted, which they cannot, and all post-spawning females recovered, it would be difficult to determine emergence success.

The literature indicates that egg-to-emergent fry survival of spring chinook ranges from about 9-90% (Table 22). In the Yakima River, Fast et al. (1991) studied emergence to assess egg-to-emergent fry survivals of spring chinook in 1985 and 1986. In 1985, they capped six chinook redds and estimated mean survival as 62.4%, ranging from 29.3% to 84.8%. In 1986, they capped eight redds and estimated mean survival as 56.7%, ranging from 21.9% to 90.0%. Combining both years, Fast et al. (1991) estimated an overall survival rate of 59.6%. In the Tucannon River, Bugert and Seidel (1988) estimated egg-to-fry survivals between 33% and 42%. Knox et al. (1984) estimated an egg-to-fry survival of 20.6% for chinook in the John Day River. In Lookingglass Creek, Oregon, Burck (1974) reports an egg-to-fry survival of 9.5%. The latter two reports probably underestimate the true egg-to-emergence survival because fry were counted after emergence. Healey (1991) indicates that under natural conditions, 30% or less of the potentially deposited eggs survive to emerge.

Survival of embryos and alevins in about a 10-mile section of the Methow River between Winthrop and the confluence of Early Winters Creek may be substantially lower than those elsewhere in the basin. This section occasionally becomes dewatered during the summer without irrigation withdrawal. Here, embryos may suffer high mortalities because of a reduction in oxygen concentrations and percolation rates. If the embryos remain damp, however, they may suffer no shortage of oxygen. For example, Becker et al. (1982, 1983) studied the effects of dewatering artificial chinook redds on survival and development rate of embryos at various stages of development. They note that alevins were most sensitive to both periodic short-term dewatering and a prolonged single dewatering, surviving at less than 4% in periodic dewaterings of one hour or a single dewatering of six hours. Eleutheroembryos were less sensitive, and cleavage eggs and embryos least sensitive. Embryos apparently suffered no ill effects from daily dewaterings of up to 22 hours over a 20-day period.

JUVENILE RESIDENCE IN TRIBUTARIES

The abundance of juvenile chinook salmon in the mid-Columbia tributaries is a function of many factors: abundance of newly emerged fry, quantity and quality of suitable habitat, abundance and composition of food, and interactions with other fish, birds, and mammals. We believe that numbers of adult chinook in the mid-Columbia basin increase as the abundance of juveniles (seeding levels) increase until an upper limit, i.e., carrying capacity, is reached. Hillman and Miller (1994) observed that mid-summer juvenile chinook numbers in the Chiwawa River increase with increasing escapement of adults. In the Warm Springs River, Oregon, Lindsay et al. (1989) found that the Ricker model best explained the relationship between number of spawners and recruits of spring chinook. It appears, therefore, that at relatively low seeding levels, environmental conditions that set the carrying capacity will place little constraint on the abundance of juveniles and adults. As spawner abundance approaches full seeding, biotic or physical factors that set the carrying capacity express themselves. Healey (1991) suggests that good redd sites are few in most rivers, and that fry and smolt production may be more related to the amount of good spawning area than to the number of spawners.

Theoretically, density-independent factors (amount of suitable habitat, quality of cover, productivity of the stream, disturbances, and certain types of predation) set an upper limit on the abundance of juveniles. Interactions that function in a density-dependent fashion (competition, disease, and some types of predation) hold the population to or about that level (Poff and Ward 1989). In the mid-Columbia basin, environmental factors such as temperature, suitable space, and water quality probably regulate the distribution and abundance of juvenile chinook. On a smaller scale, juvenile chinook respond to velocity, depth, cover, substrate, competitors, and predators. Although interactions among many of the relevant physical and biotic variables are not well defined for streams in the mid-Columbia basin, we next discuss what we know about juvenile rearing in tributaries and, where possible, identify factors that appear to limit the populations.

Egg-to-parr survival

Mullan et al. (1992b) estimated egg-to-parr survival rates of spring chinook salmon for tributaries of the mid-Columbia River. Using habitat quality index scores, they estimated egg-to-fall parr survivals of 2.7-4.3%, 3.1-4.7%, and 5.8-13.3% for the Wenatchee, Entiat, and Methow river basins, respectively. In the Chiwawa River basin, Hillman and Miller (1994) estimated egg-to-parr survival rates of 5.7% (95% CI 5.1-6.2%) and 9.5% (95% CI 8.0-11.0%) for brood years 1991 and 1992, respectively. The 5.7% survival for brood year 1991 is probably an underestimate for the basin because mid-summer parr densities were estimated only in the Chiwawa River. Later work included surveys in all chinook streams in the Wenatchee River basin. Mullan et al. (1992b) estimates an egg-to-parr survival rate of 9.8% for spring chinook in Icicle Creek. Using a Beverton and Holt model, Hubble (1993) estimates that egg-to-parr survival of chinook in the Chewack River ranges between 13% and 32%, depending on percent seeding level in the basin.

These estimates comport with those from other streams (Table 22). For example, Kiefer and Forster (1991) estimated a mean egg-to-parr survival rate of 5.5% (range 5.1-6.7%) for naturally-spawning spring chinook in the upper Salmon River basin. They also noted that egg-to-parr survival of natural spawners and adult outplants in the headwater streams of the upper Salmon River averaged 24.4% (range 16.1-32.0%). Petrosky (1990) reports an egg-to-parr survival range of 1.2-29.0% for chinook in the Upper Salmon River, Idaho. Konopacky et al. (1986) estimated egg-to-parr survival of chinook in Bear Valley Creek, Idaho, as 8.1-9.4%. Later work by Richards and Cernera (1987) in the same stream indicates an egg-to-parr survival of 2.11%.

Movements during rearing

When chinook fry emerge from the gravel, they mill about in an aggregation or they are displaced downstream. In tributaries of the mid-Columbia basin, many chinook fry are probably displaced downstream. Petersen et al. (1994) captured chinook fry emigrating from the Chiwawa River during spring (Figure 44). They estimate that 14,809 chinook fry emigrated from the river between 11 and 30 June 1993. Hubble (1993) also reports a spring emigration of chinook fry from the Chewack River. A large downstream movement of chinook fry immediately after emergence is typical of most chinook populations (Healey 1991). This initial movement reduces the clumped distribution of the fry and probably maximizes access to available food and space.

Chinook that elect to hold in the tributaries after emergence may emigrate almost any time of year. However, it appears that as the juveniles grow during the summer, they tend to move less. Petersen et al. (1994) documented fewer subyearling chinook emigrating from the Chiwawa River during the summer than during the spring and fall sampling periods (Figure 44). Downstream movement of chinook in the upper Methow basin is restricted throughout much of the summer because some of the Methow channel may dry upstream from Winthrop. Thus, fish in Early Winters Creek, the upper Methow River, and the Lost River must remain there until higher flows rewater the channel in the fall or winter. Not only do juvenile chinook disperse downstream, but there also appears to be an upstream movement. For example, Hillman and Miller (1994) observed juvenile chinook about 1.0 mile upstream from the upstream-most spawning site in the Chiwawa River. They also found juvenile chinook in Chiwawa tributaries in which no spawning occurred.

Movements in summer by spring chinook tend to concentrate in hours of darkness or during high turbidity (Burck 1993). Burck (1993) could detect no effect of moon phase on diel migration patterns in Lookingglass Creek, Oregon.

As stream temperatures decrease, juvenile chinook tend to move downstream in search of suitable overwintering habitat. Both Petersen et al. (1994) and Hubble (1993) report a large exodus of chinook from the Chiwawa and Chewack basins, respectively. Hubble (1993) estimates that 1,982 juvenile chinook emigrated from the Chewack basin between 21 September and 18

November 1992. Hillman and Chapman (1989) report an increase in the number of juvenile chinook primarily in the upstream reaches of the Wenatchee River during fall 1986 and 1987. They speculate that the increase was from spring chinook juveniles that moved out of tributaries. In an Idaho river, Bjornn (1971) documents the downstream movement of spring chinook during the fall months. He proposed that this migration represented a redistribution of fish to more suitable wintering habitat. Others (e.g., Bell 1958; Chapman and Bjornn 1969; Park 1969; Hillman et al. 1987) have also noted a downstream fall exodus of chinook from tributaries into larger rivers.

In summary, it appears that there are three major downstream movements of spring chinook in the mid-Columbia basin. The first occurs shortly after emergence when there is an extensive downstream dispersal of fry, although some fry take up residence in the natal stream near the spawning site. The second occurs during late fall when chinook migrate to suitable overwintering habitat, usually from the tributaries to the river mainstem. Finally, in the spring there is a migration of yearling smolts to the sea.

Habitat use

Juvenile spring chinook salmon that live for an extended time in the mid-Columbia tributaries select different day and night habitat seasonally. In the Wenatchee River, where mixed spring and summer/fall chinook live, Hillman et al. (1989a) observed chinook fry at stream margins in shallow water (<60 cm) and low velocities (0-10 cm/s) during the daytime. Those fish only used areas with instream cover (woody debris, vegetation, or large substrate) and overhead brush. In that habitat, Hillman et al. (1989a) found clusters of as many as 1,400 fry in 2 m^2. They found no clusters with less than about 240 fry. At night, the fry remained along the stream margins in quiet water (<1 cm/s) near cover (Hillman et al. 1989b). Some of those fish rested on the streambed. Hillman and Chapman

(1989) note that both day and night fry habitat in the Wenatchee River are scarce during high flows, and that the lack of suitable fry habitat may be one reason why summer/fall chinook fry leave the Wenatchee River. Chapman et al. (1994a) believe that fry habitat in the Methow River may also be scarce because it, like the Wenatchee River, has segments with unvegetated banks (e.g., eroded and laid-back banks) that would not provide suitable habitat for fry at high flows.

In the Wenatchee River, as juvenile chinook grow, they move into faster and deeper water during the daytime (Hillman et al. 1989a). This comports well with the observations of Everest and Chapman (1972), who report that with growth, juvenile spring chinook in Idaho streams move into water velocities and depths in proportion to body size. They felt that much of the indirect or underlying reason for this positive correlation was food supply. Higher-velocity waters bear a greater stream of food per unit of time. In the Wenatchee River, Hillman et al. (1989a) noted that most edgewater habitats used by fry in May and June had no water in July. From July through September, during low flows, Hillman et al. (1989a) found subyearling chinook during the daytime aggregated in more open water (deep pools), near woody debris wherever it was available, and close to boulder rip-rap at the stream margins. A few solitary (territorial) chinook selected stations in riffles. In August, Griffith and Hillman (1986) observed that juvenile chinook in the Methow River also used deep pools and selected stations close to woody debris and boulder rip-rap. Unlike in the Wenatchee River, however, more chinook used riffles than pools in the Methow River. During two years of sampling in the Chiwawa basin and Little Wenatchee River, Hillman and Miller (1994) observed chinook most frequently associated with woody debris in pools and multiple channel habitats. These habitats make up about 11% of the total area of the Chiwawa basin, but they provided habitat for more than 50% of all the juvenile chinook in the basin. Apparently chinook in the Chewack River also prefer sites with woody debris. Hubble (1993) notes that the reason for the exodus of chinook from the river was the lack of woody debris.

During the summer, juvenile chinook use different habitat at night than they do during the day. At dusk in the Wenatchee River, chinook move downstream and inshore and rest all night in shallow, quiet (<1 cm/s) water (Hillman et al. 1989b). At dawn, the chinook left night stations and typically moved downstream to daytime stations. As the fish grew they moved into deeper water at night, but still selected water velocities less than 1 cm/s. Most lay on sand or bedrock at night. Hillman et al. (1989b) also report that nighttime habitat in the Wenatchee River is abundant and probably does not limit the populations. Although no one has studied nighttime habitat use in other streams in the mid-Columbia basin, we have no reason to believe that chinook behave differently at night.

With the onset of winter conditions (i.e., when water temperatures drop below 10°C), juvenile chinook change habitat and behavior. Hillman et al. (1989a) observed that chinook in the Wenatchee River conceal themselves in the substrate, usually boulder rip-rap, when water temperatures decrease below 10°C during the daytime. At night some emerge from their daytime cover and rest on the substrate (Hillman et al. 1989b). They tend to select deeper water at night during the winter (70-146 cm) than they do during the summer (30-90 cm). According to Chapman et al. (1994a), most chinook in the Wenatchee River at this time are spring chinook that have immigrated from tributaries. In Icicle Creek, chinook conceal themselves in the substrate when temperatures drop below 10°C during the daytime (Mullan et al. 1992a). Spring chinook in an Idaho stream preferred clean substrate as concealment cover; however, when clean substrate was not available, chinook concealed themselves in woody debris or in overhanging vegetation (Hillman et al. 1987). With all the boulder rip-rap in the mainstem rivers and the available substrate and woody debris in tributaries, we doubt that winter habitat would limit numbers of juvenile chinook in the mid-Columbia basin.

Food and feeding

As far as we are aware, no one has systematically studied the food habits of juvenile spring chinook in tributaries in the mid-Columbia Basin. Both aquatic and terrestrial insects are consumed, as juveniles feed at the surface and in the water column (T. Hillman, personal communication). Chapman and Quistdorff (1938) found dipteran larvae, beetle larvae, stonefly nymphs, and leaf hoppers to be the most abundant diet items of juvenile chinook in tributaries of the mid-Columbia River. These observations comport with those of Martin et al. (1992), who report that spring chinook preferred, in descending order, beetles, mayflies, and stoneflies during the summer in the Tucannon River. Loftus and Lenon (1977) found that diptera, stoneflies, and mayflies were the most important components of the diet of chinook in the Salcha River, Alaska.

We can find no evidence to suggest that food is limiting in the mid-Columbia basin. Mullan et al. (1992a) note that stream invertebrate densities were generally less than $99/ft^2$ in the Wenatchee system and between 100 and $249/ft^2$ in the Methow system. Caddisflies, mayflies, stoneflies, and dipterans constituted the majority of the benthos. Mullan et al. (1992) also report that terrestrial insects such as bees and grasshoppers are abundant in the mid-Columbia basin. They found that salmonids in the Methow basin gorged themselves with bees. In southeast Washington streams, Martin et al. (1992) found no evidence that food limited production of spring chinook salmon or other salmonids, even though they consumed the same food items.

Growth

Direct estimates of the growth of juvenile spring chinook in tributaries of the mid-Columbia River do not exist. However, we can infer growth from seasonal or monthly changes in the size of resident or migrant chinook in the Wenatchee, Chiwawa, Chewack rivers, and Icicle Creek. These estimates we view with caution because the length of residence in streams is not known precisely.

In the Wenatchee River, where spring and summer/fall chinook mix, chinook grow to about 80 mm during the summer (Figure 45). In 1987, Hillman and Chapman (1989) noted that chinook increased in mean fork length from 48 mm in June to 84 mm in August. From August to November, however, mean size only 3 mm. In 1986, mean size of chinook in the Wenatchee River increased from 70 mm in July to 79 mm in October (Hillman and Chapman 1989). Chapman et al. (1994a) speculate that the apparent lack of growth of chinook during the summer is probably a result of the departure of larger, faster-growing chinook when they reach about 80 mm.

In Icicle Creek, growth of spring chinook varied among years 1985-1989 (Figure 46) (Mullan et al. 1992). Similar to Hillman and Chapman (1989), Mullan et al. (1992) note that chinook growth appeared to decrease during late summer. They indicate, however, that the larger fish left the index area, thus the true growth of chinook was probably underestimated. The WDFW (unpublished data) found that the mean sizes of chinook that emigrated from the Chiwawa River increased logistically during the period March through September 1994 (Figure 47). In 1993, they found that the mean sizes of chinook that emigrated from the Chiwawa River reached about 80 mm in September and did not increase during the period September through November. Weights of chinook captured by WDFW in the Chiwawa River increased exponentially during the sampling periods (Figure 48). Hubble (unpublished data) indicates that the mean sizes of chinook emigrating from the Chewack River did not increase rapidly during spring (Figure 49). His data also suggest that there is little change in the mean size of fish from September through November (Figure 49).

Again, we caution that these estimates probably do not represent the true growth of spring chinook in the mid-Columbia basin. Many estimates derive from fish trapped as they migrate downstream. Thus, there is no estimate of the sizes of fish that remained in the tributaries. On the other hand, studies like Hillman and Chapman (1989) measured sizes of fish that resided in the river, but not those that migrated. Mullan et al. (1992b) indicate that the Methow basin has a higher fertility than the Wenatchee basin. This is apparently why invertebrate production is higher in the Methow than in the Wenatchee (Mullan et al. 1992b). Therefore, all else being equal, we would expect better growth of chinook in the Methow basin than in the Wenatchee basin. Perhaps Early Winters Creek and the Lost River are exceptions because of their colder water temperature regimes.

Pre-smolt movement

Fish and Hanavan (1948) reported the principal migration of chinook juveniles in the upper Wenatchee River was in the spring: *Young chinook fingerlings - progeny of naturally spawning fish - were found in greatest numbers in Nason Creek and the upper Wenatchee River during late April and early May . . .* While they report the principal early-spring movement, they note:.... *a second, smaller migration accompanies the early fall freshets of September and October.*

French and Wahle (1959) found that juvenile chinook migrated past Tumwater Dam on the Wenatchee River (RM 33) from spring through late fall. Yearlings and subyearlings were captured in the spring and only subyearlings were captured in the summer and fall months (Figure 50). During the summer and fall months, catches of subyearlings peaked in late August, mid-September, and mid-October (Figure 51).[16] Periodic sampling of Nason Creek and the Chiwawa River produced fish sizes and run timing that comported well with the catches at

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[16] We believe, based on the timing of chinook past Tumwater Dam in the mid-1950s (French and Wahle 1959), that these fish were predominantly spring chinook, a thesis that agrees with Hillman and Chapman (1989) conclusion that fish in the upper reaches of the Wenatchee River that were present in the late summer-early fall were emigrants from the upper tributaries.

Tumwater Dam (French and Wahle 1959).

Petersen et al. (1994) found spring chinook emigrating from the Chiwawa River as pre-smolts from late summer through the fall (Figure 51). In general, movement from the Chiwawa River included some yearlings leaving as early as March, extending through May, followed by subyearlings leaving through the summer and fall (until trapping ceases because of inclement weather; K. Petersen, WDFW, personal communication). Similar run timing of smolts was observed in the Chewack River in 1994 (Figure 52; J. Hubble, YIN, personal communication).

Migrations of subyearlings out of the upper tributaries in the Wenatchee and Methow river basins comport with the findings of Fast et al. (1986a,1986b,1988) from the Yakima River (Figure 53), Burck (1993) in Lookingglass Creek, Oregon, and Lindsay et al. (1989) from the Deschutes River basin, where many subyearling chinook juveniles moved downstream in the fall. In some years, subyearling migrants in the fall outnumbered yearling spring migrants in the Yakima River (Figure 53).

Movement of juvenile chinook from the higher-order streams in the fall appears to be a response to the harsh conditions encountered in the upper tributaries. Bjornn (1971) related subyearling chinook movement in an Idaho stream indirectly to declining temperature in the stream as fish try to find suitable overwintering habitat. Hillman and Chapman (1989) suggested that biotic factors, such as intraspecific interaction for available habitat with naturally- and hatchery-produced chinook, nocturnal sculpin predation, and interspecific interactions may accelerate movement of subyearlings from the mainstem Wenatchee River. This may or may not be true of the higher order streams that feed the upper reaches of the Wenatchee River, which produce most of the spring chinook in that basin. Hillman et al. (1987) related subyearling chinook movement from an Idaho stream to declining temperatures, but acknowledged that it may consist of fish seeking higher-quality winter habitat, as suggested by Bjornn (1971).

From the above, it is apparent that some portion of each year class of spring chinook for a given year migrates downstream in the first year of life. These fish apparently rear overwinter in the larger tributaries. The proportion that survives and migrates to the sea the following spring is unknown.

Egg-to-smolt survival

Egg-smolt survival of spring chinook in tributaries of the mid-Columbia basin is difficult to estimate because some fish migrate downstream as fry or parr whereas others rear for a variable length of time in the streams before migrating downstream (see section on movements). Mullan et al. (1992b) estimated egg-to-smolt survivals of 1.35-2.15%, 1.55-2.35%, and 2.90-6.65% for spring chinook in the Wenatchee, Entiat, and Methow systems, respectively. Mullan et al. (1992b) calculated these survivals by extrapolating rearing densities for the total basin rearing areas by habitat quality index ranking with an assumed 40% overwinter survival. In the Chiwawa River, Petersen et al. (1994) estimated chinook egg-to-smolt survivals as 10.1% and 2.93% for brood years 1991 and 1992, respectively. They based their calculations on the number of spring smolts trapped near the mouth of the Chiwawa River. These survivals may not represent the true egg-smolt survivals of chinook in the Chiwawa basin because some fry and parr leave the basin early and may survive to smolt.

The foregoing estimates fall within the range of egg-to-smolt survivals reported in the literature (Table 22). Some of the highest egg-to-smolt survivals that we found were reported by Bugert and Seidel (1988) in the Tucannon River, Washington. Using a migrant trap on the lower Tucannon River, Bugert and Seidel (1988) estimated an egg-to-smolt survival that ranged from 13-22% between 1985 and 1987. In the Yakima River, Major and Mighell (1969) estimated that 5.4-16.4% of the potential spring chinook egg deposition survived to migrate as yearling smolts. Later work by Fast et al. (1989) indicates that, on average, 4.94% (range, 4.2-6.5%) of the eggs survive to migrate as smolts in the Yakima

River. In the John Day River, egg-to-smolt survivals of spring chinook were estimated as 3.6-8.6% (Knox et al. 1984), while Lindsay et al. (1989) reports spring chinook survivals of 2.1-8.7% in the Deschutes River.

Healey (1991) believes that estimates of survivals that are calculated by assessing potential egg deposition by counting redds and multiplying by the average fecundity of females, as is done in most studies, may be erroneous. In his view, this procedure is liable to give a positively-biased estimate of potential eggs deposited because false redds may be counted as true redds (negative bias), because redds may be missed, or because the fecundity of local stocks differs from that of the general population. Some of the biases that Healey (1991) lists tend to cancel each other.

Competition

For competition to occur in mid-Columbia River tributaries, demand for food or space must be greater than supply (implies high recruitment or that the habitat is fully seeded) and environmental stresses few and predictable. Few studies have addressed possible competitive interactions in the mid-Columbia basin. We believe that the most likely form of interspecific competition would be between juvenile chinook and steelhead. Hillman et al. (1989a, 1989b) investigated the interaction between summer/fall chinook and steelhead in the Wenatchee River between 1986 and 1989. They report that chinook and steelhead used dissimilar daytime and nighttime habitat throughout the year. During the daytime in summer and autumn, juvenile chinook selected deeper and faster water than steelhead. Chinook readily selected stations associated with brush and woody debris for cover, while steelhead primarily occupied stations near cobble and boulder cover. During winter days, chinook and steelhead used similar habitat, but Hillman et al. (1989a) did not find them together. At night during both summer and winter, Hillman et al. (1989b) found that both species occupied similar water velocities, but subyearling chinook selected significantly deeper water than steelhead. Hillman et al. (1989a, 1989b) state that the two species segregate because of disparate times of spawning.

Although the work by Hillman et al. (1989a, 1989b) examined interactions between summer/fall chinook and steelhead, it is likely that it applies to spring chinook as well. For example, Hillman and Miller (1994) found that chinook and steelhead segregated in the Chiwawa basin, Nason Creek, and the Little Wenatchee River. They note that chinook were more often associated with pools and woody debris during the summer, while steelhead occurred more frequently in riffle habitat. Observations by Hubble (1993) seem to suggest that chinook and steelhead segregated in the Chewack River. These observations comport well with those of Everest and Chapman (1972), who found that steelhead and chinook selectively segregated in Crooked Fork and Johnson Creeks, Idaho. They also noted that this segregation resulted from disparate times of spawning by the two species.

Under appropriate conditions, interspecific interaction may also occur between juvenile chinook and redside shiners. Hillman (1991) studied the influence of water temperature on the spatial interaction between juvenile chinook and redside shiners in the field and laboratory. In the Wenatchee River during summer, Hillman (1991) notes that chinook and shiners clustered together and that shiners were aggressive toward salmon. He reports that the shiners used the more energetically profitable positions, and that they remained closer than chinook to instream and overhead cover. In laboratory channels, shiners affected the distribution, activity, and production of chinook in warm (18-21°C) water, but not in cold (12-15°C) water (Hillman 1991). In contrast, chinook influenced the distribution, activity, and production of shiners in cold water, but not in warm water. Although Hillman (1991) conducted his fieldwork in the lower Wenatchee River, he reports seeing large numbers of redside shiners in the Wenatchee River downstream from Lake Wenatchee during the summer. Juvenile spring chinook occur in this area and may interact with the shiners there. It is likely, however, that the interaction would be less intense in the upper Wenatchee River because of the cooler water temperatures there.

It is possible that juvenile spring chinook interact with bull trout, brook trout (*S. fontinalis*), and cutthroat trout if they occur together. Hillman and Miller (1994) observed chinook, bull trout, and brook trout together in several tributaries of the Chiwawa River and in the Little Wenatchee River. In tributaries of the Chiwawa River, Hillman and Miller (in prep) observed chinook and juvenile bull trout in the same habitat. They report seeing bull trout and chinook nipping each other in Big Meadow, Rock, and Chickamin creeks. Usually the aggressive interactions occurred in pools near undercut banks or in woody debris. In contrast, Martin et al. (1992) investigated the interaction between juvenile bull trout and spring chinook in the Tucannon River, Washington, and found that the two species have different habitat preferences. Juvenile spring chinook occurred more often in open, slow-water habitat without complex hiding cover. Bull trout, on the other hand, more frequently used riffle and cascade habitat. Bull trout numbers inversely correlated with amounts of woody debris and the two species did not compete for food because food was not limiting in the Tucannon River (Martin et al. 1992).

Although Hillman and Miller (in prep) observed juvenile chinook and brook trout together in many tributaries of the Chiwawa River and in the Little Wenatchee River, they did not see aggressive interaction between the two species. Welsh (1994), on the other hand, studied the interaction between the two species in Idaho streams and found that when chinook were introduced into a stream with brook trout, the latter was displaced into marginal habitat. Over a six-year period, Welsh (1994) notes that brook trout vanished from his study sites. We can find no studies that address the interaction between chinook and cutthroat trout.

Predation

Fish, mammals, and birds are the primary natural predators of juvenile chinook in tributaries of the mid-Columbia basin. Although the behavior of chinook precludes any single predator from focusing exclusively on them, predation by certain species can nonetheless be seasonally and locally important. Recent changes in predator and prey populations along with major changes in the environment, both related and unrelated to development in the mid-Columbia basin, have reshaped the role of predation (Mullan et al. 1986; Li et al. 1987).

No one has quantified the loss of juvenile chinook that results from predation in tributaries of the mid-Columbia Basin. Several observers, however, have reported interactions between chinook and predators. In the Wenatchee River, for example, Hillman et al. (1989a) observed both wild and hatchery rainbow/steelhead feeding on chinook fry in May. Predation was most intense during dawn and dusk. At that time, rainbow/steelhead occupied stations immediately adjacent to aggregations of chinook. Hillman et al. (1989a) noted that within the prey cluster, the largest, lighter-colored chinook were closest to shelter and seldom eaten. Small, darker-colored chinook were farther from escape cover and usually eaten by predators. Hillman et al. (1989a; 1989b) suggest that predator-mediated interaction for shelter was strong and contributed to the rapid decline in chinook numbers in May. Although this work was done in the Wenatchee River, the results probably hold for other tributaries where the two species occur together.

Sculpins (*Cottus* sp.) can be an important predator of recently emerged chinook fry. Hillman (1989) studied the nocturnal predation by shorthead sculpin (*C. confusus*) on chinook fry in the Wenatchee River. He found that shorthead sculpins larger than 85 mm preyed heavily on small (<55 mm) chinook fry at night during May, June, and July. Only chinook were consumed in May, a mix of salmon and steelhead during June and July, and mostly steelhead later. Hillman

(1989) reports that the number of fry eaten per night appeared to be related to sculpin size, with the largest sculpins consuming the most fry per individual. We believe that sculpins consume chinook fry in other tributaries in the mid-Columbia basin, but the significance of the interaction remains unknown.

Other predators have been observed in tributaries of the mid-Columbia River. For example, Hillman and Chapman (1989) observed bull trout and northern squawfish (*Ptychocheilus oregonensis*) living in the Wenatchee River. Griffith and Hillman (1986) observed bull trout (*Salvelinus confluentus*), cutthroat trout (*O. clarki*), squawfish, and smallmouth bass (*Micropterus dolomieu*), an exotic species, residing in the Methow River. In the Chiwawa River basin, Hillman and Miller (1994) found bull trout, cutthroat trout, rainbow trout, and brook trout in the same areas as juvenile chinook. They also observed bull trout and brook trout living near juvenile chinook in the Little Wenatchee River. Mullan et al. (1992b) report the occurrence of bull trout and brook trout in Icicle Creek. They also document the occurrence of bull trout, brook trout, and cutthroat trout in many spring chinook rearing areas in the Methow basin. Bull trout also occur in the Entiat and Mad rivers. Although no one has observed these species eating juvenile chinook in the tributaries, some of them are known to be important predators of chinook (Mullan et al. 1992b). Of these, we believe bull trout are probably the most important predator of juvenile spring chinook salmon in the basin. These two species occur together in most tributaries, hence the probability for interaction is high. The presence of both fluvial and adfluvial stocks of bull trout in the Wenatchee basin further increases the likelihood for interaction there.

The extent of bird predation on juvenile spring chinook in tributaries of the mid-Columbia River is unknown. We have seen great blue herons (*Ardea herodias*), gulls (*Larus* sp.), American dippers (*Cinclus mexicanus*), belted kingfishers (*Ceryle alcyon*), osprey (*Pandion haliaetus*), and common mergansers (*Mergus merganser*) fishing in the tributaries. According to Wood (1987), the latter species limits salmon production in nursery areas in British Columbia. He estimates that young mergansers consume almost one-half pound of subyearling chinook per day. Thus, a brood of ten ducklings could consume between four and five pounds of fish daily during the summer. Both kingfishers and gulls are common in the basin and may also influence chinook numbers in tributaries.

No one has studied the influence of mammals on numbers of juvenile chinook in the mid-Columbia basin. Observations by Don Chapman Consultants (unpublished data) indicate that river otters (*Lutra canadensis*) occur throughout most the Wenatchee River basin. They are probably common also in the Entiat and Methow basins. Observations by Don Chapman Consultants (unpublished data) indicate that at least two otters fished the Wenatchee River and one worked in Icicle Creek in 1987 and 1988. They observed the two in the Wenatchee River during late fall and early winter. Employees of DCC also observed several otters in the Chiwawa River. They saw them most often in pools with large woody debris. According to Hillman and Miller (1994), juvenile chinook are most abundant in these pool types, thus, the probability for an encounter is high. Dolloff (1993) examined over 8,000 otoliths in scats of two river otters during spring 1985 and found that at least 3,300 juvenile salmonids were eaten by them in the Kadashan River system, Alaska. He notes that the true number of fish eaten was much higher, as it was unlikely that searchers found all the scats deposited by the otters. Other predators, such as raccoon (*Procyon lotor*) and mink (*Mustela vison*) also occur in tributaries throughout the mid-Columbia basin. Their effects on numbers of juvenile chinook are unknown.

We believe that anglers may negatively influence numbers of juvenile chinook in tributaries. We have observed anglers removing juvenile chinook from both the Wenatchee and Methow rivers. Anglers in the Chiwawa basin have told us that they frequently catch (and release) juvenile chinook salmon. This may be why Hillman and Miller (1994) report finding few juvenile chinook in the Chiwawa River near campgrounds. Furthermore, observations by Don Chapman Consultants (unpublished data) indicate that juvenile chinook are susceptible to angling and react quickly to bait, lures, and flies. Observers found dead chinook in the Wenatchee River that were killed from catch-and-release fishing. More information is needed, however, before we can quantify the loss of chinook from angling in tributaries.

MIGRATIONAL CHARACTERISTICS

Petersen et al. (1994) and J. Hubble (personal communication) found smolts leaving the Chiwawa and Chewack rivers as early as March (Figure 51-52). The exodus of smolts from the Chiwawa River corresponds to the observations of smolt appearance at Rock Island Dam (Figure 54). PIT tagging in Snake River tributaries, beginning in 1989, revealed that migrational timing varies for fish from different natal areas and hatcheries. In the Snake River basin, the migration of wild spring chinook smolts is later and more protracted than that of hatchery-reared spring chinook (Achord et al. 1995). We expect deme-specific timing, or at least a protracted migration of wild spring chinook in comparison to the movements of hatchery-produced fish, in the mid-Columbia region. Thus, in the material below in which we discuss run timing, it is important to remember that PIT-tag studies have not been completed in the mid-Columbia region to permit report of deme-specific run timing.

Run timing

Wells Dam:

Between 1981 and 1984, Douglas County Public Utility District investigated the run timing and distribution of juvenile salmonids in the forebay of Wells Dam, and in some years, in the tributaries of the reservoir (Weitkamp and Neuner 1981; McGee and Truscott 1982; McGee et al. 1983; McGee 1984). In the Methow

River, the peak occurrence of yearling chinook coincided within one day with the release from Winthrop (Weitkamp and Neuner 1981; McGee et al. 1983).

In the forebay of Wells Dam, the peak appearance of yearling chinook was strongly related to the release of fish from Winthrop NFH. Abundance of chinook yearlings usually peaked between the middle of April through the first two weeks of May, two to nine days after the release from Winthrop NFH (Weitkamp and Neuner 1981; McGee and Truscott 1982; McGee et al. 1983; McGee 1984).

Rock Island Dam:

Downstream migrants were captured in the cooling water screens of the first powerhouse of Rock Island Dam from the late 1950s to the late 1970s[17] (Figure 21, Edson 1958; Chelan PUD, unpublished data). These fish were entrained into the cooling water intakes, located in the roof of the scroll case of the turbine intake. Most of the chinook juveniles collected in the cooling water screens appear to have been subyearlings, based on their size distribution (Figure 22). It is probable that the fish collected in the water cooling screens were not reflective of the population migrating past Rock Island Dam,[18] but the information can be used to infer run timing and, to a lesser degree (for chinook), length distribution.

Run timing of juvenile chinook salmon at Rock Island may have shifted through the years (Figure 55). We are cautious of drawing conclusions from these data because of the possibility of sampling bias associated with the samples

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[17] The second powerhouse was not constructed at this time.

[18] Since the intake for the cooling water screens is located in the roof of the turbine intake, only the proportion of fish entering the turbine intake high in the water column, or those individual fish that would be more susceptible to being swept into the intake would be captured (e.g., very few steelhead were captured).

collected in the 1950s and 1970s.[19] If the run timing has changed, it may be due to a different hydrograph, or more probably, to the fact that the majority of the smolts are now of hatchery origin. Hatchery-produced smolts are released at specific dates, and they have been shown to affect the run timing of smolts at Wells Dam and Rock Island Dam.

Since 1985, the migration of juvenile salmonids has been monitored at Rock Island Dam powerhouse No. 2 bypass trap between April 1 and August 31. Chinook salmon are routinely broken into two groups: yearlings and subyearlings. It is not possible to distinguish between naturally- and hatchery-produced individuals unless the fish is marked. Unlike steelhead trout, where hatchery-produced individuals show great fin erosion (Peven and Hays 1989), the fin condition of hatchery-reared chinook is generally not deteriorated, making them indistinguishable from naturally-produced fish.

The average run timing of chinook yearlings past Rock Island Dam in the recent 10 years is depicted in Figure 54. Since 1985, the average 10th, 50th, and 90th percentile passage was April 21, May 10, and June 3, respectively. Run timing of yearling chinook at Rock Island Dam is strongly related to the release of fish from Leavenworth NFH, which reach Rock Island Dam generally two days after release (Peven 1991). Most of the chinook sampled at Rock Island Dam are of hatchery origin (C. Peven, personal communication), but based on sampling of migrants from the tributaries, we believe that the naturally-produced migrants have a run timing similar to that of the hatchery component of the run.

The migrational timing of yearling spring chinook salmon is regularly indexed at Rock Island Dam as part of the Smolt Monitoring Program. Fish that enter the collection system are enumerated by species and reported as the daily passage

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[19] It appears most of the juvenile chinook collected in the 1950s were subyearlings, based on length distribution illustrated in Figure 22. Most of the juveniles sampled in the 1970s were subyearlings. The data from 1985 through 1994 are exclusively from yearlings.

index. This is the only dam in the mid-Columbia where such information is regularly acquired. It is not possible to identify individual stocks within the admixture arriving at Rock Island Dam, except for certain hatchery stocks that carry freeze brands in some years. Currently, no branded hatchery stocks are released in the basin. The last freeze-brand groups were released in 1992.

Timing at other dams:

Peak movement of yearling chinook at Priest Rapids Dam usually occurs in mid-May (Sims and Miller 1977; Faurot 1979; CH2MHill 1980). Reports of the Fish Passage Center, Portland, depict movement of yearlings at Rock Island Dam bypass trap, McNary Dam sampling facility, John Day Dam, and Bonneville Dam. Movement at Rock Island Dam and McNary Dam peaks about mid-May. The peak moves to about the third week of May at John Day Dam, and to the last week of May at Bonneville Dam. Gill ATPase, an index of readiness to enter saltwater, increases in spring migrant chinook from mid-April to end May at Rock Island Dam bypass trap and in the McNary Dam sampling facility.

The migrational timing of individual hatchery stocks from the mid-Columbia can be indexed at McNary Dam by examining the passage distribution of marked/tagged groups at that site. The FPC provides estimates of the median passage time for those stocks on an annual basis. We have compiled their estimates for the years 1991-1993 (Table 23). These annual median passage dates generally represent the timing for those stocks in most years.

Spring chinook tend to move more in hours of darkness than in daytime (Faurot 1979, Sims and Miller 1977), but can reverse this pattern (CH2MHill 1980). The latter paper shows diel timing for only three days late in May. In 1983, Olson (1984a) sampled vertical distribution at Wanapum Dam turbine intakes with fyke nets for about three weeks in May, 1983. He found that chinook moved into intakes and gatewells somewhat more in daytime than at night. But he also notes that yearling chinook move deeper in the water column at night. This means that information based on gatewell dipping (Faurot 1979, CH2MHill 1980, Sims and Miller 1977) could result in an underestimate of the importance of night movement (Olson 1984a). However, the same conclusion, when applied to the data of Faurot (1979) and Sims and Miller (1977), makes their finding of predominantly nighttime movement into gatewells more important. Fyke net catches at Wells Dam (Olson 1984b) in 1983 reveal a ratio of 20:80 for day:night passage of spring chinook. Again, spring chinook moved deeper in the water column at night than in daytime, for both spill and no-spill conditions (Olson 1984b). Spring chinook tend to move high in the water column, generally higher than subyearling chinook or sockeye, but not as high as coho and steelhead (Olson 1984a)

DAM PASSAGE

As juvenile salmonids migrate seaward through the impounded Columbia River, they encounter a variety of natural and man-made hazards that can cause mortality. There are two general categories of hazards associated with the hydro system; those associated with dam passage, and those incurred within the body of the reservoir. The population incurs some level of "passage mortality" as smolts pass through the dam by spillway, turbine flow, or any existing bypass system. These types of effects involve direct physical injury due to mechanical and hydraulic conditions at the dam, and indirect mortality associated with predation on either stunned/injured, or concentrated streams of smolts. "Reservoir mortality" results from conditions smolts encounter while traversing the pool created by the project. The principal mortality mechanism appears to be predation by other fish species. Additionally, river water can become over-saturated with dissolved gas, if spillage at some sites is excessive in volume and duration. This condition can result in both juvenile and adult mortality.

In the mid-Columbia, smolts encountering a dam can pass the structure by way of two routes; either the spillway or the powerhouse. Currently, there are no mechanical bypasses emplaced at any dam in the system, but a number are planned for installation in the future. Wells Dam has a unique spill system that provides enhanced passage of smolts over the spillway, which lies directly over the turbine powerhouse. The system at Wells Dam often referred to as a bypass, but it is fundamentally different from the mechanical screens and collection bypass systems at dams throughout the Snake River and lower-Columbia River.

Spill efficiency

The proportion of the smolt population that passes through the powerhouse or spillway does not necessarily split evenly with the proportion of the water discharged through each route. At three of the five dams, the proportion of fish passed through the spillway exceeds the proportion of the water spilled; Wells Dam, Rock Island Dam, and Wanapum Dam. There are no species-specific estimates at any site. At Priest Rapids Dam and Rocky Reach Dam, the proportion of fish that passes through the spillway is less than the proportion of water spilled. We summarize estimates of spill efficiency in Table 24.

Spill mortality

Smolt survival over spillways is estimated to be high at dams throughout the Columbia River, near 98 to 99% (Center for Quantitative Science 1993). Spillways presently provide the most benign passage route for smolts at dams in the mid-Columbia. Spillway survival has been estimated at Wells Dam (Weitkamp et al. 1981) for steelhead, and at Rocky Reach Dam (Heinle and Olson 1981) for coho. In both studies, mortality was negligible at nearly 0% to 1%. Similar results were observed for fall chinook at McNary Dam, where spillway mortality averaged 2% (Schoeneman et al. 1961). No spill deflectors were, or are, in place at any of these dams.

However, results from one evaluation are inconsistent with those reported above. At Lower Monumental Dam in 1974, NMFS estimated the survival of juvenile steelhead passing through spillbays with and without flow deflectors (Long et al. 1975). They estimated that steelhead that passed through spillways not equipped with flow deflectors incurred high mortality, at 27.5%. Whereas, at a spillbay equipped with a flow deflector, mortality decreased to 2.2%, a magnitude consistent with that observed at other sites. Recently, NMFS again evaluated spillway survival at Lower Monumental Dam using yearling chinook salmon fitted with PIT-tags (Muir et al. 1994a). They reported the relative survival as 0.93 and 0.99 for fish released through spillbays with and without spill deflectors, respectively. Although the survival estimates were not significantly different, they still indicate that the presence of deflectors may appreciably increase spillway mortality. Clearly this issue deserves further study, since the installation of more spillway deflectors at other dams is being considered as a means to abate gas saturation.

Turbine mortality

Turbine mortality is generally cited as ranging from 10 to 15% at dams on the Columbia and Snake Rivers (Center For Quantitative Science 1993, McConnaha and Anderson 1992). Estimates from several studies fall in this general range. We discuss selected studies for various species and locations here to provide general background for the reader.

In the lower Columbia River (McNary Dam and Big Cliff Dam as a surrogate for McNary Dam), Schoeneman et al. (1961) estimated that 89% (range = 87 to 91%) of the sub-yearling chinook released through a turbine at McNary Dam survived to recovery traps deployed approximately 20 to 50 miles downstream and at Bonneville Dam (145.9 miles downstream). Holmes (1952) released treatment groups of sub-yearling chinook in the Bonneville Dam forebay and control groups in the tailrace. Basing estimates on adult return data, he calculated survival past the dam as 85 to 89%. Reasonably, the Holmes estimate includes both turbine and any forebay effects, such as predation.

At Lower Granite Dam on the Snake River, Giorgi and Steuhrenberg (1988) estimated turbine survival at 83% (95% CI = 74 to 92%) for yearling chinook released into the turbine intake. Controls were released from shipboard tanks, just downstream from the turbine boil of the test unit. Estimates were based on PIT-tag detections at Little Goose Dam. Studies conducted in 1993 produced similar estimates at Lower Granite Dam. Iwamoto et al. (1994) estimated average turbine survival at that dam to be 82%; whereas the estimated survival through turbines at Little Goose Dam was 92%. Muir et al. (1994) reported a total turbine survival rate of 86.5% for Lower Monumental Dam in 1994.

At mid-Columbia dams, turbine survival estimates span a somewhat broader range. Weitkamp et al. (1981) estimated 84% survival for steelhead passing through turbines at Wells Dam. In contrast, tests conducted at Rock Island Dam indicated that bulb turbines are more benign in effect than the vertical Kaplans described to this point. Olson and Kaczynski (1980) estimated that turbine mortality was only 3% for steelhead and 7% for coho.

The preceding studies employed techniques and protocols that reflect both direct and indirect effects in the survival estimates. Direct effects derive from mechanical or physical injury incurred during turbine passage, resulting in either acute or delayed mortality. Indirect effects result from predisposition of debilitated, disoriented, or stunned fish to additional sources of mortality, such as increased vulnerability to predation. Some studies capture only direct effects. For example, investigators using balloon tags estimated 94% survival for yearling chinook that passed through adjustable-blade Kaplan units at Rocky Reach Dam (RMC and Skalski 1993).

The size of fish passing through turbines can affect the mortality rate. Eicher et al. (1987) reviewed a large number of turbine mortality tests that used juvenile salmonids as test animals. They reported that smaller fish generally survived at higher rates than larger ones. Ruggles (1985) presented data for Atlantic salmon (*Salmo salar*) smolts that confirmed size-related effects. He found that turbine-related mortality increased with the size of test fish, which ranged from 135 to 190 mm. The Columbia River studies cited in previous paragraphs did not evaluate size as a variable.

Bypasses

Although mechanical screened bypass systems are not currently in place at any of the mid-Columbia dams, they are planned for installation in future years. Thus, we discuss survival associated with bypass systems.

The purpose of installing a mechanical bypass system is to divert smolts from turbines into a collection/bypass/outfall system that imparts less mortality than smolts experience in turbine passage. Effects of the bypass include those incurred at the diversion screens, gatewells, in the conduits, and at or near the outfall. Thus, as with turbine passage, there are both direct and indirect effects. Similar to those described for turbines, direct effects include physical injury incurred at the mechanical devices and within conduits. Indirect effects are associated with intense predation targeted at smolts discharged in a concentrated stream in the tailrace. To some extent, stressful conditions experienced in the bypass may exacerbate this effect by debilitating fish in some fashion.

Direct mortality associated with bypass is generally reported to be low. Ceballos et al. (1993) reported facility mortality of chinook at collector dams over an 11- to 12-year period. Through 1992, mortality averaged less than 1% at Lower Granite Dam, 1.7% at Little Goose Dam, and 0.9 and 1.9 % respectively for yearlings and subyearlings at McNary Dam. However, there is evidence that the combined direct and indirect effects may be so large at some dam sites that turbine passage is preferable to bypass routing. Ledgerwood et al. (1990, 1991) reported that at Bonneville Dam second powerhouse, bypassed subyearling chinook survived at nearly the same rate or a rate lower than fish that passed through the turbines. Subsequent investigations (Dawley et al. 1993) confirm that subyearling survival is higher for fish that pass through turbine draft tubes than for fish that pass through the bypass systems at either Bonneville Dam powerhouse (PH) 1 or PH2. Predation on outfall-released fish appears to be pronounced. So concerned was NMFS that in 1993 they ordered the screens pulled from the turbine intakes at the dam. Although the data of Dawley et al. (1993) were derived for subyearling chinook, we expect that predators at Bonneville Dam tailrace also would concentrate on the stream of spring-migrant prey downstream from the bypass outfalls. Lower spring temperatures do not prevent predation from occurring in May and June, during the peaks of the spring migration of yearling chinook (Rieman et al. 1991).

Study of survival of subyearling chinook released in turbine intakes at Bonneville Dam PH1 and PH2, just downstream from submersible traveling screens, and into the bypass gallery at Bonneville Dam PH1, and released in midriver 2.5 km downstream from Bonneville Dam, provides an interesting example of bypass-related effects. Ledgerwood et al. (1994) recovered marked juveniles in the Columbia River estuary from the several release points. For groups released from 18 June to 9 July, recovery percentages for the downstream release averaged 36.7% greater than for the turbine releases in PH2, 23% greater than turbine releases in PH1, and 39.6% greater than for releases in the bypass system. These results demonstrate not only that fish were better off going through turbines than through the bypass system, but also that very substantial mortality occurs between Bonneville Dam and a point 2.5 km downstream. We examined the temporal change in gains enjoyed by downriver releases over bypass releases to learn if the earliest few test groups of subyearlings, which migrated near the end of the yearling migration, might have suffered less mortality. Those groups were released 18-25 June, when the lower Columbia River at Jones Beach averaged 17-20° C. The mean difference between recoveries of fish released at the downstream point and those released in the bypass system before 25 June equaled 0.0978. Relative to the mean recovery rate for the bypass releases in that period (0.353), the downstream release groups were recovered at a rate 27.7% higher (Figure 56). These data suggest that mortality is very substantial in the 2.5 km between Bonneville Dam and Hamilton Island. We infer from these data on subyearlings that at least the latter portion of the spring chinook smolt passage at Bonneville Dam could be subjected to high mortality just downstream from Bonneville Dam. Modal size of subyearlings released before 25 June was about 85 mm, while yearlings that pass Bonneville Dam should have a modal length over 100 mm. The 1992 study year, during drought, may have been unusual (Ledgerwood et al. 1994). Additional years of information will be valuable. However, Ledgerwood et al. (1990) also reported substantial mortality in 1987 between Bonneville Dam PH2 and the Hamilton Island site 2.5 km downstream. It would be illuminating and worthwhile to undertake a study like that conducted by Ledgerwood et al. (1994) during the spring migration of yearling chinook.

Mid-Columbia: vertical slot bypass at Wells Dam

At Wells Dam, Douglas County PUD has developed and installed a bypass system that is an alternative to screen designs. The vertical slot system was retrofitted to the spillway at this project. Kudera et al. (1991) discussed the development of the system, described the structure, and evaluated its effectiveness. They found that the bypass has been particularly efficient at passing smolts at the project. In 1990, they estimated that 84 and 77% of the spring and summer migrants respectively, passed via the bypass. Skalski (1993) analyzed hydroacoustic data acquired over a three year period, and estimated that passage efficiency averaged 89% for all migrants.

A small-scale evaluation in 1993 with balloon tags revealed no mortality or injury problems associated with passage over the spillway portion of the bypass at Wells Dam (R. Klinge, Douglas County PUD, personal communication). However, total direct and indirect effects associated with passage through the system have not been formally evaluated. Experience at Bonneville Dam indicates that comprehensive evaluations of bypass systems are warranted, even vital. We suggest it would be prudent to conduct such evaluations at Wells Dam, particularly since managers are now considering vertical slot surface collectors as an alternative to mechanical screened systems at several dams.

Other mid-Columbia projects

Chelan and Grant County PUDs are considering both mechanical screened bypasses and vertical-slot systems for application at their projects. Mechanical systems are being designed and evaluated for use at all these dams. Additionally, vertical-slot bypasses are being evaluated for testing at Rocky Reach Dam and Wanapum Dam. Later in this report, using the downstream passage model CRiSP1.5, we will examine the benefits of mechanical screen bypass systems relative to other mitigative options.

RESERVOIR PASSAGE

Sources of mortality

The principal mechanism that causes smolt mortality associated with migration speed through reservoirs is thought to be predation by fishes.

Migrational delay theoretically increases the length of time for which smolts remain exposed to predation within reservoirs. From this logic derives the argument for increasing water velocity to increase smolt speed and lower the probability of predation-related mortality. In addition, increased water velocity may disperse predators staging in the tailrace areas and reduce their feeding efficiency (Faler et al. 1988, Poe 1992).

Northern squawfish are the dominant smolt predator in the system. Rieman et al. (1991) estimated that 2.7 million juvenile salmon were consumed annually in John Day Dam pool, during 1983-1986, and squawfish were responsible for 78% of that loss. Since squawfish consume both dead and live smolts (Poe 1992), consumption does not equate to predation-caused mortality. Furthermore, recent research has indicated that in tailrace areas squawfish may select dead smolts (killed from passage effects) over live ones (Gadomski and Hall-Griswold 1992). Peterson (1994) recently revised the estimated number of smolts consumed by squawfish in John Day Dam pool downward to 1.4 million, approximately a 50% decrease from estimates initially reported by Rieman et al. (1991) . Thus, the emerging information indicates that predation was probably overstated initially, perhaps by a considerable amount. Nevertheless, basin-wide estimates of consumption indicate predator-caused mortality is still substantial throughout the Snake and lower-Columbia River reservoirs (Shively et al. 1991). Furthermore, in the mid-Columbia region, predator density and predator indices (reflecting abundance and consumption) appear comparable to data available for most other reservoirs in the lower Snake and lower Columbia rivers (Burley and Poe 1994).

Spring chinook likely incur lower mortality rates from predaceous fish than summer migrants. Yearling spring chinook migrate seaward during the spring when water temperatures, and corresponding predator activity, are thought to be lower than in late spring and summer. Rieman et al. (1991) found that smolt consumption by predatory fish was about 8% of smolts that entered John Day Dam reservoir in April, 11% in May, and 7% in June. The loss rate increased throughout the summer migration to 61% in August.

Reservoir mortality and migration speed: an overview

The speed of migration will affect the length of time fish remain exposed to reservoir hazards, which in turn affects the magnitude of mortality incurred during migration. Some data indicate that some species/races increase migration speed at higher water velocities (as indexed by flow volumes). It has been suggested that providing increased flows will appreciably increase the migration speed and associated reservoir survival of all species/races of salmon throughout the impounded sections of the Columbia and Snake rivers. This concept lies at the core of prescriptions for flow augmentation and reservoir drawdown in the Columbia and Snake rivers. However, the extent to which increased water velocity translates into improved smolt survival through reservoirs remains unquantified for any species or race of salmon. To provide the reader a perspective with which to assess data acquired for yearling chinook, we will briefly review some relevant investigations that have been conducted throughout the basin.

Factors that affect migration speed

There is a considerable amount of information available that describes the migratory characteristics of yearling chinook in the impounded portions of the Columbia and Snake rivers. Consistently, two variables have been identified as influencing migration speed; prevailing flow volume and the level of smolt development expressed by the migrant population. However, these two factors often co-vary, confounding our ability to determine the extent to which each factor separately affects the response (Beeman et al. 1990, 1991).

In the 1970s, NMFS investigators first described the relationship between yearling chinook travel time and flow (Sims and Ossiander 1981), and continued those studies into the early 1980s (Sims et al. 1984). Those investigations were staged in the Snake and lower Columbia rivers. The FPC (1988) added to that set of information through 1987. In these initial investigations the level of smolt development was not considered as an influential factor.

More recently, investigators have examined the influence of variables in addition to flow, including measures of smolt development and water temperature. Analyses based on data sets acquired in the Snake River have consistently identified flow and the level of smolt development as dominant variables that explain observed variation in yearling chinook travel time (Berggren and Filardo 1993; Beeman et al. 1990, 1991; Maule et al. 1994), with temperature entering some models. However, consistently in the mid-Columbia data sets, the level of smoltification appears to have a dominant role in influencing migration, with flow being a secondary variable in some analyses. We examine the mid-Columbia data in detail in the following sections.

Winthrop Hatchery spring chinook:

In the mid-Columbia, Berggren and Filardo (1993) used multiple regression techniques to analyze factors that influence the travel time of Winthrop Hatchery spring chinook for the years 1983-1990. The model they identified contained only release date (a surrogate for degree of smoltification) as a predictor variable; flow effects were not discernible in that data set.

In 1989, Beeman et al. (1990) documented pronounced increases in gill-ATPase in the Winthrop Hatchery smolt population over the course of the migratory period, consistent with inferences founded on using release date as an indicator of the level of smolt development as suggested by Berggren and Filardo (1993). Since that publication there have been three additional years (1991, 1992, and 1993) of travel time estimates acquired for that population (FPC 1992, 1993, and 1994). We incorporated both sets of estimates into graphs that relate the estimated travel time to the flow index and release date reported by those authors (Figure 57 and Appendix 9). The inclusion of the 1991-1993 data does not result in appearance of a flow effect for this stock over a broad range of discharge. Consistent with Berggren and Filardo's findings, the expanded data set reveals a significant correlation between smolt travel time and release date (r^2 =0.60 and P=0.0003). Another interesting observation is that in most analyses of smolt travel time, flow and release date almost always enter the model together, with a high degree of colinearity between the two predictor variables. Evaluation of the 1983-1993 data does not reveal a relationship between flow and release date.

Leavenworth Hatchery spring chinook:

Another hatchery that has a reasonably long historical record of brand releases is the Leavenworth National Fish Hatchery on the Wenatchee River. Marked groups were released from that site during the years 1985-1992. We examined spring chinook travel time for evidence of flow and/or smoltification effects in a manner consistent with the approach of Berggren and Filardo (1993). Travel time estimates from the hatchery to McNary Dam, flow indices, and release dates were obtained from appendices in FPC annual reports for the years 1985-1992, and detailed in our Appendix 10. In some years, several releases were made on different dates; we treated each as a separate estimate. In cases where multiple groups were released on a single day, we averaged the reported estimates and indices for the marked groups and used that average in our analyses.

Using stepwise multiple regression, we found that of the two predictor variables that we considered, julian release date and flow, only release date entered the model (r^2 =0.67, and P=0.002) (Figure 58):

TT = 115.02 - 0.799 (julian date)

This finding is consistent with findings of Berggren and Filardo (1993) for Winthrop Hatchery stock. We found no evidence of a flow effect for Leavenworth fish, but a strong relationship between travel time and release date.

Release date is a general index of smolt development. We base this position on information provided by Rondorf et al. (1985), who demonstrated a moderate but steady increase in gill-ATPase activity in Leavenworth spring chinook during hatchery residence from April into May. This is consistent with the Berggren and Filardo (1993) interpretation of release date as a surrogate for smoltification in the Winthrop Hatchery population and Snake River hatchery populations of spring chinook.

Entiat Hatchery spring chinook:

Branded groups released from Entiat Hatchery during a five-year period, 1988-1992, and a PIT-tagged group released in 1993, provided data for which travel time estimates. Although the data set for Entiat Hatchery is much more limited, it displays the same patterns evident in both the Winthrop and Leavenworth populations. A pronounced relationship between travel time and release date is indicated ($r^2 = 0.92$, $P=0.004$), whereas flow effects are not (Figure 59, Appendix 10). Consistent with other data sets, the level of smolt development appears to have a dominant influence on migration speed through the Mid-Columbia River.

Active migrants; Rock Island to McNary Dam, FPC:

More recently, the FPC (1994) and Maule et al. (1994) expanded investigations in the mid-Columbia region by analyzing information from migrants sampled and PIT-tagged at Rock Island Dam. The FPC (1994) analyzed five years, 1989-1993, of PIT-tag data with multiple regression techniques. The response variable was the median travel time of release groups to McNary Dam. The predictor variables included flow indices, water temperature, and release date.

Release date was used as a surrogate that reflects the degree of smoltification of the yearling chinook population that passes Rock Island Dam. Based on gill-ATPase profiles constructed by USFWS investigators and reported by the FPC, this position appears sound in some years, but not necessarily all. In Figure 60 we compile ATPase profiles for three years, 1990-1992. Patterns in 1990 and 1992 clearly indicate a strong positive correlation between date and ATPase as assayed in the population at Rock Island Dam. However, in 1991, ATPase levels were relatively stable and overall much lower than observed in the other two years. This suggests that more direct measures of smolt development are preferable when attempting to account for physiological effects.

The FPC (1994) identified five models as candidates for explaining the observed variation in travel time. The models contain mixtures of several variables; flow, release date and water temperature. The FPC (1994) reported the strongest relationships between travel time and release date (smoltification), noting that the flow effect appeared to be secondary to the smoltification effect. Even so, using two of the five models, they indicated that increasing flow from 120 to 200 kcfs is predicted to decrease median travel time about four days. This equates to approximately one day per 20 kcfs increment of flow over that discharge range.

National Biological Survey investigations:

Investigators from the National Biological Survey (NBS) similarly analyzed data acquired in 1991 and 1992, but considered direct measures of physiological development as predictor variables, rather than relying on surrogates. Consistent with the FPC findings, they concluded that the same three factors; level of smolt development, flow, and temperature explained the observed variation in yearling chinook travel time (Maule et al. 1994). They derived two models (Figure 61), similar except for different measures of smolt development used in the construction of each model. In one case, gill-ATPase was used as the measure of smolt development, while condition factor was employed in the alternative model. Consistent with the findings of the FPC, NBS investigators found that ATPase, or condition factor and temperature explained a larger amount of the variability in travel time than did flow. These findings are consistent with information describing hatchery stocks released in the mid-Columbia, as we reported previously.

PIT-tags, Rock Island to McNary Dam: additional analysis:

We also analyzed the Rock Island PIT-tag data, but in a manner that differed somewhat from the FPC (1994) approach. The FPC (1994) calculated the median travel time to McNary Dam for release groups each day at Rock Island Dam. The medians were used as the response variable for their multiple regression analyses. We also used multiple regression analyses, but our analyses differed in the following respects:

1. We used the observed travel time of each PIT-tagged fish as the response variable.

2. We analyzed data through one additional year, from 1989 through 1994.

3. We considered four predictor variables; release date, water temperature on that date, the five-day average flow commencing with the release date, and fish length. FPC (1994) did not treat the latter variable.

Table 25 summarizes numbers of tagged fish released and detected in each of the six years, and tagging dates and range of values for predictor variables. Of the total 3,701 detections, four were excluded as outliers. Of those outliers, two were larger than 250 mm, one was recorded as only 27 mm, and the fourth yielded a travel time of over three years.

Over those years, our flow indices ranged from 69.3 to 207.3 kcfs, spanning a broad range of conditions. Water temperatures over the collective release dates over all years ranged from 42.0 to 55.9° F. Fish size was broadly represented, with individuals ranging in size from 60 to 222 mm fork length (FL) at release. Tagging commenced in late April and continued through most of May. We depict data sets for each year graphically in Appendix 11 of this report. Observed travel times ranged from 2.0 to 67.9 days.

We inspected scattergrams of travel time and several predictor variables and observed some inconsistent patterns (Figures 62-66). Typically, early in the migration period, fish moved slower and overall travel time varied more. Farther into the migration period, in early May, travel time decreased as did variability (Figure 62). However, during the 1991-1993 migrations this general pattern was disrupted by the appearance of some particularly slow chinook during May (Appendix 10). At first, we suspected they were sub-yearling chinook, but rejected this explanation upon examining the size frequency distribution (Figure 66). Virtually all of the detected fish were larger than sub-yearlings are likely to be in May. We further focussed on those fish in May that were the slowest, with travel times of 25 days or more. We would expect that if these fish were the smallest segment of the population, it may indicate that some particularly early-emerging or fast- growing ocean-type chinook may be present. However, inspection of that group of fish revealed they were large, too large to reasonably be sub-yearlings during May. All fish in our data set are of a size that indicates they are yearling chinook. Consequently, we did not exclude any of the slower fish from the data set that we analyzed. This is in contrast to the FPC (1994) approach, where in 1992 and 1993, release groups tagged during the latter third of May were excluded from the data set, due to concern regarding the presence of sub-yearlings in the samples.

What mechanism might have resulted in some larger yearling-size fish migrating at slow rates characteristic of sub-yearling, ocean-type chinook? As a possibility, we considered that the hatchery production of yearling summer/fall chinook at several hatcheries upstream from Rock Island Dam might provide a plausible explanation. Over the last decade, a portion of the summer/fall chinook production has been reared to yearling-age. These fish may have migrational characteristics different from yearlings of stream-type race stocks. This has proved difficult to examine. We located only one report of a PIT-tagged release group of such fish. That single evaluation involved Wells Hatchery summer chinook released as yearlings in 1993 (FPC 1994). The fish were released from the hatchery on or about 19 April, 1993. The median travel time to McNary Dam was 28 d or 8.0 m/d. This was identical to the migration speed estimated for yearling spring chinook released from Leavenworth Hatchery, at 8.0 m/d. Furthermore, the minimum and maximum travel times observed for these two stocks were similar, ranging from 10.7 to 63.5 and 14.2 to 70.8 for Leavenworth spring chinook and Wells summer/fall chinook, respectively. From this limited observation it appears that yearling summer chinook migrate with the same rapidity as yearling spring chinook.

Inspection of scattergrams revealed no consistent patterns between travel time and any predictor variable across the six years (Appendix 11). We examined the data for all years combined (Figures 62-66). Correlations between travel time and any variable were weak, as evidenced by low r-values (Table 26). Except for temperature and release date, colinearity among the predictor variables was not apparent.

In a stepwise multiple regression analysis that used the natural log of travel time (ln TT) as the dependent variable, and the predictor variables; release date, flow, temperature and length, we found that only release date explained even a small part of the variation in travel time ($r^2 = 0.071$). Even so, two other variables, flow and temperature, could be entered to form two additional models. However,

r^2 values increased only to 0.075 and 0.078 with each additional respective step (Table 27). Temperature likely carries information redundant to release date, since it correlates strongly with the latter. Thus, flow and temperature explain a negligible amount of the observed variation in yearling chinook travel time from Rock Island Dam to McNary Dam Dam.

Our findings differ somewhat from those of the FPC (1994) and Maule et al. (1994). Unlike those investigators, we did not identify release date as being a particularly strong predictor variable for yearling chinook travel time, although a weak correlation was apparent. Furthermore, we see no evidence to indicate flow is an important factor influencing travel time, whereas the other investigators indicate flow has an effect, albeit weaker than, and secondary to, smoltification (FPC 1994, Maule et al. 1994). On the other hand, our findings are consistent with those of Berggren and Filardo (1993), who reported that only release date explained variability in travel time for Winthrop Hatchery spring chinook.

Passage time to estuary:

In 1977, Dawley et al. (1978) recovered two spring chinook that had been released from Leavenworth NFH; one on April 13, another on April 19. Respective recovery dates were both June 1. Thus, the time intervals from release to recapture were 48 and 42 days, and apparent rates of movement to the estuarine sample site at RKm 75 were 14-16 km/d. These fish would not have been transported from McNary Dam, as experimental transport began in 1978.

Dawley et al. (1979) recorded median passage time and rate of movement for fish marked at mid-Columbia hatcheries (Leavenworth, Entiat, and Winthrop hatcheries) in 1978. Median rate of movement ranged from 26-30 km/d from hatchery to RKm 75 for an estimated 167 recovered marks from three release groups. This rate need not be corrected for transported fish, as only previously-unmarked yearling chinook were marked specifically for transport studies, and no mass transportation occurred.

In 1979, an estimated 398 Leavenworth and Winthrop hatchery smolts were calculated to have traveled at 22-23 km/d to RKm 75 (Dawley et al. 1980). The possibility arises that some of these fish might have been transported from McNary Dam to Bonneville Dam tailrace, inasmuch as 349,744 yearling chinook were transported, or 87% of fish collected in the bypass facility (Table 28).

In 1980, Dawley et al. (1981) captured an estimated 31 marked yearling chinook from Leavenworth NFH at RKm 75. They had traveled at 24-27 km/d. Some could have been transported among the 795,141 yearlings transported from McNary Dam to downstream from Bonneville Dam. About 95% of bypassed fish were transported at McNary Dam (Table 28). In evaluating likelihood that movements from the hatchery to RKm 75 were sped by transportation, one should note that FGE for yearling chinook has been estimated at 65-75%. When 95% of yearlings collected were transported, the chances are that some fish recovered at Jones Beach were transported at McNary Dam, even where spill occurred. Thus, movement rates in 1979 and 1980 should be regarded with caution.

The peak period of yearling chinook capture in purse seines at RKm 75 in 1978-80 was about mid-May. Very few yearlings appeared in sets after mid-June (Figure 67).

Passage through the estuary:

In 1978, peak purse seine catch of yearling chinook at Jones Beach occurred about 10 May, and 90% of fish captured in purse seines were taken before mid-June. Catches of yearling chinook at RKm 75 peaked on 11 May in 1980. Based on peak catches at RKm 16, average travel time was two days, indicating movement at about 30 km/d in 1980 (Miller et al. 1983). Thus median date of sea entry of yearling chinook probably was about 15 May. Very limited contrary information, based on median recaptures of Methow River marked fish at the two sampling points (99 fish at RKm. 75 and 21 fish at RKm. 19, indicates a movement rate of only 8 km/d. This rate, slower than that at which fish moved between the hatchery and RKm. 75, may be an artifact of small observed sample size. Tidal flux might have influenced the rate of movement in the lower estuary. That rate of fish movement would suggest ocean entrance about June 2. Yearling chinook in 1978 ranged in size from about 125-150 mm in May. Yearling chinook averaged about 140 mm fork length in mid-May (Dawley et al. 1984b).

Implications:

The collective analyses indicate that the level of smolt development pronouncedly affects smolt migration speed, particularly in hatchery populations. Furthermore, flow effects are indiscernible in the hatchery populations. If swifter migration speed offers a substantial survival advantage to smolts, then there are potential gains to be made by releasing yearling chinook from these hatcheries in as advanced a state of smoltification as possible. As evidenced in the data presented here, merely delaying the release date may accomplish that goal. Alternatively, the employment of photoperiod and temperature treatments could be useful. At Dworshak Hatchery, Muir et al. (1994d) accelerated smolt development, thus increased migration speed and improved recovery proportions in experimental groups of spring chinook exposed to photoperiod and temperature regimens. Similar treatments applied to mid-Columbia hatcheries may appreciably accelerate smolt development and speed migration.

The collective information available for active migrants, those intercepted and tagged at Rock Island Dam, indicates the level of smolt development is a key factor affecting travel time. Some investigations indicate flow plays a secondary role, but is still influential, whereas our analysis reveals no flow effect. If one wishes to adopt the generalized flow response indicated in two of the FPC (1994) models, then increasing mid-Columbia flow from 120 to 200 kcfs is predicted to decrease median travel time about four days from 13.2 to 9.6 d, or an average of less than one day per 20 kcfs. These findings contrast to those for mid-Columbia steelhead, which respond strongly to increased flow by traveling faster, as demonstrated by all analytical approaches (Chapman et al. 1994b; FPC 1994).

Water velocity: spring

It is instructive to examine water velocity profiles in different segments of the mid-Columbia reach during the spring migration period. From 1971-1993, spring flow volumes have varied widely. Using average May flows at Rock Island Dam as an index, we find that flows ranged from 79 kcfs in 1973 to 269 kcfs in 1971. Using the volume replacement method, we estimated average water velocity through the mid-Columbia from Wells Dam tailrace to Priest Rapids Dam over that range of flows as 0.9 to 3.1 f/s (Figure 68).

Within the mid-Columbia, estimated average water velocity varies considerably by reach. Generally, at any flow level the average water velocity through the reach from Wells Dam tailrace to Rock Island Dam is nearly 60% higher than in the Rock Island Dam to Priest Rapids Dam reach. For example, at 80 kcfs the velocity through the lower reach is estimated at 0.7 f/s, whereas in the upper reach it is approximately 1.1 f/s, a 0.4 f/s or 57% greater velocity. At 240 kcfs, we estimate velocity in the lower reach at 2.1 f/s; in the upper reach at 3.4 f/s, a 1.3 f/s or 62% greater water velocity.

During the spring, Columbia River water velocity is substantially faster than that in the Snake River. In the Snake River, monthly average flows for May typically range from about 60 to 140 kcfs. We estimated the average water velocity from Lower Granite to Ice Harbor to range from 0.6 to 1.4 f/s over that range of flows (Figure 68). That velocity range is less than half of that estimated through the mid-Columbia.

Migrational delay and the biological window

It has been suggested that migrational delay lessens survival at seawater entry, apart from the mortality incurred during passage through the mainstem (CBFWA 1991). The theory is that the timing of seawater entry was historically synchronized with a biological window, and that today migrational delay associated with impoundment has disrupted that process, decreasing survival. The implication is that this sea-entry period is of limited duration and well defined, and that changes in survival have been documented. In fact, these points have not been demonstrated or even supported by anecdotal information for spring chinook.

There is evidence that steelhead lose salinity tolerance during the summer after their normal spring migration (Wagner 1974). However, there is no direct evidence that migrational delay on the order of one to three weeks impairs success of seawater entry for chinook. On the contrary, Healey (1991) notes the plasticity of chinook with regard to their ability to adapt to seawater, and Hoar (1976) states that the chinook.... *acquires high salinity resistance gradually while in freshwater without any sharp increase associated with a smolt transformation*. Furthermore, Wagner et al. (1969) show that chinook survival after seawater entry increased with age and did not diminish. These observations seem to refute the physiological premise of the biological window, at least for chinook.

Another type of opportunity window may be important for yearling chinook arrival in the estuary. In 1992 and 1993, El Niño brought warm water to the continental shelf as far north as Sitka. With that warming came Pacific mackerel (*Scomber* sp.) and other predaceous fishes. It is likely that high rates of predation by mackerel were responsible for record low runs of spring chinook to the Columbia River in 1994 and for predicted lower runs in 1995. El Niño has been predicted to return in 1995, bringing mackerel with it (Portland Oregonian, March 23, 1995, quoting B. Riddell, Canada Department of Fisheries and Oceans. End-of- March surface water temperatures were 3° above normal).

If El Niño events occur with increasing frequency as a result of changing climatic cycles (e.g., if global warming is a reality), arrival of spring migrants before arrival of warm water may be important if smolts are to move northward along the continental shelf without suffering intensive predation from mackerel and other species. As noted later in our report, maximum transportation of spring migrants would place smolts in the estuary more promptly than any alternative mitigation, including greater flow augmentation. Stimulation of early smolting in hatchery-produced juveniles could help move these fish to the sea promptly. Our observations are speculative, for little is known about optimal smolt timing and the extent and importance of intrusion along the continental shelf in El Niño events.

SURVIVAL ESTIMATES: THROUGH RIVER REACHES

The goal of increasing migration speed is to increase smolt survival through reservoirs, and perhaps at ocean entry. A fundamental consideration is the magnitude of change in reservoir survival associated with change in migration speed. It is often implied that the gains in survival are substantial and certain to occur. However, the relationship between speed of migration and reservoir mortality has never been directly measured for any species, in any reach of river. The relationship has only been inferred from system survival estimates reported by NMFS during the 1970s and early 1980s for both yearling chinook and steelhead. These estimates are actually general indices of survival acquired through the impounded Snake River to The Dalles Dam. The accuracy, precision and relevance of the estimates are questionable (Giorgi 1992, Steward 1994), to the extent that efforts to continue producing them were abandoned.

The system survival indices reflect both dam passage and reservoir effects; there are no direct measures of reservoir mortality. Instead, modelers have indirectly derived estimates from the system indices. To do this, dam passage mortality had to be estimated and the system estimate adjusted; the residual survival was assigned to the reservoirs. The resultant reservoir mortality estimate was then expressed as a function of flow, presumably reflecting speed of migration. Suffice it to say, this process is based on a variety of assumptions and presumed values, as well as statistically deficient system survival estimates (Giorgi 1992,1993 provides further discussion on this matter). This reservoir mortality/flow relationship is the foundation for many passage models employed in the region.

Raymond (1979) reported system survival estimates for both steelhead and yearling chinook traversing the Snake River into the Columbia River, for the years 1966 through 1975. The investigations were continued by NMFS until 1983, when the last of such estimates were calculated and reported (Sims et al. 1984). From 1966 through 1982, system survival for yearling chinook ranged from approximately 3% to 62% (see Figure 69, reproduced from Sims et al. 1983). Over those years the number of dams increased, flow and dam operations varied widely, and the dams themselves changed (e.g., installation of bypass systems). These factors all affect smolt survival.

The relationship between flow and smolt survival was reported by NMFS (Sims et al. 1983) and graphically depicted in their 1982 annual report (Figure 70). The NPPC used these estimates, as well as estimates from additional years to indirectly derive reservoir mortality estimates for yearling chinook salmon. The estimated reservoir mortality per mile of reservoir length was expressed as a function of prevailing flow volume over some index period. Since the system mortality estimates for yearling chinook and steelhead are so similar, so were the reservoir mortality estimates derived by the NPPC. This flow/reservoir mortality relationship is the foundation for several regional passage models for steelhead. As a fundamental consideration, these estimates clearly indicate that effects associated with flow, either due to migration speed or spill level, were reflected in observed changes in smolt survival.

It has become increasingly popular for some fisheries managers to contend that measures of in-stream survival are not useful because effects may not be detectable until ensuing adult returns. Clearly, the NMFS historical measures of smolt survival, as associated with river conditions and dam operations (indexed by flow), refute this position. Furthermore, adherence by fish managers to that contention contradicts their reliance on the Sims and Ossiander smolt survival data as the primary indicator of flow effects and the central driver in their passage models.

Mid-Columbia reach survival estimates: spring chinook

In addition to the NMFS system survival studies, there have been additional efforts to estimate steelhead smolt survival through impounded reaches in the mainstem Columbia River. During the years 1985-1987, the FPC estimated steelhead smolt and yearling spring chinook survival through the mid-Columbia River and in portions of the Snake River (FPC 1988). In the mid-Columbia, freeze-branded groups of Winthrop Hatchery spring chinook were released in the Methow River. Smolt survival was estimated to a control release site in the Priest Rapids Dam tailrace. Estimated mean survival was consistent from year to year (Table 29).

Smolts encountered five dams en route to the sampling site at McNary Dam. Over the three years 1985-1987, survival averaged 45% from release at the hatchery to the control release site downstream from Priest Rapids Dam. However, FPC investigators cautioned that test and control fish were physiologically different. As such, the treatment and control groups may differ in susceptibility to guidance at screens at the McNary Dam sampling point. Smoltification/FGE interactions have been observed for yearling chinook (Giorgi et al. 1988). This in turn possibly affected recovery proportions and resultant survival estimates. The FPC suggested, given this uncertainty, that the estimates may have limited application.

The earliest mid-Columbia system survival estimates date back to 1980, and

1982-1983. During those years, the mid-Columbia PUDs estimated spring chinook survival from a release site near Pateros to downstream from Priest Rapids Dam. Additionally, in the latter two years estimates through segments of the mid-Columbia were provided. Branded groups of yearling spring chinook from Leavenworth Hatchery were used in these investigations. During the 1980 investigations, atypical operating conditions at McNary Dam compromised brand recovery and study design. Thus, estimates from that year were considered less reliable than the subsequent two years. Therefore, a range of survival estimates was reported for 1980, based on several different estimation methods. Survival from Pateros to Priest Rapids Dam tailrace ranged from 23 to 40%, with a narrower range of 33 to 40% considered to be more likely by Chapman and McKenzie (1981) and the mid-Columbia Studies Group. The estimates suggest an average project-specific (includes both reservoir and dam) survival rate of 75 to 83%.

Studies were repeated in 1982 (McKenzie et al. 1983) and 1983 (McKenzie et al. 1984). They provided estimates of survival through the same reach as in 1980, and in the river segments Pateros to Rock Island Dam, and Rock Island Dam to Priest Rapids Dam tailrace. We summarize results in Table 30. In those two years, reach survival estimates were nearly identical at 44 and 45%. Using the segment-specific survival estimates, the investigators calculated the survival per project (dam and pool combined). In 1982, they reported 87% survival for Wells Dam, Rocky Reach Dam and Rock Island Dam, and 83% for Wanapum Dam and Priest Rapids Dam. In 1983, they reported 84% and 87% for those same projects respectively. Overall, in both years the average survival per project was approximately 85%, if we assume mortalities were evenly distributed across all projects. There was no attempt to relate survival to prevailing river flow, spill, or smolt migration speed in those investigations. The 1982 and 1983 survival estimates from Pateros to Rock Island Dam were identical to those reported by the FPC during the latter part of the decade (FPC 1988).

Since system survival was estimated using a hatchery population, it may not properly characterize survival realized by wild fish. One issue that is not clear is whether these estimates reflect only passage-related survival, or if some latent post-release mortality is also expressed. Theoretically, the experimental protocol using treatment and control groups should adjust for that additional mortality. In practice, that assumption is difficult to substantiate. Nevertheless, the magnitude of the per-project survival estimates is generally consistent with those recently estimated in the Snake River using a different experimental design; the single release method (Iwamoto et al. 1994). Per-project survival in the mid-Columbia averaged near 85%. In the Snake for hatchery chinook, it averaged 90% through a portion of Lower Granite Pool and Dam, and 86% through the Little Goose Pool and dam (Iwamoto et al 1994). In 1994, based on preliminary results and a limited comparison, we note that Snake River wild and hatchery chinook survived at nearly the same rate. From release near Silcott Island to the Lower Granite Dam tailrace, survivals were estimated at near 0.93 and 0.92 for wild and hatchery chinook, respectively.[20]

Modeling passage survival: Mid-Columbia reach

We modeled the relative change in survival that may occur if some broad mainstem mitigation measures are implemented in the mid-Columbia reach. Dr. J. Anderson, of the University of Washington, used CRiSP1.5 for the modeling exercise.

Our approach was to run branded groups of Winthrop Hatchery spring

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[20] Preliminary survival estimates reported in NMFS memo from M. Schiewe to J. G. Smith, dated 5 August, 1994.

chinook that were released from the hatchery during the years 1983-1990 through the model. In some years, two or three branded groups were released from the site on different dates. For those years, CRiSP1.5 provided estimates of survival for each branded group. We calibrated travel time to approximate the average reported by Berggren and Filardo (1993). The model then predicted survival to Priest Rapids Dam tailrace, as well as to the Bonneville Dam tailrace. In the model, each group experienced river and dam operations similar to those they would actually have encountered in the specific migration year. The change in water temperature over the migratory period each year was characterized by using temperature records from mid-Columbia dams for those years.

The dam passage parameters used in this exercise, e.g., spill survival, spill efficiency, FGE, etc., were those adopted in the System Operation Review (SOR) (1992). In the model, reservoir mortality is a result of predation by fish and gas saturation. Predator-related mortality is a function of predator density, and predator activity, the latter a function of water temperature. Predator density is presumed to be equivalent to that estimated for the lower Columbia and Snake as reported by USFWS and ODFW. Readers should refer to the CRiSP.1 manual for details and documentation regarding the model mechanisms and parameter estimates.

We do not assert that the predicted survival estimates accurately reflect reality. Rather, we are interested in the change relative to basecase conditions that the identified alternatives provide.

Passage alternatives:

We examined four different passage alternatives: 1) basecase, 2) a reconfigured system with mechanical screened bypasses, 3) transport from those reconfigured mid-Columbia dams and McNary Dam, and 4) a spill program.

1. Base case: First we ran a basecase condition, imposing passage conditions as occurred during the years 1982-1990. The Wells Dam vertical slot bypass was not activated during this basecase period. Fish were not transported from McNary Dam. A broad range of flow conditions occurred over these years.

2. Mechanical (or bar-) screened bypasses: For this alternative, we emplaced screen systems at every site as proposed for the future in the mid-Columbia, and bypassed fish back to the river. In the model, full powerhouse bypasses were installed at Rocky Reach Dam, Rock Island Dam PH1, Wanapum Dam, and Priest Rapids Dam. All units were screened at these sites, and FGE was projected to be 70% for yearling spring chinook. In addition, at Rock Island Dam, average daily spill was prescribed at 17% of daily average total river flow during the spring migration period, to mitigate for no bypass installation at the second powerhouse. Our experimental groups were then exposed to these conditions. Additionally, the vertical slot bypass was emplaced at Wells Dam with a prescribed efficiency of 89% (Skalski 1993), and passage survival was assumed to be 98%. The CRiSP1.5 model partitions a reservoir reach in to three sections: the tailrace, the reservoir body, and the forebay. The partioning is used to help account for variable predation rates but does not account for concentration of predators on bypassed fish downstream from the bypass outfall.

3. Transportation: In this alternative, all fish collected at each mechanical bypass system (RR, RI, Wanapum Dam, PR and MCN) were transported to a release site downstream from Bonneville Dam. Survival of transported fish was estimated from a TBR of 1.6 as measured in evaluations conducted at Lower Granite Dam by NMFS in 1986 (Matthews 1992).

4. Spill program: To assess relative benefits of spring spill programs to enhance smolt survival, we imposed a generalized spill program at the mid-Columbia projects. For this alternative, the daily average spill was provided at a rate of 30%

throughout the 24-h period each day during the spring migration at Priest Rapids Dam, Wanapum Dam, Rock Island Dam and Rocky Reach Dam. The Wells Dam bypass was activated.

Model results:

The model results (Appendix 12) indicate that bypassing fish at every mid-Columbia dam should moderately improve survival above basecase conditions (Figure 71). Under basecase conditions, predicted survival to the Priest Rapids Dam tailrace ranged from 27.9 to 42.3%. With bypasses installed at all sites and the Wells Dam vertical slot system activated, predicted survival increased to 34.5 to 53.9% across all years modeled. For the spill alternative, CRiSP1.5 predicts no improvement over basecase conditions. Predicted survival under the spill alternative ranged from 27.8 to 43.2%.

It is possible, if not likely, that this model underestimates true bypass effects, since indirect effects as those identified at Bonneville Dam PH 1 and PH2 (Dawley et al. 1993) are not reflected in the model. This being the case, the predicted survival under the bypass alternative in this modeling exercise may be overly optimistic.

With regard to the spill alternative, some may contend the nitrogen effects predicted in the model are unrealistically high. We recognize that the predicted effects are founded on laboratory observations, caged-fish experiments, and generalized information on vertical distribution of smolts in the water column. The predictions may not accurately reflect responses in the natural environment. However, we suggest this model poses a hypothesis that begs enquiry. If the model is correct, moderate spill may be detrimental rather than beneficial to smolts, not to mention adults. Only accurate empirical estimates of smolt survival through the river system under various levels of spill will resolve this controversy. To this end, a PIT-tag detector must be installed at John Day Dam. Fish tagged and released at McNary Dam could be recovered there. With this configuration, smolt survival from anywhere in the mid-Columbia system can be estimated.

Viewing survival to the Bonneville Dam tailrace mirrors relative survival benefits to the Priest Rapids Dam tailrace as associated with the bypass program and spill alternative, as compared to basecase inriver survival (Figure 71). However, the transportation alternative indicates substantial gains in survival to the Bonneville Dam tailrace are possible, relative to basecase conditions. In this exercise, all fish collected at every mid-Columbia dam fitted with a mechanical bypass were transported to downstream from Bonneville Dam.

However, we recognize some parties may argue that the assumptions regarding transport benefits are overly optimistic, and the results show unrealistic improvement in survival. Rather than focussing on the magnitude of the estimates, we suggest the results indicate potential for gain is there, and that the option to transport should be empirically evaluated before it is dismissed.

We recommend that it would be prudent to conduct research in two key areas. First, we should acquire reliable estimates of system and project survival through the mid-Columbia reach. Secondly, we should thoroughly evaluate transportation as a passage option for yearling chinook from the mid-Columbia dams that will in the future be equipped with bypass systems.

Vertical slot fishway systems offer the hope for improved fish passage efficiency (FPE) relative to those practically expected for mechanical bypass sytems. Thus, the relative survival benefits in terms of project passage should exceed those levels predicted for bypasses as modeled in this analysis. Beyond this, the vertical slot system could also serve to reduce the need for voluminous spill, thereby reducing the risk of excessive gas saturation.

Summary and conclusions on travel time and flow

Migration speed:

We conclude that flow is at best a minor, if not negligible, factor influencing yearling chinook migration speed through the mid-Columbia River. This conclusion is based on analyses reported by FPC and NBS investigators, as well as our evaluations for this report. The only variable that may substantively affect speed of migration is the level of smolt development expressed by individuals in the population. This pattern was evident for populations liberated directly from hatcheries, and to a lesser extent for active migrants that passed Rock Island Dam. If it is perceived to be advantageous to hasten smolt migration, manipulating smolt development in the hatchery offers real opportunity, whereas flow augmentation appears ineffectual.

Survival:

Based on system survival estimates acquired during the 1980s by the FPC and PUD consultants, survival of yearling spring chinook consistently averaged near 45% past five projects. This equates to about 85% survival per project through the mid-Columbia. However, The FPC voiced concerns regarding the validity of certain assumptions inherent in the experimental protocol, and suggested the estimates may have limited utility. This stresses the need to obtain statistically reliable empirical estimates of smolt survival through the mid-Columbia reach for both hatchery and wild populations. The installation of PIT-tag detector/diverters at strategic locations would provide this capability. Skalski and Giorgi (1993) presented a plan for proceeding with such efforts in the mid-Columbia and other reaches as well. A detector should be sited at John Day Dam. Fish PIT-tagged in the mid-Columbia region could be detected and bypassed at McNary, then re-detected at John Day Dam. This would permit survival to be estimated from any location in the mid-Columbia to McNary Dam.

Passage modeling; mitigative opportunities:

Our passage modeling predicts that the installation of proposed bypass systems at four mid-Columbia dams will improve smolt survival moderately, but likely not enough to appreciably improve overall stock productivity. CRiSP predicts spill is ineffectual, apparently because of offsetting gains and losses associated with improved passage survival and gas saturation, respectively. This hypothesis requires resolution. Only empirical estimates of system survival under varyious spill levels can verify or refute the hypothesis.

The model analysis suggests that transporting fish from all four mid-Columbia sites may provide substantial gains in survival to a point downstream from Bonneville Dam, far exceeding those offered by any other alternative. We recognize that some will argue that the assumptions regarding transport benefits are overly optimistic, and the results show unrealistic improvements in survival. The model results indicate the potential for appreciable gain exists, and that the option to transport should be empirically evaluated before it is dismissed.

MODES OF DIRECTIONAL MOVEMENTS BY CHINOOK

Within the river migration corridor, it seems reasonable that cues needed for downstream movement consist of little more than direction of flow and perhaps location of the thalweg or shoreline (Mains and Smith 1964). However, once juveniles reach the estuary where tides influence direction of water movement, other factors may well come into play. McInerney (1964) proposed that juvenile salmon use estuarial salinity gradients as one of the directive cues in the seaward migration. He stated:

> *The downstream migrant having reached the estuarial region finds an environment very different from the river. The net transport of water*

although still seaward, is masked by the effects of complex tidal oscillations. Moreover, estuarial water is frequently turbid and the overall dimensions of the environment gradually increase so that the depth and horizontal dimensions are many times those of the river proper. In an otherwise difficult environment salinity gradients offer a potentially useful set of orientation cues.

McInerney (1964) offered typical examples of the horizontal and vertical salinity gradients in a typical northern river. The gradients in the Columbia River estuary, while they must demonstrate increasing salinity with both depth and with proximity to the open ocean, will differ somewhat from typical Canadian systems that enter protected straits. However, the Columbia River plume moves northward in the spring smolt migration period of May and June (Ebbesmeyer and Tangborn 1993). Decreasing salinity may indeed offer a cue for directional movement. That explanation demands somewhat less complex responses than does a postulated response of smolts to navigation with electromagnetic forces or polarized light.

Healey and Groot (1987) conclude that Pacific salmon can use a variety of mechanisms to navigate. The direction-finding mechanism of juvenile chinook is probably compass orientation by geomagnetic and other cues, according to Taylor (1986). Taylor (1986) demonstrated that juvenile chinook kept under artificial light in a rectangular holding tank aligned east/west for 18 months, showed a preferred temporal and directional orientation of 270 degrees with respect to water flow and food source. They maintained that preference in unfamiliar circular holding tanks. A 90-degree shift in the horizontal component of the earth's magnetic field resulted in a corresponding shift by fish in mean axial orientation. Removal of the 90-degree shift brought back the westerly orientation. Upon return of chinook as adults, the mechanism may include compass orientation and a goal orientation (involves experience) to the vicinity of the natal stream, after which olfaction becomes important in the upstream migration (Healey and Groot 1987).

Quinn (1982) postulated:

> *.....salmon navigate using a map, based on the inclination and declination of the earth's magnetic field, a celestial compass with a backup magnetic compass, and an endogeneous circannual rhythm adjusted by daylength.*

Quinn (1982) also noted that homing has a learned component, for juveniles imprint on the odors of the home stream and can recognize the natal stream as adults. He suggested that they may imprint on the local magnetic field before migrating to sea as juveniles. A combination of salinity gradient and electromagnetic fields may affect the seaward movement of spring chinook and their migration along the continental shelf.

OFFSHORE DISTRIBUTION AND ORIGIN OF CHINOOK

Miller et al. (1983) purse-seined from Tillamook Bay to Copalis Head in 1980 in three separate cruises. The first, 27 May-7 June, captured the only marked yearling spring chinook salmon from the mid-Columbia region. Seven spring chinook were captured with coded wire tags or brands that indicated that they originated from Leavenworth NFH. Because only the first cruise captured marked stream-type[21] chinook, Miller et al. (1983) believed that ocean-type chinook made up catches in subsequent cruises 4-15 July and 28 August-8 September. Marked Leavenworth spring chinook averaged 141 mm (fork length) at ocean capture. Because cruise 1 did not begin until 27 May, and median date of sea entry by

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[21] Stream-type chinook spend the first winter of post-emergence life in fresh water. Ocean-type chinook enter the sea in the first summer or fall of life and spend the first winter in the sea.

yearling chinook was about 15 May, it is possible that the cruise was too late to capture many marked spring chinook (Miller et al. 1983).

On cruise 1 of Miller et al. (1983), 80% of the chinook were taken in net sets with opening toward the south. On the later two cruises, direction of set and catch did not correlate. Catches in cruise 1 were almost exclusively from the Columbia River mouth northward. Thus, it appears that chinook moved northward in the period of sampling of the first cruise, but had no predominant direction of movement in the later cruises. These findings comport with the postulated presence of stream-type chinook in the first cruise and their northward movement. Miller et al. (1983) note that in all marking of juvenile chinook off the Washington coast by WDF of small chinook salmon that had spent only one winter at sea, none returned to hatcheries as a spring chinook.

Most chinook were caught within 30 km of the shoreline, and few beyond that point. Hartt and Dell (1986) show a distribution along the continental shelf of juvenile chinook salmon through summer. A few chinook juveniles use offshore areas in the Gulf of Alaska in July and August. Hartt and Dell (1986) note that chinook salmon, like coho, are typically about 10 cm larger than sockeye, chum, or pink salmon in most areas of sampling. They suggest that if offshore movement is related to size, then size may account for the presence offshore of some coho and chinook, but not sockeye, chum, and pink salmon in the first year of ocean life. We summarized evidence in Chapman et al. (1994b) that steelhead move directly offshore from the Columbia River mouth, which comports with the hypothesis that large size confers ability to survive and use offshore waters. Steelhead leave the Columbia River at large size, usually 40-50 mm larger than yearling chinook (Dawley et al. 1984b).

Chinook movements at sea are more complicated than those of sockeye and pink salmon. Although the majority of chinook appear to remain along the continental shelf more than other species, occasional catches well offshore have been made (Hartt and Dell 1986). Three juvenile fish tagged near shore at latitude

59° N returned to the Columbia River as spring chinook; one was tagged in August, 1965 and recovered in mid-March 1968, a second was tagged in mid-August 1966 and recovered in late May, 1968, and a third was tagged mid-August 1966 and recovered in early May of 1968. One fish, tagged in Hecate Strait, B.C., in July, 1968, was recovered in mid-April, 1970. Ocean-type chinook may move farther north and around the continental shelf along the Alaska Peninula, as indicated by recoveries of ocean-marked chinook (distribution summarized in Chapman et al. 1994a, from Healey 1991; Healey and Groot 1987). That behavior would comport with the longer ocean residence of ocean-type chinook (3-4 yr instead of the 2-3 yr usually spent by stream-type chinook). However, Hartt (1962) reports that a chinook of age x.2 was tagged south of the central Aleutian Islands and recovered July 7 in the Salmon River, Idaho. Hartt and Dell (1986) suggested that that recovery adds to the evidence that juvenile spring chinook (stream-type) salmon from the Columbia River tend to migrate more extensively at sea than fall-run (ocean-type) fish.

Hartt and Dell (1986) offer a diagram of their postulated ocean distribution of chinook salmon in the first summer at sea and in the first fall and winter (Figure 72). It is based on sketchier data than the diagram for sockeye (see Hartt and Dell 1986). However, Ware and McFarlane (1989) used catch-to-biomass ratios to estimate that the Central Subarctic Domain (Figure 73) contains about 2000 t of chinook salmon while the Coastal Upwelling and Coastal Downwelling domains, respectively, contain 21,000 t (B.C., West Coast Vancouver Island only, the areas likely used by Columbia River spring chinook) and 22,000 t, respectively. This independent estimate tends to confirm the modest use of offshore regions by chinook and the extensive use of the coastal domains.[22]

[22] Estimates of salmon biomass are approximations. In some years, considerably higher biomasses can be expected. Ware and McFarlane (1989) note that between 1973-84, the biomass of salmon (all species combined) in the Central Subarctic Domain may have reached 820,000 t, an increase of 70% over what it had been in the two previous decades. They suggest that the Aleutian

Healey (1991) postulates that stream-type chinook tend to use the open waters of the Gulf of Alaska more than ocean-type chinook. That behavior would help explain the relatively very few recoveries of coded wire tags from fish produced in hatcheries of the mid-Columbia region (see section on ocean harvest).

PREDATION AT SEA

The use mostly of coastal domains by chinook, sockeye, chum, and pink salmon in the first ocean summer and fall minimizes overlap of salmon juveniles with the distribution of large pelagic predators, including albacore (*Thunnus alalunga*), pomfret (*Brama japonica*), and mackerel, which move northward into the Central Subarctic Domain in August and September.

Movement along the coastal belt is adaptive in that a low standing stock of resident finfish predators generally uses the shelf along the eastern boundary of the Gulf of Alaska (Ware and McFarlane 1989). When that pattern changes because of intrusion of warm water onto the continental shelf, as occurs in El Niño events, pelagic predators may devastate populations of juvenile salmon. In 1992 and 1993, when water temperatures along the coast of Vancouver Island were much higher than normal, Pacific mackerel in very large numbers moved inshore. They decimated chinook smolts from Robertson Creek (B. Riddle and B. Hargreaves, CDFO, personal communications). Wing (1993) reported documentation of high water temperatures (Figure 74) in the eastern Gulf of Alaska, noting that sea surface temperatures monitored at Auke Bay in 1993 were 1°-3° C above average in spring and summer. Large catches of Pacific mackerel were made in the Ketchikan and Noyes Island seine fisheries in August and September; up to 4,000 per net set. Pacific mackerel were also caught near Sitka

low pressure area may have strengthened in the 1970s, increasing upwelling in the Alaska Gyre and productivity in the Central Subarctic Domain. Sockeye, pink, and chum, the more pelagically-oriented species, benefited more from this than did chinook (Rogers 1987).

and off Cape Yakutaga in the northern Gulf of Alaska. Wing (1993) suggested that sightings of tropical fishes and turtles off Alaska may be the result of El Niño and northward transport of relatively warm waters (14°-15° C) from Washington and California. The temperature increase from normal was greatest in May through August.

Based on the preceding scenario, we suggest that yearling chinook that left the Columbia River in 1992 and 1993 were heavily preyed upon by mackerel and perhaps other intruders in the coastal zone. The spring flow conditions in the Columbia River, often thought to be a bottleneck for survival of yearling migrants, were considered very poor in 1992, but excellent in 1993. However, the 1994 run of spring chinook to the Columbia River, adults that moved downstream as smolts mostly in 1992, was about 20,000 fish, about one-fifth of the 10-year average return. The escapement goal at Bonneville Dam is 80,000 fish. The 1995 run will fail, as predicted from jack salmon returns in 1994.[23] The predicted return will be less than 10,000 adults (based on the jack return in 1994 and the relationship between jack numbers in year i and adult numbers in year i+1), or about 10% of the 10-year average return. Returns of sockeye, which also migrate north along the coast, were poor in 1994, indicating that the smolt runs may also have suffered high mortality from unusual intrusion of predators.

OCEAN CURRENTS

Sea surface pressures, water temperatures, and currents are influenced by geographical position and intensity of high-altitude pressure ridges and troughs in

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[23] The poor adult returns for smolt runs of 1992 and 1993 illustrate that adult returns in one or two years cannot serve to demonstrate survival conditions associated with the freshwater migration corridor. Any benefits that might have accrued to smolt survival in the 1993 migration year were obscured by low ocean survival.

the northwestern Pacific (Davydov 1989), and undoubtedly in the northeastern Pacific as well. These broad-scale events, with global atmospheric overtones, can be contrasted with local phenomena, like El Niño, that directly affect salmon ecology. For example, a persistent, poleward-flowing coastal current moves over the inner continental shelf, inshore from the 100-m depth contour along Vancouver Island (Thomson et al. 1989). The coastal current is highly baroclinic and driven onto the shelf by the changes in low density water (runoff). Maximum near-surface speeds can exceed 0.50 m/s in the current core. In summer, water of low salinity from Juan de Fuca Strait drives the current, which flows against the prevailing northwesterly winds of the outer coast. The winds tend to reverse the flow in the top 10-20 m of the water column, so the coastal current core lies at some depth. In winter, runoff from Juan de Fuca Strait and coastal streams drive the current with the aid of southeasterly winds. Thomson et al. (1989) postulate that the coastal current has a strong effect on a variety of west coast fisheries, and acts as an alongshore conduit and cross-shore barrier to transport of biomass over the continental margin of Vancouver Island.

The Columbia River plume moves southward in summer in response to northwesterly winds, and north in winter as southerly winds predominate. The northerly winter flow would tend to override ocean currents that move southward in winter. The winter northerly plume, less than 50 km wide, is detectable as a band of lower salinity as far north as Kains Island, at the northern tip of Vancouver Island. Ebbesmeyer and Tangborn (1993) point out that transfer of Columbia River discharge from spring and summer to winter (Figures 75-76) has tended to increase salinities in summer in coastal surface waters affected by the southerly plume, and to decrease them in the northerly surface waters affected by the plume (Figure 77). Inasmuch as chinook juveniles in the first year of ocean life move well to the north of the plume effects, we see little implication of salinity changes for Columbia River spring chinook rearing at sea. Ebbesmeyer and Tangborn (1993) discuss potential effect of salinity changes on homing of spring chinook in late winter and spring. We suspect that concern may be misplaced, and that increased Columbia River flows in late winter and a northward extension of the plume edge probably should, if anything, increase, not decrease, ability of homing fish to find the river mouth.

PRODUCTIVITY DYNAMICS AT SEA

Production in pink, chum, and sockeye salmon has varied from 275,600 t to 837,400 t 1925-1989. Highest production occurred in the mid-1980s, a period of highest Aleutian Low Pressure Index (ALPI). The ALPI apparently has weakened since 1986. The abundance of copepods at Ocean Station "P" correlates with the ALPI ($r=0.50$, $p<0.05$). Average annual production of copepods from 1965 to 1975 was 86.6/m^3 compared to 129.8/m^3 from 1976 to 1980 (Beamish and Bouillon 1993). One would expect zooplankton production increases to benefit oceanic species (pink, chum, sockeye), and combined catches of North American pink, chum, and sockeye salmon comport with that hypothesis for the late 1970s. We plotted chinook runs of southeastern Alaska to California (Figure 78, adapted from Rogers 1987), noting substantial changes over time, but no coincidence of chinook and plankton production. Events along the continental shelf may differ enough to obscure effects of the ALPI on chinook. There is little doubt that long-term fluctuations occur in chinook production. From a high in the mid-1950s, chinook runs from southeastern Alaska to California declined steadily from almost 6 million to under 4 million in the early 1960s. Runs then steadily rose to nearly 6 million again in the mid-1970s (Rogers 1987). Those numbers include both ocean- and stream-type chinook.

More recently, stream-type chinook runs reached a high in the late 1980s, then declined to 1994. For example, spring chinook runs in the Queets, Hoh, and Quillayute, which include return to the river not adjusted for ocean harvest, obviously peaked in about 1989 (Figure 79). An earlier peak, in the late 1970s, may have occurred, but was reduced by intensive ocean fishing on the northern Washington coast and off British Columbia. Spring chinook runs to the mid-Columbia River, as plotted in Figure 80, increased sharply in the mid-1980s, comporting fairly well with spring chinook runs on the Olympic Peninsula (Figure 79), perhaps stimulated by increased ocean survival. Hatchery output and possibly migration success of smolts add variability to the mid-Columbia data.

We frequently see various reasons postulated for changes in adult run size. For example, TAC (1991, p. 7) states:

> *When viewed over the 30-year period, 1960-90, natural production in upper and mid-Columbia River tributaries, above and below the Snake River, appears to be relatively stable, except for minor declines 1979-84. The quick recovery after the 1979-84 decline and continued stable production in recent years may, in part, be due to the benefits of mainstem flow supplementation provided by Water Budget releases, and the fact that smolts emigrating from some of these streams have fewer dams to pass enroute to the ocean than Snake River stocks.*

We suggest that use of adult return data in a short data sequence to draw conclusions about in-river survival is inappropriate,[24] for the following reasons:

1. It ignores the effects of interdecadal changes in ocean productivity. In Figure 79, we plotted spring chinook terminal run size in the Hoh, Queets, and Quillayute rivers, which drain westward

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[24] We do not mean here to single out the TAC statement for particular criticism, but to use it to make a point.

from the Olympic National Park and are undammed. Those populations also quickly recovered from lows in the 1979-1984 period to highs in the late 1980s.

2. Snake River returns increased more rapidly 1979-1988 than did mid-Columbia returns (see Figure 81).

3. Returning spring chinook in 1994 migrated downstream as smolts in 1992, a year of conditions considered by some to be very poor for migration, and returned as adults at 20% of the previous 10-year average return. Predicted return of adults in 1995, based on jack numbers, will be only 10% of the same 10-yr average, yet those adults migrated as smolts in conditions considered ideal by agencies and tribes, with high flows and spill induced by heavy spring rainfall. It appears that whatever survivals were afforded by in-river migration conditions, they were overridden by oceanic factors. It appears that the 1992 and 1993 outmigrations were decimated by predation, probably by Pacific mackerel.

We conclude that nothing can be inferred about in-river smolt survival from short-term adult returns without controls.[25] This is not to say that test and control experimentation within year is unproductive. Reach-specific survival studies with PIT-tags best address in-river survival issues (see Skalski and Giorgi 1993; Iwamoto et al. 1994).

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[25] We suggest that if the 1995 adult spring chinook return were to equal twice the 10-year average, while the 1994 adult run was only 20% of the 10-year average, too many observers would be quick to ascribe the large run to good flows and spills during the smolt outmigration in 1993, and the poor run of 1994 to low flows in 1992. This "story telling" is common in the Columbia River region. It should stop. Scientific method offers a more reliable evaluation technique.

DENSITY DEPENDENT INTERACTIONS AT SEA

Chapman et al. (1994a) discuss density-dependent interactions in chinook salmon at sea. The available information points to use by five species of Pacific salmon of the same areas at sea in at least part of the ocean life phase, and to broadly similar food habits. In the marine waters of southeastern Alaska, chinook of marine ages x.0, x.1, and x.2 were caught to a depth of about 37 m by trollers that fished small hooks and lures (Orsi and Wertheimer 1995). Vertical distribution did not differ significantly between ocean- and stream-type fish, but larger chinook tended to be found deeper than smaller ones. Chinook salmon were significantly deeper in February than in September or May, and deeper in September than May. Coho tended to use waters closer to the surface than chinook, but distributions of the two species overlapped considerably, especially from 15-30 m (Orsi and Wertheimer 1995).

Other species, such as sockeye, use the same portion of the water column as coho and chinook, although sockeye seem to use the top 15 m more, especially at night, than do chinook (French et al. 1976; Manzer 1964). Manzer (1964) caught coho, chum, pink, and sockeye in vertical net sets in the Gulf of Alaska but, significantly, no chinook. The several species overlapped considerably in use of depths within the water column.

Recently, Bigler and Helle (1994) reviewed decreases in size of North Pacific salmon of five species. Mean body size trended downward in all chinook populations that they examined, except for chinook harvested in California and British Columbia. All other populations and species have decreased in size at rates that range from just detectable with statistical analysis to rates evident to fishery participants. The declines in body size of chinook (Figure 82) extend to the Columbia River.

We examined data on lengths of returnees to Leavenworth, Entiat, and

Winthrop NFHs to determine if a trend in mean size could be detected over time. The results (figures 83-85) indicate a downward trend in mean length from 1980 to 1992, the period spanned in the graph (body weight) of Bigler and Helle (1994). Mean size rose again in 1993 and 1994 at mid-Columbia hatcheries.

Available data on wild spring chinook of the mid-Columbia region do not permit an analysis specifically directed to change in mean length. However, it seems prudent to assume that spring chinook are not immune to effects of various enhancement programs on ocean carrying capacity. Size of fish in fisheries is not the only factor of importance in this possible phenomenon. Reduction in body size can equate to reduced potential reproductive success. Bigler and Helle (1994) comment:

> *Deleterious effects of reduced average size among salmon will likely first be evident in populations where large body size is an important adaptation....Larger adult size aids a prolonged upriver migration, as large fry size aids in the downriver migration.*

While large fry size in migration would pertain more to summer/fall chinook than to spring chinook,[26] other factors may be important. Smaller body size leads to reduced fecundity and egg size. Egg number and adult body length correlate positively in chinook (Healey and Heard 1984). Strength and longevity on the spawning grounds may be involved.

Although chinook tend to use shelf and inside waters more than do other salmon species, this may not exempt them from effects of interspecific competition at sea, and certainly not from intraspecific competition. One may well

[26] Larger smolts should survive at higher rates than smaller smolts, as evidenced by success of the hatchery steelhead program in the mid-Columbia region (Mullan et al. 1992b), and by the positive correlation between sockeye smolt size and survival (Burgner 1991). Healey (1991) also suggests that chinook of larger size have higher survival rates at sea.

ask what managers can do about ocean carrying capacity. The answer is probably "nothing" with respect to the carrying capacity itself. However, with the aims of gene conservation for wild stocks in preeminence, managers may have a great deal to do with the availability of productive capacity of the sea for various stocks and species. While one may argue that in the pre-development era, more chinook juveniles reared at sea than at present, that thesis could be questioned on several grounds. Not the least is that as managers have improved abilities to manage for an optimum escapement in more stocks, recruitment has been optimized and stabilized for more natural stocks. This in itself increases aggregate smolt output to the sea. Hatchery programs have concentrated the timing of smolt arrival at sea and possibly the density of smolts with similar distributions and timings of use. That is, they have reduced the magnitude and strength of biodiversity, thus may have concentrated use of ocean pastures in certain areas. For example, wild demes of stream-annulus chinook from various tributaries of the Snake River pass downstream as smolts over a period from mid-April to late June, while hatchery groups move downstream in a much shorter time window (Chapman et al. 1991).

Beamish and Bouillon (1993) cautioned:

> *Hatchery production appears to have followed the trends in wild production of the 1970s and 1980s and may have assisted in the rate of increase of abundance by providing large numbers of smolts at a time of improved marine survival. However, when production trends change, it may not be an appropriate strategy to continue to release large numbers of artificially reared smolts during a period of decreasing marine survival of salmon.*

It is feasible, though likely unpalatable, for managers to reduce hatchery output of smolts to give wild fish the greatest opportunity at sea. It is also possible, albeit again unpalatable, to divert a large fraction of hatchery smolt production to freshwater landlocked fisheries. Such measures may apply to hatcheries that are oriented to production instead of genetic conservation. Examples include Carson, Leavenworth, Entiat, and Winthrop hatchery production not directed at aiding wild demes. Other hatcheries, like Eastbank production of fish to supplement Chiwawa production, and the Methow supplementation program, would be poor candidates for diversion.

Because the productive capacity of the sea is a commons, conventions would be required to assure that capacity saved for one species or one country is not preempted by another species or nation. Complexity and conflict are to be expected in development of such conventions. However, it seems appropriate to actively pursue protocols now, before undetected genetic shifts occur because of excessive enhancement.

In considering reduced hatchery outputs to comport with depressions in ocean productivity, managers should also evaluate how those reductions might affect predation rates on wild smolts. No one knows whether large hatchery outputs and shifts in fish communities have created a situation in which reduced hatchery output may exacerbate predation rates on wild fish. This possibility may be of particular importance at and downstream from bypass outfalls.

HARVEST

Incidental catches at sea

Erickson and Pikitch (1994) estimated catches of chinook by commercial bottom trawls off the coast of California, Oregon and Washington. Catches were highest in winter in a depth range of 100-482 m. Catches were low in summer, and mostly in shallow water (<220 m). The salmon caught in trawls typically weighed one to two kg, and measured 40-55 cm. Larger fish apparently can evade the trawls by swimming in front of it for extended periods (Erickson and Pikitch 1994). Estimates of chinook salmon catches by the entire bottom trawl fleet for 1987 probably equaled about 1.4% of the 1987 commercial chinook salmon landings for equivalent areas (statistical areas including most of Oregon and all of Washington). Columbia River spring chinook mostly move northward from the river. It seems likely that bottom trawls in localized areas along the continental shelf of Canada and Alaska would capture small numbers of chinook, possibly including some spring chinook from the mid-Columbia region.

Ocean salmon fisheries

We examined coded wire tag data[27] for fish released from Leavenworth, Entiat, and Methow hatcheries, and one group from the Chiwawa acclimation pond. Of the many marked groups, 19 had sufficient recoveries to justify examination. Of 2,059 estimated (expanded for sampling intensity) recoveries, ocean catch made up only 2.23%, in-river catch in zones 1-6 made up 20.5%, sport catch (mostly tributary catch) 22.48%, hatchery recoveries amounted to 54.5%, and other spawning areas 0.24% (Figure 86). Brood years included were all post-1974.

The mean harvest rate for return years 1978-1993 equaled 6% for upriver spring chinook in zones 1-6. Using proportions of ocean CWT recoveries to CWT recoveries in the in-river fishery, we can estimate that ocean harvest rate amounted to about 0.6% for mid-Columbia spring chinook (2.23/22.48)(6.01). Of all ocean commercial and sport recoveries, 85% were made in Canada, 6% in Oregon, and 9% in Washington. Calculation of ocean harvest rate in the manner

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[27] There is some ongoing question about the accuracy of expanded tag estimates. Considerable effort is now being expended on modifications of the data base. Change in expansions could modify the results that we report here.

above likely overestimates and underestimates the rate if our interest is in the exploitation rate at sea. Natural mortality of uncaught but exploitable adults between the time of ocean fishing and time of return to the Columbia River removes a small portion of the returning run, so that harvest rate at sea should be lower than estimated. On the other hand, CWT tags in fish lost to hooking mortality at sea cannot be recovered, a factor that leads to underestimation of fishing rate. However, for our purposes, the calculations above are sufficient to show that ocean fishing is negligible for spring chinook produced at the three national fish hatcheries in the mid-Columbia region.

In comparison, ocean CWT recoveries for two marked groups of Ringold spring chinook (Cowlitz origin, 1975 and 1977 broods) were 53% of 4,058 estimated recoveries; inriver recoveries were only 15.2%. These data suggest that the ocean harvest rate for Ringold fish was roughly three times greater than the in-river harvest rate, or about 20%. Cowlitz spring chinook appear to remain more in areas in which they are vulnerable to ocean exploitation.

Recoveries shown in the database for wire-tagged spring chinook from the Chiwawa acclimation pond amount to only 12 fish (1989 brood).[28] Of those, three were caught at sea, five in Zone 6, and two each were recovered in brood stock examination and on spawning areas. More detailed examination of the data should await larger sample sizes and more brood years in the database.

In-river harvest

As noted elsewhere, in-river harvest rates for upriver spring chinook in the Columbia River declined after 1960, and averaged only 6% post-1978. Zone 6 catch amounted to an average of 85% of the post-1978 harvest rate in zones 1-6,

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[28] Appearance of recoveries in the database lags behind collection of field data. Thus, 12 tags in the database is an underestimate of recoveries.

or about 5.1%. These statistics , more than many other measures, point out the run depression caused by dam construction since the 1950s, when harvest rates in zones 1-6 averaged close to 60%.

Sport fisheries on spring chinook in the mid-Columbia region have been closed in recent years, except for fishing in Icicle Creek (and in most years in the Wenatchee River downstream from the mouth of Icicle Creek about two miles) directed at adults returning to Leavenworth NFH. Some loss to poaching occurs in tributaries (J. Mullan, personal communication), with the Entiat River a known problem area.

UPSTREAM MIGRATION

Migration rate

In the absence of dams, adult spring chinook migration rates were assessed for Snake River spring chinook as 17.7 to 24.1 km/d (OFC 1960). Movement rates of spring chinook in the main Columbia River through multiple projects were estimated for Bonneville Dam to McNary Dam in 1973 as 18 km/d (Young et al. 1974); Bonneville Dam to Little Goose Dam in 1973-74 as 21.6 km/d and 14.7 km/d for low and high flows, respectively (Gibson et al. 1979).

Young et al. (1978a) reported average passage timing for tagged spring chinook between Bonneville Dam and Little Goose dams as 19 days in 1973, 27 days in 1974, and 28 days in 1975. These time requirements convert to respective movement rates of 18, 13 and 12.5 km/d. Flows in the respective years equaled about 150, 350, and 250 cfs, respectively. Modal time lapse to arrival in the three years was 15, 21, and 24 days, which converts to 23, 17, and 14.5 km/d for the respective years. Movement of spring chinook was considerably faster at Columbia River flow of 150 kcfs than at the higher flows, but there was surprisingly little difference between movement rates at 350 and 250 kcfs.

Movement rate of spring chinook through reservoirs in the Snake River generally exceeds movement rate through free flowing river sections. Bjornn et al. (1994) reports movement rates through reservoirs as 23.7-64.3 km/d, and movement in the Snake River to the Grande Ronde and Lower Salmon River as 30.5-38.4 km/d. Because adults may slow as they move farther up tributaries, we may best compare movement rates in Lower Granite pool (median = 55.6 km/d) with those in the free-flowing reach immediately upstream (median = 30 to 38 km/d).

Migration delay

Adult delays increase with river flows. Spring chinook were delayed at Lower Monumental Dam in 1973 by an average 42 h during low river flow (39 kcfs) and 84 h at higher flow (77 kcfs) (Monan and Liscom 1974; Monan et al. 1979). In 1976 and 1977, with the latter an extreme low-flow year, Haynes and Gray (1980) reported delay of radio-tagged spring/summer chinook as 216 and 90 h in the respective years at Little Goose Dam and 50 and 58 h at Lower Granite Dam for the same respective years. Turner et al. (1983) found delays that averaged 32 h during low flows at Lower Granite Dam (spill <25 kcfs), and 176 h in higher flows (spill >25 kcfs). Median delays in 1982, a year of above-average discharge, median delays of spring chinook were 119 h at Ice Harbor Dam and 45 h at Lower Monumental Dam (Turner et al. 1984). We can compare those delays with those recorded by Bjornn et al. (1994) in 1992 (a low-flow year) at the same dams (respective means of 58 and 14 h).

Median time required for radio-tagged spring/summer chinook to pass dams in the Snake River ranged from 0.2 d at Little Goose to 1.3 d at Lower Granite (Bjornn et al. 1994). Spring chinook and summer/fall chinook radio-tagged at John

Day Dam and tracked in the mid-Columbia region in 1993 (Stuehrenberg et al. 1994) permit assessment of dam passage delay. Overall passage time at mid-Columbia River dams ranged from 14.6-60 h, with the longer passage times spent by fall chinook destined to remain downstream from the dam to which they were traveling. Overall passage times were similar to those estimated from radio-telemetry in lower Columbia and Snake river dams. Stuehrenberg et al. (1994) state:

> *In general, after arriving at the tailraces of the dams, all stocks of fish moved rapidly to the vicinity of the collection channel and, with the exception of spring chinook salmon at Priest Rapids and Wanapum dams, quickly made a first entry within the collection channel. Radio-tagged spring...chinook salmon spent only a few hours passing up the fish ladders, and ladder-passage times were also comparable to those recorded at lower Columbia and Snake River dams......At all dams, most passage delay occurred at areas associated with collection channels. Collection-channel passage time included timing of fish with multiple collection-channel entries and exits, multiple trips up and down the inside and outside of the collection channels, multiple arrivals at the base of the ladders, and multiple entrances into the ladders. .... We believe that eliminating most collection-channel entrances and producing laminar flow from the ladders to the collection channels has the highest potential for reducing adult passage times at the dams. The most successfull passage into collection channels occurred through large entrances; however, some large entrances were totally ineffective.*

Johnson et al. (1982) report behavior of spring chinook adults at John Day Dam, based on radio-tagging. They state that tagged spring chinook oriented mostly to the shoreline of the Columbia River, and that most tagged fish moved constantly. Spring chinook avoided the south shore approach when powerhouse discharge exceeded 40 kcfs. Johnson et al. (1982) also note no harmful effects on chinook that moved around and through spill discharge. However, large spill volumes delay spring chinook passage. Radio-tagged spring chinook took 1-1.5 d to pass Little Goose Dam and Lower Granite Dam when no water was spilled, and up to 7.5 d when spill exceeded 40 kcfs (Turner et al. 1984). During high spill, chinook moved to areas on the north side of the navigation locks, away from all fishway entrances.

Radio-tracking of adult salmon at McNary Dam and John Day Dam in 1985 indicated that median delay in passage at McNary Dam was 17.7 h for chinook. At John Day Dam the delay was less than 30 h (Shew et al. 1985).

Migrational timing

Pre-dam arrival times at Rock Island Dam can be used to infer effects of dams (and perhaps stock composition changes) on travel time of adults in the largely free-flowing river. Data of Fish and Hanavan (1948) indicate that arrival at Rock Island Dam for spring chinook peaked from 1935 to 1947 in the seven-day periods ending May 28 (mean = 582 fish), with slightly lower numbers (mean = 537) in the following week. In the ten years 1985-1994, peak spring chinook movement (mean = 3,756 adults) occurred at Rock Island Dam in the week ending May 12, with slightly lower numbers (mean = 3,574) counted in the week ended May 19. Thus, peak movement occurred about two weeks later during the pre-dam era (only Bonneville Dam was present downstream from) than at present (Figure 87).

The reasons for earlier peak movement at Rock Island Dam in the current era are not obvious. Stock composition has changed, with the fish from Winthrop, Entiat, and Leavenworth hatcheries largely originating from Carson stock. It appears that adults, once they cross the dams themselves, now move more rapidly through hydropower reservoirs than they would through the free-flowing river. Although changes in timing of spring chinook arrivals at Bonneville Dam do not apply solely to mid-Columbia spring chinook, we examined aggregate timing to learn if peak movement at Bonneville Dam occurs earlier now than half a century ago. The plot of peak movement day number post-March 31, 1938-1993 trends downward (Figure 88). It appears that peak movement day declined an average of about 10 days in 50 years. If we assume that mid-Columbia spring chinook arrive at Bonneville Dam in the same temporal pattern as the aggregate of upriver spring chinook, we discount effects of mainstem dams and reservoirs on the earlier arrival of spring chinook at RIS.

One might assume that the earlier passage responds to the hydrograph changes produced by Canadian storage. Ebbesmeyer and Tangborn (1993) plot mean discharge of the Columbia River for the 1930s and 1980s (Figure 75), depicting higher discharges through winter in the later period and reduced summer flows. However, flows in April and early May in the later period differ but little from those in the 1930s.

Another possible explanation is that spring chinook had adapted to the obstruction at Celilo Falls, and to intensive fishing there, by attempting to pass during favorable conditions produced by increased flows. Peak arrival at The Dalles Dam, just downstream from the location of Celilo Falls, suggests that spring chinook would have arrived at the falls an average of about one week after they arrived at Bonneville Dam.

Water temperature of the Columbia River has increased in spring, probably in part as a result of Canadian and other storage (Figure 89). Warm water began arriving earlier in the 1960s. In addition, annual maximum water temperatures have risen, and temperatures have remained higher longer at Bonneville Dam (Figure 90). Some of this shift in temperatures may be caused by global warming.[29] Burn (1994) plotted and analyzed long-term trends in the julian day of peak spring runoff across Canada, and trends in average spring temperatures for a collection of stations across western Canada. He found a trend toward higher spring temperatures, especially over the most recent 30 years, and a trend toward earlier runoff. He concluded that the trend toward earlier spring runoff was real, consistent with the temperature trend, and consistent with what one would expect as a result of climate change induced by greenhouse gas.

Finally, a shift to a higher fraction of hatchery spring chinook may have affected arrival time. Some selection of early-arriving broodstock may have occurred. However, sockeye, largely of wild origin, also migrate upstream earlier now (Figure 87). We suggest that earlier migration of chinook and sockeye may be a response to environmental change, rather than a result of hatchery culture.

The role of in-river fishing in affecting run timing should not be ignored. As noted in our material on harvest, fishing rates have changed from about 60% in the pre-1960s to about 6% in recent years. However, sockeye fishing, while reduced from the earlier period, has been substantial in some recent years.

Homing and straying

A general review of homing and straying in spring chinook is available in Chapman et al. (1991). We will not repeat that review here.

Information on straying specific to the mid-Columbia region is available. Reports from spawning ground surveys in the Wenatchee River basin, captures of fish at hatcheries, and the data extracted from the Pacific States Marine Fisheries Management Council's (PSFMC) data base show that small numbers of spring chinook stray (or colonize) to the mid-Columbia region (Table 31). Some of the fish that have been recovered are from distant locations, even beyond the

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[29] We use the term "global warming" without assuming that temperature increases are man-caused, although they may be.

Columbia River basin (e.g., Trinity River, CA). In 1993, and in the late 1970s and early 1980s, some fish released from the Ringold Hatchery (downstream of Priest Rapids Dam on the mainstem Columbia River) appeared on the spawning grounds in the Wenatchee River, and possibly in the Methow River.[30] Some straying from distant locations is not surprising, and may even be evolutionarily adaptive.

Some straying from hatchery production programs has occurred in the Wenatchee River tributaries. Peven (1994) sampled 300 spring chinook carcasses in 1993, finding that 32 bore coded wire tags. About 65% of these were recovered in Nason Creek. The recoveries in Nason Creek were fish released in the Chiwawa River in 1991 from the acclimation pond built as part of the Rock Island Hatchery Complex. Two tags were from fish released from Ringold Spring Chinook Facility, in the Hanford Reach, and one from Leavenworth NFH. One fish from the Chiwawa releases was recovered in the White River, and eight others from the Chiwawa were recovered in the upper Wenatchee River upstream from the confluence of the Chiwawa River. One tag from the Little Wenatchee River (not included in the 32 tags noted above) was lost before it was read. Straying in 1993 is thought to have been caused by the Chiwawa River weir. Attraction flow into the weir trap apparently was not sufficient to permit some portion, and possibly most, adult spring chinook to enter the trap and ascend the river to spawning grounds. Thus, some fish were forced to spawn downstream from the weir, either in the Chiwawa River or in other tributaries. The weir was modified in 1994 to permit more efficient trapping of adults. Sufficient information is not available to ascertain whether the modifications were effective or not. Of four adults radio-tagged at Tumwater Dam, one died en route to the Chiwawa, one spawned in Tumwater Canyon (this fish was marked late in the season), and two ascended the Chiwawa River. Of the two that moved up the Chiwawa, one

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[30] We could not confirm where spring chinook with CWTs that were recovered on the spawning grounds in 1993 in the Methow River basin (Scribner et al. 1993) originated from .

passed while the weir was in the down position, and the other passed the erect weir with no delay.

LaVoy (1994) estimated, based on CWT expansions, that Chiwawa hatchery fish contributed 136 spring chinook spawners to the natural spawning population of the Wenatchee River basin in 1993. He estimated that in addition to the 27 Chiwawa hatchery fish that passed upstream at the Chiwawa River weir, 61 returned to Nason Creek, 34 to the mainstem Wenatchee downstream from Lake Wenatchee, and seven each to the Little Wenatchee and White rivers. All recoveries in 1993 came from the 1989 brood release in 1991.

LaVoy (1994) estimated the natural spawning population of spring chinook in the Wenatchee River basin as 1,339 adults in 1993. He estimated that that number was comprised of 758 chinook of wild origin, 136 chinook from the Chiwawa release of hatchery fish (broodstock from the Chiwawa River), 79 from Leavenworth NFH, and 366 from Ringold Spring Chinook Facility. Hatchery spring chinook made up 43% (581 adults) of the natural spawning population, based on analysis of coded wire tags. Given that the 366-fish expansion for Ringold is based on recovery of only two tagged fish, we tend to view the expanded number skeptically.

When LaVoy (1994) examined scales to determine the contribution of hatchery fish, he estimated that fish of hatchery origin contributed 27.8% (372 adults) to the natural spawners. The percentage would decline to 21.5% if hatchery-fish spawning in Icicle Creek were excluded. Scale analysis suggests that hatchery contribution to the natural spawners in the basin equaled only 94 Chiwawa fish, rather than the 136 indicated by CWT analysis.

LaVoy (1994), summarizes stock composition in natural spawners. Important spawning areas most affected by infusions of hatchery fish appear to be Nason Creek, the main Wenatchee River, and, of course, the Chiwawa River. Contribution of hatchery fish appears slight in the Little Wenatchee and White rivers. The latter may have special significance because the genetic makeup, as indicated by isozymes, appears to differ for White River chinook from that of other Wenatchee River spring chinook (see section on genetics).

In the Methow River, one should expect contributions of hatchery-produced adults in the Chewack and Twisp rivers, where adult broodstock is obtained and resulting juveniles are released back to the drainage where their parents were collected (first adult returns expected in 1996). The degree of straying of the adults is unknown.

Interdam loss rates

The best and most definitive data on interdam loss of spring chinook is the passage success of spring/summer chinook from Ice Harbor tailrace to Lower Granite pool as obtained for 519 radio-tagged fish in 1992 (additional radio-telemetry analysis of 1993 data in the mid-Columbia may also shed light on interdam loss in the mid-Columbia region). After removing data for 16 fish that entered the Tucannon River, Bjornn et al. (1994) calculated that at least 79% of the fish successfully transited the four dams.[31] This would convert to a loss rate of 5.7% per dam. It may be more realistic to calculate an interdam loss rate based on known arrivals at Lower Granite tailrace, providing data to equivalent points (tailraces instead of tailrace to final pool). Those calculations indicate a success rate of 92%, or an interdam loss rate of about 2%.

Because the data of Bjornn et al. (1994) were obtained in 1992, a year of low flows and lack of spill, they may not apply to years of average or higher flow. For example, fallback at Lower Granite was only 1.8% for radio-tagged fish. Fallback through the juvenile bypass system at Lower Granite was 87 adults from April through July, or about 0.4% of 21,924 salmon counted in fishways. Some

[31] Bjornn et al. (1994) used the term "at least" because the receivers at Lower Granite tailrace and at the top of the ladders were not 100% efficient, thus may have missed some fish.

adults undoubtedly went through turbine runners.

Shew et al. (1985) report that one spring chinook, or 2.2% of the fish that they had radiotagged, fell back at McNary Dam. At John Day Dam, four chinook, or 8.5% of the tagged sample, fell back.

Patterns of flow through powerhouses and spill bays affect proportions of adult spring chinook that enter alternative fishway entrances (Bjornn and Peery 1992). More importantly, interdam losses of adults appear to increase with discharge and spill. For fishway entrances to successfully attract adults, the fishway flow should be uninterrupted and directed downstream (Bjornn and Peery 1992). Bjornn and Peery (1992) state:

> *High turbulent flows near fishways entrances can mask the attraction flows, while misplaced flows can attract fish away from the entrances and increase delays in entering the fishways. The optimal spillway flow will set up a velocity barrier angling toward the fishway entrances to guide fish to the fishway openings. During high river flows, Junge and Carnegie* (1972) *recommended that a crowned spill pattern be used whereby spill is highest through the central spillbays and decreases outwards to the end bays, forming a V-shaped flow pattern in the tailrace. When relatively little spill occurs, a split spill pattern was recommended where the flow is concentrated in the end bays to enhance attraction toward the fishway entrances.....Spill conditions described by Junge and Carnegie (1972) that should be avoided include differences of gates openings of four feet or more in adjacent spillbays. This situation creates a slack water area adjacent to a high velocity jet. Fish crossing from the slack water area into the high velocity jet will most likely be killed from the high shear force. High spills in the end bays can create the greatest problems by producing high velocities, turbulence, and vortexing that will*

completely block access to the fishway entrances. High spills can also create currents that will misguide fish away from the entrances.....When spill through the end bays is too low relative to the central bays an eddy can form along the shoreline which can eliminate or even reverse flow direction near the fishway entrance.

The foregoing concerns about attraction flows are important in day-to-day operations, of course. But they also call attention to the unknown current patterns that drawn-down reservoirs may create. Drawdown to spillway crest, for example, will change flows and flow patterns through powerhouses and spill, thus leading to untested conditions in tailraces. Haas et al. (1969) described a difficult hydraulic pattern faced by chinook attempting to pass newly-constructed John Day Dam. We can expect unforeseen patterns to cause migration problems wherever powerhouse and spill volumes and currents are changed in ways not previously tested. Hydraulic models may help predict problem areas. Bjornn and Peery (1992) note and cite many difficulties with flow patterns and fish attraction at Columbia River dams. In general, high spill rates cause delays in upstream movement (Turner et al. 1984).

Delay at dams when gas supersaturation is at high levels may lead to increased stress and gas bubble trauma (GBT). Of special concern is any inability of fish to find fishway entrances promptly. In 1968, when John Day Dam was in final construction phases, total dissolved gas (TDG) was high and an estimated 20,000 adult summer chinook were killed. The actual kill probably exceeded that estimate (Haas et al. (1969). Haas et al. (1969, 1976) estimated that in addition, 32% of fish migrating from John Day Dam to McNary Dam were lost, and noted that losses continued upstream on the migration route to spawning areas.

At high TDG, delay of chinook in relatively shallow fishways exposes adults to potential GBT (Monan et al. 1971) and may aggravate existing symptoms. This might, of itself, mandate operations at dams to minimize time that adults spend in fishways. Monan and Liscom (1971) suggested minimizing periods when counting station gates were closed. They cited Coutant and Genoway (1968) as drawing attention to the potential for incidence of GBT when adults ascend fishways. However, turbulence in fishways should permit gas to escape to the atmosphere to some extent. So far as we know, no study of TDG dynamics in fishways has been reported.

Chinook salmon move through navigation locks as well as fishways. Fortunately for managers attempting to assess numbers of fish at various river points, that movement makes up only a small fraction of the total migration. Data in Turner et al. (1984) indicate that two of 37 adults that crossed Ice Harbor Dam passed through navigation locks. Shew et al. (1985) tracked two chinook through the navigation lock in 1985 at John Day Dam, or 1.7% of the fish tracked there.

Weiss (1970) reported that substantial mortality to adult spring chinook occurred downstream from both Bonneville Dam (13% loss rate) and The Dalles Dam (12-25% loss rate) dams in 1970. Young et al. (1978b) evaluated unexplained losses of adult spring and summer chinook from Bonneville Dam to Ice Harbor or Priest Rapids Dam. They corrected fishway counts for estimated dam fallback (Figure 91). Their plot of percentage loss against river discharge is useful because it relates increased interdam loss to increased river discharge. The degree to which the dashed line in Figure 91, adjusted for fallback, reflects reality depends not only on the accuracy with which the authors estimated fallback, but on estimates of interdam harvest and on the assumption that turnoff to each tributary makes up the same percentage of the adult population in each year plotted. Still, the graph suggests increased interdam loss with increased flow. Young et al. (1978b) concluded that no interdam loss occurred at Columbia River flows of 150 kcfs, except at John Day Dam, where they estimated a mortality of about 20% independent of flow.

Pratt and Chapman (1989) and Chapman et al. (1991) estimated interdam losses of about 5% for spring chinook. Dauble and Mueller (1993) used biological assessments and run reconstructions of the Columbia River Technical Staffs to develop adult passage conversion rates per project for the mainstem Columbia River and for the Snake River (Table 32). The estimated per-project conversion rate was 0.878 for the area from Bonneville Dam to McNary Dam, and 0.944 for Snake River projects. It is possible that fallback and reascencion at some mainstem dams, particularly Bonneville Dam, may have inflated the Bonneville Dam count, contributing to the relatively high interdam loss estimate in the lower Columbia River. Without such an explanation, it is somewhat difficult to understand why interdam loss would be so much higher at the four lower Columbia River dams, then decrease to about 5% in the Snake River and in the mid-Columbia River. It is conceivable that adults weakened by hooking at sea, net dropout, or by encounters with marine mammals (Park 1993a) may die at greater rates in passage over the first few dams, but this explanation is doubtful.

Fallback in spring chinook had not been investigated in the mid-Columbia region from Priest Rapids Dam upstream until the 1993 studies reported by Stuehrenberg et al. (1994). Fallback was a surprisingly high, at 17.7% for spring chinook at Priest Rapids Dam, 8.1% at Wanapum Dam, about 2.5% at Rock Island Dam, near zero at Rocky Reach Dam, and about 3% at Wells Dam (Figure 92). Of the 52 fish that fell back at Priest Rapids Dam and Wanapum Dam, 32, or 61.5%, were last detected downstream from Priest Rapids Dam. Ten of the 32 fish entered the Ringold Spring Chinook Salmon Facility or Priest Rapids Hatchery. Another 16 spring chinook overshot the Ringold facility and, although not detected by radio receivers, were recovered at the facility.

The high incidence of fallback at the first two dams upstream from Ringold Spring Chinook Facility has implications that extend into questions of estimates of escapement and interdam loss in the mid-Columbia region. If one were to calculate interdam loss based on counts of spring chinook at Priest Rapids Dam and Rock Island Dam, one would overestimate the loss through that river reach. Behavior of spring chinook released from the Ringold Spring Chinook Salmon

Facility may consistently lead to inflated estimates of escapement at Priest Rapids Dam.

We extracted available fallback data for Columbia and Snake River dams from the literature (Table 33), using a format similar to that of Dauble and Mueller (1993). Fallback at mainstem dams in the lower Columbia River has ranged from 2.2% to almost 14%; in the Snake River from 4% to 18%. If fallback were equal at all dams, and similar fractions of fish that fall back reascended ladders at all dams, little concern would attend assessments of counts at successive dams. Of considerable concern, however, would be the effect of fallback on estimated escapements at the uppermost counting station. A consistent fallback there of, say, 10%, with only 3% reascent, would lead to a 7% overestimate of escapement. Another concern is the effect of fallback on adult viability. Some fish that fall back through turbine runners will be killed or wounded so severely that they cannot spawn successfully. Injuries occur even in fish that are diverted by traveling screens and enter juvenile bypasses (Wagner and Hillson 1992).

CAUSES OF DECLINE

Long-term changes in stock productivity

Mullan (1990) examined escapements of spring chinook to the Wenatchee, Entiat, and Methow rivers as the differences between adult counts at various dams. He subtracted harvest in tributaries and returns to hatcheries to estimate wild escapements. He estimated that an average of 8,431 naturally-produced spring chinook returned to the Wenatchee (4,465), Entiat (1,247), and Methow (2,719) rivers in the period 1967-87. Using those estimates, he adjusted numbers to the Columbia River mouth by accounting for 5% interdam loss per hydro project. Thus, Mullan's estimate of fish at the mouth of the Columbia River was

12,600. Inriver catch in the period of interest would increase adults to 15,750, and 10% ocean harvest would increase adult recruitment to 17,400.

Mullan (1990) noted that runs of adult stream-type chinook salmon in the undammed Fraser River average only 19,000 to 31,500. He suggested that there is no evidence that the Wenatchee, Entiat, and Methow rivers ever produced more spring chinook than they do now. We examined stock-recruitment plots of Chapman et al. (1982) for the period before the late 1950s, before the era of mainstem dam construction. The plot for aggregated spring chinook (Figure 93) returns to the Columbia River in relation to adult escapements suggest that an optimum escapement of about 60,000 adults then produced an average of about 200,000 progeny adults, exclusive of ocean harvest. If we add, say, 10% for ocean harvest, optimum escapement produced about 220,000 adults. This translates to a ratio of recruits to spawners (R/S) of about 3.66 and an MSY exploitation rate of about 73%. The estimates by Mullan suggest an R/S ratio of 2.1, and MSY exploitation of about 52%, of which interdam loss takes an absolute 31-37%, or a relative 60-71% of the potential MSY. We assume, reasonably, the same R/S ratio for mid-Columbia spring chinook as for the aggregate spring chinook of the Columbia River in the period before the late 1950s. We also assume that the habitat quality and quantity available in the mid-Columbia region has not decreased since then (Mullan et al. 1992). With those assumptions and Mullan's (1990) estimate of adult production, we can estimate that the mid-Columbia region now produces approximately 43% fewer adults per spawner than it did in the 1950s.

The role of ocean productivity should be considered before we accept the decline estimate as attributable solely to conditions in fresh water. From 1967-1987, the period of Mullan's (1990) analysis, the Aleutian Low Pressure Index[32]

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[32] The Aleutian Low Pressure Index is calculated as the area in km^2 in the North Pacific Ocean that has sea-level barometric pressures lower than 100.5 kilopascals.

(ALPI) increased markedly (Figure 94). In the period 1941-1962, the period in which ocean rearing conditions apply to the adult return data in the stock-recruit function developed by Chapman et al. (1982), the ALPI declined markedly (Beamish and Bouillon 1993). The mean ALPI for 1941-1961 (periods when progeny of brood years used by Chapman et al. (1982) were at sea) was 5.274 million km^2 (median = 3.455 million km^2); that for 1965-1986 (period when ocean rearing took place for adult returns used by Mullan (1990)) equaled 6.366 million km^2 (median = 5.778 million km^2).

Another factor that could contribute to error is our assumption that ocean fishing took about 10% of the adult recruits in the 1940s and 1950s and in the later period. We have no way to accurately assess the fishing rates in the earlier period, but Chapman et al. (1982) believe that rates increased from the 1950s through the 1970s. A 10% harvest rate at sea on spring chinook, based on CWT data on upriver spring chinook from Carson, Klickitat, and Leavenworth hatcheries, was used by NPPC (1986) for conditions in the 1970s. If the ocean harvest rate was only 5% in the 1940s and 1950s, instead of 10%, the R/S ratio for that period would be reduced by 5% to 3.5 instead of 3.66; with negligible effect on our conclusion that R/S ratio has declined sharply after mainstem dam construction. However, the increased ocean productivity discussed in the preceding paragraph and the change in ocean fishing rate would have opposite and cancelling effects on the R/S decrease.

NPPC (1986) and Mullan (1990) may have used an ocean harvest rate greater than the real rate. The Technical Advisory Committee (TAC 1991) concluded that upriver spring chinook are not known to be harvested significantly in ocean fisheries, probably due to timing and structure of fishing seasons. They noted that in April 1988, the Upriver Spring Chinook Task Force reported that *Current CWT and GSI information indicates upriver spring chinook are impacted by ocean fisheries at a lower rate than any other Columbia River chinook race.* The TAC stated that the ocean harvest rates are lower than anticipated (2%) when the

Columbia River Fishery Management Plan was drafted. Thus, correction of Columbia River returns by a factor of 10% to account for ocean fishing may be excessive. If, for example, the correction should only be 2%, then the average number of recruits for the period 1967-1987 at the mouth of the Columbia River (15,750) should only be adjusted upward to 16,071, which lowers the R/S ratio to 1.91. In turn, this would reduce MSY exploitation to 48%, and adjustment of this percentage by the interdam losses would further reduce harvestable numbers and demonstrate a greater reduction in productivity of the stocks than we calculated above. The actual ocean harvest rate appropriate for application to the data of Mullan (1990) almost certainly is less than 10%, and may be less than 5%.

In summary, we conclude that the mid-Columbia tributaries formerly produced substantially more spring chinook in the period before extensive main-stem dam construction and development of upstream storage. We estimate a productivity reduction of at least 43% from the 1950s to the 1980s. The current R/S ratio leaves much less room for harvest, on average, than was the case in the 1950s, in part because of interdam losses of adults between the estuary and natal streams.

Marine mammal predation on upstream migrants

Observers at Lower Granite Dam on the Snake River have tabulated bites, scars, and open flesh wounds on spring/summer chinook salmon adults that arrive at the dam. For 1990-1992, incidence of marks thought to be bites of harbor seals *Phoca vitulina* amounted to 14.0-19.2%, and bite incidence in the spring of 1993 amounted to 30% (Park 1993a). Severe incidence before the 1990s had only been recorded in 1973. Chapman et al. (1994a) reviewed bite incidence through the season, and concluded that it is higher in spring migrants than in summer- or fall-migrating chinook. Park (1993a) estimated that 4,000 to 9,700 spring chinook of Snake River origin died as a result of consumption by harbor seals and delayed mortality from wounds.

Seal and sea lion *Zalophus californianus* populations have increased sharply under protection of the Marine Mammal Protection Act of 1972. The Oregon herd of harbor seals amounts to about 12,000. The Columbia River portion is thought to contain at least 3,000 animals and to have grown at 6-11% annually since 1978 (Oarj 1993; Beach et al. 1985). From 2,000 to 3,000 seals and 300-500 sea lions use the lower Columbia River through the winter and early spring (Brown and Jeffries 1993).

No quantitative observations are available on the degree of wounding or marking of mid-Columbia spring chinook by marine mammals. We would expect the incidence of marking to equal that of Snake River spring chinook, inasmuch as Columbia River and Snake River spring chinook enter the Columbia River at the same time.

Olesiuk et al. (1990) estimated that B.C. harbor seal populations grow at 12.5% per year, and noted no evidence of density-dependent changes in the population growth rate. Thus, the B.C. population doubles each 6 years. Beach et al. (1985) counted seal pups and estimated the count increased by 19.1% per year 1976-1982. The Washington Department of Fisheries (Anonymous 1992) listed marine mammal effects on salmon as one of six planning uncertainties, stating:

> *Consumption of salmon by marine mammals must now be considered in planning. These are fish which otherwise may have been caught by commercial and recreational fishers.*

The rapid expansion of protected marine mammals may bring them into direct conflict with salmon management objectives. The legal ramifications of conflict between the Marine Mammal Protection Act of 1972 and the Endangered Species Act lie beyond the scope of our spring chinook status review. However, we repeat the reflections of Chapman et al. (1994a):

> *One can argue that pinnipeds and salmon coexisted long before man interfered ecologically. A contrary argument would note that it is unrealistic for man to manage and intensively prey upon salmon without managing one of their principal predators.*

Furthermore, human intervention may well have increased the ease with which marine mammals can find and attack spring chinook. For example, we have moved discharge from spring and summer to winter (Ebbesmeyer and Tangborn 1993) and reduced turbidity. Barriers, e.g., Bonneville Dam, and bank encroachment through the estuary may have increased vulnerability of spring chinook to marine mammal attack. Reduced populations of adult salmon may have moved predation by marine mammals toward or into a depensatory phase, in which the rate of killing and wounding increased as spring chinook decreased. We speculate here, of course, but suggest that these questions suggest research at minimum, and may justify adaptive management in the form of population control in marine mammals. Examples of adaptive management might include selective harvest and/or sterilization of live-captured seals on haul-out beaches.

Pathogens

Incipient lethal temperatures and migration temperature ranges do not tell the entire survival story for adult migrants (Bouck et al. 1975). Pathogen infections in the host fish become more intense with temperature. Fish stressed by migration at high temperature, damaged by contact with marine mammals, fishing gear or hydro dam physical structure, or suffering from gas bubble disease, would likely succumb more readily to pathogens.

Sockeye salmon tested by Bouck et al. (1975) at high holding temperatures had a lower antibody titer against *columnaris* disease. Holt et al. (1975) found no mortality in salmonids caused by *Flexibacter columnaris* when the temperature did not exceed 9.4° C, but increased temperature caused progressive increases in mortality. Udey et al. (1975) reported that time to death for fish exposed to *Ceratomyxa* decreased with increased holding temperatures.

Chinook salmon in the Columbia River have high incidence of bacterial kidney disease (BKD). Incidence appears highest in spring chinook (Fryer 1984). Howell et al. (1985) state that BKD can be a major problem in hatchery-reared juvenile spring chinook in the mid-Columbia region. Sanders et al. (1992) state that BKD *....is one of the most prevalent diseases among hatchery-reared salmonids and is a major problem at hatcheries throughout the Columbia River basin*. They collected samples of chinook salmon with beach seines and purse seines at Jones Beach, in the lower Columbia River. The beach seines took mostly subyearlings and purse seines took mostly yearlings. Of 549 yearling chinook sampled, prevalence of infection was 25%. In the first year of study, captured fish were transferred to a freshwater holding facility at Round Butte Hatchery and held at 10° C. After 150 days, 48% of the yearlings had died.

Banner et al. (1983) established that BKD causes mortality in chinook salmon in salt water, and noted some indications of horizontal transmission. Sanders et al. (1992), in the second year of their study, beach-seined subyearling chinook and divided catches in half, with one portion taken to Round Butte Hatchery and the complement to ultraviolet-treated salt water at the Hatfield Marine Science Center at Newport, Oregon. Both groups were held 150 days. Prevalence of BKD at the end of the 150 days was 9% for the group held in fresh water and 46% for the salt-water group. The authors concluded that salt-water rearing increased mortality over that in fresh water. They suggested that the additional stresses imposed by adjustment to salt water caused the pathogen to be more efficient.

Elliott and Pascho (1993) report that wild/natural spring chinook in the

Snake River basin bear BKD at high prevalence but low infection levels in comparison to hatchery-produced juveniles. Degree of infection by BKD affects smolt survival during the downstream migration. Pascho et al. (1993) demonstrated that hatchery-reared spring chinook that were progeny of maternal parents with low or no detectable BKD infection survived as smolts at higher rates to the first downstream detection point than smolts from maternal parents with high BKD infections. Timing of arrival of the groups did not differ, but cumulative recoveries at Lower Granite, Little Goose, and McNary Dam dams totaled 51% of the smolts released from the low-BKD group and 42% from the high-BKD group.

Horizontal transmission of BKD may or may not occur in transportation vessels and collection facilities in the Snake River and at McNary Dam. One way to reduce the likelihood of such transmission is to reduce density of chinook smolts in collection systems and transportation tanks. Managers may reduce hatchery smolt densities by reducing smolt output from hatcheries. A practical means for accomplishing this may be to reduce rearing densities used to produce a given number of adult salmon (not smolts). Ewing and Ewing (1995) reported that percent yield of chinook salmon as adults decreased as rearing density increased in 14 of 15 experimental brood years at the several hatcheries included in their review. Percent yield is not the same as adult yield per pond. Increased rearing density increased adult yield per pond in only 4 of 15 years.

Total dissolved gas supersaturation

When water plunges over spillway crests at Columbia River dams into downstream pools, carrying air with it, entrained air goes into solution. Gases so dissolved can reach supersaturation levels.

Pressure and temperature influence the solubility of gas in water. Pressure increases rapidly with depth, so deep water holds more gas in solution than shallow water. Warm water can hold less gas in solution than cold water.

Fish exposed to nitrogen-supersaturated water can develop symptoms of gas bubble trauma (GBT). Symptoms include blistering, loss of vision, and damage to tissues. Weitkamp and Katz (1980) thoroughly reviewed effects of gas supersaturation. When large segments of the Columbia River reach 125% gas supersaturation, mortality should be expected (Ebel 1971; Ebel and Raymond 1976). Ebel (1969) and Meekin (1971) reported the first indications of a serious gas supersaturation problem in the main Columbia River. TDG reached 120-130% saturation in 1966 and 1967. GBT was observed in the lower Columbia River in juvenile salmon in 1968 (Beiningen and Ebel 1970). Severe mortality in adults was noted downstream from John Day Dam in 1968, when the entire river flow was spilled because turbines were not yet installed. TDG reached 123-143% for extended periods, and an estimated 20,000 adult summer chinook were killed. If adults can effectively compensate for high TDG by seeking deep portions of the river, one must enquire why these adults perished.

Weitkamp and Katz (1980) wrote that the supersaturation problem in the Columbia River had been essentially eliminated, and Ebel (1979) stated that in the Columbia and Snake Rivers ....*fishery agencies believe the problem of supersaturation and corresponding losses of fish to gas bubble disease is solved.* Those assessments may have been premature. Certainly TDG reaches levels of over 120% saturation frequently in the Columbia River. The Options Analysis EIS (USACE, et al. 1992) shows maximum TDG levels at Wells Dam, Rocky Reach Dam, Rock Island Dam, Priest Rapids Dam, and at downstream dams. In some years, TDG maxima exceed 130%. Data in reports of the Fish Passage Center demonstrate frequent saturation levels for total dissolved gases (TDG) in excess of 110% in 1992-1994. Gas levels can successively increase downstream as spill occurs at sequential dams, even where spillway deflectors are installed, if spill fractions and discharges are high.

Investigators found internal symptoms of GBT in tissues of salmon sampled at Bonneville Dam in 1994. The degree to which GBT in tissues predisposes fish to loss from other factors is unknown. What is known is that many fish can recover from GBT if removed from supersaturated water. For example, Meekin and Turner (1974) noted that juvenile chinook recovered after exposure to 120% and 135% N_2 (equivalent to 110% and 122% total gas pressure). After exposures of 4 to 67 days, stressed fish were placed in equilibrated water. Seven of the 67 fish died within 24 h. The remaining fish appeared healthy after a two-week recovery period. Fish that died included fish with and without exterior symptoms. Weitkamp (1976) held fish with GBT at depth in live cages. Fish that had been exposed to 118-126% TDG for 10 or 20 days were held at a depth of 3-4 m for 20 days. Most of the stressed fish recovered, but about 10% died. The dead fish had fungal infections in the caudal fin, where circulation may not be adequate to prevent secondary infection at lesions in that area.

Fish with access to deep water may be able to sound to prevent exposure to water with high TDG. In the case of smolts, the degree to which additional predation may occur in deeper water is unknown. Fish infected with BKD, then exposed to stress from TDG, may be more vulnerable.

We found no evidence that fish with GBT subsequently have higher mortality than unstressed fish after they reach salt water. Bouck et al. (1976) exposed juvenile chinook and sockeye to 110%, 115%, and 120% TGP, then transferred them to gas-equilibrated salt water. The transferred fish either survived for over 5 days or died from causes unrelated to TDG. Bouck et al. (1976) concluded that no latent or delayed deaths occurred because of GBT.

Safe levels of TDG:

The issue of what constitutes a "safe" level of TDG is greatly complicated by certain unknowns. One of the uncertainties is the degree to which smolts and adults sound to avoid TDG. Another is the question of synergism between GBT and other pathogens, e.g., BKD. However, Weitkamp and Katz (1980) discussed regulation of TDG as follows:

Since the identification of dissolved gas supersaturation as a problem in the Columbia River system in the late 1960's, there have been criteria and standards promulgated by a variety of regulatory entities. The National Academy of Sciences/National Academy of Engineering (1972), using available data, recommended that aquatic life will be protected when total dissolved gas pressure in water is no greater than 110%. Subsequently the states of Washington, Idaho, and Oregon promulgated dissolved gas standards, initially for dissolved nitrogen and later for total dissolved gas. The regulations specified human activities should not increase dissolved gas levels above 110% in Washington and Idaho and 105% in Oregon. Other states have since passed similar regulations.

The water quality standards were reviewed in 1975 by a group of four agency representatives from the United States Environmental Protection Agency, Idaho, Oregon, and Washington (Rulifson and Pine 1976). This group suggested a standard of 115% total gas saturation for the Columbia-Snake River system except during particularly high-flow years. Their recommendation was ignored by the Environmental Protection Agency criterion issued in 1976 (USEPA), which again recommeded a criterion of 110% TGP. Recently, Ebel et al. (1979) have reviewed the most recent Environmental Protection Agency criterion, and indicate defensible dissolved gas criteria could be established at either 110, 115, or 120%.

A NMFS-appointed panel of experts, meeting in Seattle, WA., on June 24, 1994, summarized gas supersaturation effects on GBT in fish. The panel had three major recommendations on reduction of TDG:

1. *An active search should be made for mechanisms to provide water*

for outmigration at levels of TDG that are not detrimental to fish.

2. An active program is needed to reduce TDG below the current standards of 110% of barometric pressure in the Columbia and Snake rivers.

3. Carefully evaluated, innovative engineering and water management projects should be identified and implemented to lower TDG and provide adequate fish passage.

The panel further considered GBT in the context of overall river management, stating that:

> *1. TDG and GBD* (GBT) *are but one consideration among many for management of flow and fish passage in the Columbia and Snake rivers.*
>
> *2. Risk management among the many sources of biological damage depends on having reasonably complete quantitative knowledge of the effects of each source, including TDG and GBD.*
>
> *3. Overall reduction of risk to fish may require other groups to consider reconfiguration of engineering structures and water management rather than minor operational adjustments to alter TDG.*

Finally, the panel concluded:

> *The induction of GBD in both juvenile and adult Pacific salmon is one of the important risks to be balanced in water management in the Columbia and Snake rivers. The panel's review of GBD signs and monitoring at the request of the NMFS Northwest Fisheries Science Center confirmed that much is known about the sensitivity of salmonids to gas supersaturation and that signs of GBD may be*

expected in salmonids inhabiting shallow waters near the current water quality standard of 110% saturation. The panel highlighted that key information is needed about biological (physiological) effects of gas bubbles in fish and survivorship of fish with GBD signs in the river before it is reasonable to depend on real-time monitoring of symptoms to protect fish populations. This information can be obtained by carefully planned laboratory and field studies and continued biological

and physical monitoring of the river environment during experimental spill programs.

The Columbia River System Operation Review (SOR) notes that gas supersaturation may also be an issue that relates to fish guidance and predation. Where fish guidance is designed on assumed travel of smolts in the upper 15 feet of the water column, for example, smolt travel at depth in the forebay to avoid supersaturated water could affect guidance success.

Dawley et al. (1976) reported bioassays of losses in juvenile salmonids at various levels of air supersaturation in shallow tanks. CRiSP.1 modeling documentation for version 4 uses data from Dawley et al. (1976) to estimate cumulative mortality. For example, the model predicts mortality for juvenile fall chinook of 2% at 60 days exposure at 110% and 115% nitrogen supersaturation; 2% in 30 days at 120%; 20% in 20 days at 124% supersaturation; and 10% loss in 10 days at 127%. The model predicts an exponential increase in mortality rate with increases in nitrogen saturation for spring chinook.

Dawley et al. (1976) demonstrated that exposure time to induce 25% mortality from GBT in chinook is shorter in shallow tanks (0.25 m) than in deeper tanks (2.5 m) at a given TDG level. They noted greater resistance to TDG effects in small chinook (mean length 42 mm) than in much larger steelhead (mean length 180 mm). From this we infer that larger fish, e.g., chinook adults, probably have higher mortality rates per day than do smaller fish, if held at the same depths as the latter.

Spillway deflectors, or "flip lips," designed to prevent spilled water from plunging deep into the water downstream from a dam so equipped, are installed on bays 5-14 (of 18) at Bonneville Dam, none of 23 bays at The Dalles Dam, none of 20 bays at John Day Dam, and bays 4-19 (of 22) at McNary Dam (CE et al. 1992, p. C-1). Of the five dams in the mid-Columbia migratory route for chinook salmon, none has a spillway deflector. Although spillway deflector designs may reduce buildup of TDG, recent study suggests that they may kill or injure smolts (see discussion earlier in this report).

Gas bubbles do not form when hydrostatic pressure exceeds the TDG pressure. For example, fish would not form bubbles in blood and tissues if they remain at depths greater than about 3 m, if gas supersaturation does not exceed 130%. Adult spring chinook, tagged with pressure-sensitive radio tags, swam deeper in supersaturated water in 1976 in the Snake River than in normally-saturated water in 1977 (Figure 95). Fall chinook in normally-saturated water in 1976 also swam at shallower depths (Gray and Haynes 1977). The information obtained by Gray and Haynes (1977) offers correlative information that should be followed up by additional studies.

The ability of chinook to compensate for high TDG by swimming deep in the water column would be reduced in fishways that require movement at shallow depths. Gray and Haynes (1977) note:

> *Although swimming depth of migrating spring chinook salmon may preclude gas bubble disease, delays in passage through shallow fish ladders may result in maximum exposure and could precipitate air embolism in fish with a high dissolved gas content.*

Gray and Haynes (1977) found that although radio tagged fish in 1975 moved rapidly between two dams (about 48 km in 1-3 days, they delayed for up to five weeks in passage through fish ladders. Liscom and Monan (1976) reported that chinook delayed up to two weeks at Lower Granite Dam. In both the aforementioned studies, some fish never negotiated the dams although they may have entered ladders, left them, and reentered them several times.

The radio-tracking study by Gray and Haynes (1977) is the only research that informs us of the behavior of free-swimming salmon. The degree to which juvenile chinook compensate for TDG by moving deeper in the water column is unknown. Various factors may influence compensation, including water temperature, light intensity, and turbidity (Blahm et al. 1975). Other factors may include fish size, degree of smolting, predator activity, and time of day. Behavior of smolts confined in a cage, even one that permits fish to select the water depth occupied, may not indicate behavior when fish must migrate, pass dams, feed, and avoid predators. L. Fidler (Aspen Applied Sciences, Ltd., personal communication) theorizes that juveniles do not intentionally sound to compensate for high TDG, but to offset the positive buoyancy caused by GBT. By going to depth, they can become neutrally buoyant.

Meekin and Turner (1974) reported that chinook juveniles will survive nitrogen supersaturation up to 112% with oxygen at less than saturation with insignificant mortalities for 27-32 d. Chinook survived at 0.6 m depth for 45 days in Columbia River water at nitrogen level of 109% and oxygen at 108%. Meekin and Turner (1974) noted that squawfish survive in 120% TDG in shallow troughs (8 in) for 17 d but become lethargic and do not prey on juvenile salmonids. Squawfish die in nitrogen levels of 135% saturation in 44 h when held in shallow (8 in) troughs. Bioassays in Columbia River water led to almost total mortalities of chinook held at the surface in nitrogen concentrations greater than 120% and supersaturated oxygen. Chinook held 2.5-3 m deep did not die after periods of 10-14 d. In tests in cages that extended from 0-3 m depth, chinook survived for 21-28 d at TDG of 128%, but more survivors from the 28-d test had external symptoms of GBT. This probably reflects failure of fish to remain at 3 m. Excursions upward to shallower depth may result in trauma.

Meaningful monitoring of TDG effects on smolts and adults is difficult at best. Juveniles taken from bypass sampling systems have sounded to enter gatewells, which should force gas bubbles into solution. Renucleation of excess gas in fish that have resided in gatewells and gallery for various times may only be detectable by careful tissue examination (L. Fidler, University of British Columbia, personal communication). Because gas bubbles disperse when fish sound to enter gatewells, re-form in very small sizes, monitoring of external symptoms in fish that are examined at sampling points in fish bypasses may not detect the incidence of GBT at all (Fidler 1994).

Fidler (1995) cautioned the State of Oregon against raising the E.P.A. standard of 110% TDG. He pointed out that:

> *In summary, a great deal is known about the effects of DGS on fish from laboratory experiments and, to a limited extent, from in-river observations. However, the ability to interpret this information in terms of overall survival of fish in the Columbia and Snake Rivers is quite restricted. Before monitoring data can be used as a means of controlling the effects of DGS/GBT on fish and assuring their survival, a considerable amount of research is needed. The reports of the June and November NMFS expert panels address many of these research needs. Furthermore, given the inability to interpret signs of GBT in fish in terms of overall survival, it is not possible to perform meaningful comparative risk assessment analyses of the impacts of DGS on fish survival.*
>
> *In the mean time, the safest approach for protecting fish from the effects of DGS is to abide by the U.S. EPA guideline and at the same time rapidly move toward implementing methods for reducing*

DGS while at the same time allowing adequate flow for fish passage. If the proposed rule change is implemented, the smolt and adult monitoring programs will have to be redesigned to ensure that monitoring reflects the true condition of all fish species and stocks in the hydrosystem and that dissolved gas levels are not raised to the point where signs of GBT appear in fish.

The foregoing comments by Dr. Fidler lead us to recommend caution in permitting elevated TDG in the Columbia River, and to doubt that the monitoring of external symptoms of GBT in smolts at fish sampling points, and as reported weekly by the Fish Passage Center, yields useful data.

MITIGATION OPTIONS

Stream habitat alteration

Hillman and Miller (1994) report that subyearling chinook in the Chiwawa River basin and Little Wenatchee River most frequently occur in close association with woody debris. Sites with woody debris make up about 11% of the total stream area of the Chiwawa Basin but provide habitat for more than 50% of all juvenile chinook in the basin. In the Wenatchee River, subyearling chinook appear to prefer sites with extensive cover such as woody debris and overhanging vegetation (Hillman et al. 1989a). In the Chewack River, subyearling chinook reside near woody debris Hubble (1993), but because wood is scarce in the Chewack, few chinook rear there throughout summer.

These observations indicate that woody debris is an important component of the rearing habitat of subyearling chinook in the mid-Columbia Basin and that where wood is scarce, few salmon occur. It follows, then, that the production of chinook may increase in streams lacking wood accumulations if wood is added. Therefore, we recommend that rearing and spawning streams or stream reaches lacking woody debris (e.g., Chewack River) be studied for physical suitability as sites for experimentally-added accumulations of woody debris. The examination of physical suitability would include geomorphology, gradient, and hydrology. If determined suitable, test sites could be modified with appropriate debris additions.

Placement of single logs is ineffective in increasing chinook production (B. Platts, Don Chapman Consultants, personal communication). However, proper placement of jams or debris accumulations can increase production. For example, Sedell et al. (1984) indicate that juvenile coho and chinook salmon are 2-3 times more abundant in small accumulations of various sized pieces of wood than in habitat formed by single pieces of wood or trees. They note that jams provide the most complex and best used habitats in all sizes of streams. In the Nechako River, debris catchers were effective at retaining woody debris, and pipe-pile debris catchers maintained position and configuration under variable flow conditions and were not displaced during high flow (Triton Environmental Consultants 1992).

Bypass at dams

Turbine intake screens and bypasses have been proposed by agencies and tribes for installation at mid-Columbia dams. Screens and bypasses are fully installed at McNary Dam, John Day Dam, and Bonneville Dam, and installation is underway at The Dalles Dam. The only dam where mid-Columbia spring chinook are transported is McNary Dam. Various groups, including the state fishery agencies, U.S. Fish and Wildlife Service, and Indian tribes, want to end transportation in most years at all collector dams. If that occurs, bypass will be the operational mode at McNary Dam. Thus, effects of bypass on survival of smolts is of considerable concern.

Turbine intake screens divert smolts from the turbine intake flow upward into gatewells. One or more orifices near the top of the gatewell lead smolts into a gallery that runs transversely along the dam axis. Once orifices from all gatewells (three gatewells per turbine) have delivered smolts to the gallery, the combined flow of the gallery amounts to about 500 cfs. That flow passes through a downwell to an upwell to reduce head. If fish are not collected for transportation, the smolts would then pass through piping to the bypass outfall downstream from the dam. The assumption behind installation of bypasses is that fish that enter the bypass system will survive at higher rates than smolts that pass turbine runners directly to the tailrace. We next discuss that assumption.

We begin by listing bypass-related effects that could occur. Bypass effects theoretically and practically begin when fish sound toward turbine intakes. They continue at the deflection screen, where fish may impinge on screens or suffer injury such as descaling. Once juveniles reach the gatewell, they may become injured from contact with hard surfaces such as vertical barrier screens or concrete. They may be delayed in the gatewell, where large smolts or other predators could consume smaller fish, possibly including spring chinook. Debris removal from gatewells helps to reduce contact of smolts with debris such as sticks and thistle bundles, but injury can occur where debris blocks orifice exits, as fish move out of the gatewell.

Once fish reach the gallery, they may hold where they can, avoiding downstream passage for some time. Fatigue and stress may result. Matthews et al. (1987) held yearling smolts in saltwater for 43 d., and evaluated subsequent mortality for fish taken directly from the gatewell, near the upwell after passage through orifices, gallery, and downwell. They found that passage from gatewell to pre-separator significantly increased subsequent mortality. Park et al. (1984) marked spring chinook and released them in the gatewell at McNary Dam. It took 45 h for the 75th percentile to reach the area near the downwell, possibly indicating an orifice passage problem. The fish that passed through the bypass system had suffered some descaling as a result.

Direct bypass effects would include everything that happens to smolts from first encounter with deflection screens to the point at which the bypass outfall delivers smolts to the river downstream from the dam. Indirect bypass effects include predation downstream from the bypass outfall, where predators may target the concentrated fish. Stress and injury produced through the bypass system may exacerbate indirect effects after bypassed smolts reach the outfall.

It is difficult to obtain useful information on the impingement and injury that could occur at deflection screens and in gatewells. For example, some impinged fish later wash off screens, hence would not appear when screens are lifted for examination. Descaling can be compared in gatewells with and without deflection screens.

Transportation as a mitigation tool

Chapman et al. (1994b) extensively reviewed effects of point-of-origin transport of hatchery steelhead to downriver sites for release. They pointed out that such treatment increases survival from smolt to adult, but causes decay of homing efficiency. Similar problems can be expected for spring chinook transportation from hatcheries directly to a downriver point.

Mundy et al. (1994) reviewed effects of transportation on straying. They, too, differentiated between point-of-origin transport and transportation of fish intercepted during the downstream migration. They concluded that fish to be transported should be captured after some period of migration, rather than transporting them from the point of hatchery origin. They did not specify or suggest how much downstream migration would be needed to properly imprint smolts to assure homing in returning adults.

Evidence from the Snake River does not indicate homing deterioration in spring-migrant chinook salmon transported from collector dams (Ebel 1973). It seems likely that transport of actively-migrating smolts after they have migrated from natal streams dozens to hundreds of miles upstream from the collection point embodies sufficient imprinting on waters encountered en route to that point and on a large volume of water (Snake River) that likely is detectable down the full length of the Columbia River, even partially mixed with other tributary waters.

Priest Rapids transport study:

Although no final report on that study is available, we examined available information on truck transportation of spring chinook from Priest Rapids Dam to a point downstream from Bonneville Dam. Spring chinook smolts were dipped from Priest Rapids Dam gatewells, hauled to a marking facility just downstream from Priest Rapids Dam, and divided into two groups. The groups were differentially marked with brands and coded wire tags for later recovery. One group was released at Priest Rapids Dam tailrace at the end of the marking day, and treated as a control. The second group was hauled by truck in an 800-gallon cylindrical tank to a release point downstream from Bonneville Dam tailrace, and considered part of a test group. Different marks were applied to groups of fish in several sequential time periods that covered the major part of the spring migration. The study was undertaken in 1984, 1985, and 1986 with both chinook and sockeye, and continued in 1987 and 1988 with sockeye only.

Observed recovery percentages for the years 1984-1986 indicate respective transport benefit ratios (TBRs) of 0.65, 1.39, and 0.63 for spring chinook (Carlson et al. 1988,1989). The data must be considered compromised to an unknown extent because of transport of a variable fraction of controls from McNary Dam to a point downstream from Bonneville Dam (Table 34). We preliminarily estimate that in 1984, 6-45% of control groups may have been transported from McNary Dam; in 1985, 6-29%, and in 1986, 4-42%.

We have not attempted to correct observed survivals for the varied proportions of control groups transported. The overwhelming weight of information on transportation of smolts from hatcheries to a downriver point indicates that survival of the transported fish is increased by the avoidance of intervening mortality. The weight of evidence on transportation of juvenile chinook salmon collected after extensive inriver migration and transported to a point downstream from Bonneville Dam indicates that survival is improved over that of inriver migrants. Thus, we believe it safe to assume that transportation of Priest Rapids Dam controls from McNary Dam to the estuary increased relative survival of controls and tended to deflate TBRs. Townsend and Skalski (1994) report a TBR of 1.55 for spring chinook transported from McNary Dam in 1986-1988.

Another factor of importance was that all releases of transported fish were made from a boat ramp in shallow water (from a tanker backed down the ramp) rather than in mid-river. Various studies have demonstrated that survival can be sharply increased by midriver release. Benefits of mid-river release for subyearling chinook of upriver bright stock in June off Tanner Creek downstream from Bonneville Dam ranged from 40-65% in 1989 and 1990 (Ledgerwood 1992). After squawfish removal near the point at which subyearlings normally entered the Columbia River at the shoreline, benefits of mid-river release decreased to 18-23%. Ledgerwood et al. (1990) showed substantial gain in survival of juvenile chinook released in mid-river as compared to Hamilton Island shoreline.

Researchers who helped to design the Priest Rapids transportation study (including the first author of our report) underestimated the effects of shoreline release. Other problems with the study include use of untrained contract drivers who lacked experience with fish. Thus, release conditions for fish from the tankers probably varied from night to night. Finally, the 800-gallon tankers are thought by some to have been too small. They also forced release protocols that may have caused stress or mortality because of a knife-gate discharge point and failure of all fish to leave the tank promptly (C. Carlson, Grant County PUD, personal communication). If adjusted to mid-river release, the TBRs would increase. If we use results from the Tanner Creek experiments, that change alone would bring the adjusted TBRs to over 1.0.

McNary Dam transport studies:

It may be more appropriate to examine TBRs for spring chinook transported from McNary Dam. These results would better represent conditions of transport under a routine transportation regime, with large trucks or barges (shallow-draft barges may be a transport option in the mid-Columbia region).

Data were obtained by NMFS in transportation studies in 1986-1988 (Matthews et al. 1990, 1993). As we stated earlier, Townsend and Skalski (1994) estimated a TBR of 1.55 for those studies.

Snake River studies:

Spring/summer chinook salmon smolts were also transported from Ice Harbor Dam to a point downstream from Bonneville Dam in 1968-1970 (summarized in Park 1993b). Those studies yielded significantly higher survival for transported than for control fish, with respective TBRs of 2.14, 1.26, and 1.45. Park (1993b) speculates that early transportation studies, like those at Ice Harbor Dam, involved a higher proportion of wild fish than later studies, a factor that may have led to higher TBRs in earlier investigations. Matthews et al. (1993) show that wild smolts from the Snake River had much higher survival than hatchery smolts in transport index evaluations in 1990.

The TBRs available for Ice Harbor and McNary Dam transport studies indicate positive benefits of transportation in five of six evaluations. We conclude from the limited available data on transport of smolts at McNary Dam and Ice Harbor Dam that transportation of smolts under similar or better collection and transport conditions from the mid-Columbia region should, on average, benefit spring chinook, particularly wild fish (see Matthews et al. 1994). More conclusive tests would have to await availability at McNary Dam of PIT-tag detection equipment that would permit return of control fish to the river and placement of test fish in barges, obviating necessity to capture, anesthetize, and handle test and control groups.

Mundy et al. (1994) plotted untransported observed return percentages against transport return percentages for the numerous transportation studies that have been conducted with yearling and subyearling chinook, and with steelhead, 1968-1989, in the Columbia River basin (Figure 96). That plot demonstrates that survivals of controls and transported fish varied in general concert, and that transport increased survival to adulthood *under the conditions imposed by the tests*.

Mundy et al. (1994) stated: *...rates at which both the transported and untransported juveniles survive the river system appear to vary in concert with one another and with conditions in the river.* Also, survival of the two groups will vary in concert because of conditions that they encounter at sea.

Increasingly, recommendations are heard to conduct experiments with transported and untransported fish that do not require fish handling at the dam. Studies to date have relied on capture of smolts from gatewells and bypass systems, anesthesia, differential marking of test and control groups, and release of controls to the river while transport groups are barged or trucked to a point downstream from Bonneville Dam. Ideally, test group handling would differ from control group handling only with respect to the transportation process. Realistically, this ideal has not been attainable. Transported fish remain in transport barges for the period of transport, and have more opportunity to recover from effects of collection and marking. Control release points and procedures may not typify those that would obtain if bypass to the river were the operative condition. For example, bypass to the bypass outfall of 50,000 marked control fish might lead to more or less predation than would occur if all fish were bypassed every year (in which case predators might concentrate on the prey stream, or large numbers of prey might swamp predator ability to consume prey). On the other hand, transport to the same point downstream from Bonneville Dam in each trip may encourage prey consumption by concentrated predators. In other words, the conditions encountered by smolts may either inflate or deflate the TBR from conditions that would obtain in a "production" transport or bypass mode. For studies at all dams to date except McNary Dam, some fraction of control fish has been transported at McNary Dam (see our comments re. transport of Priest Rapids Dam controls at McNary).

The ideal experiment would be to place facilities at dams that would automatically shunt PIT-tagged smolts back to the river or into transportation barges. Presence of large numbers of PIT-tagged smolts in the outmigration would permit allocation of fish to either bypass or transport and assessment of survival of the two groups. PIT-tagged fish that never were interrogated at bypass systems would contribute to the analysis upon adult return, permitting assessment of survival of fish that either did or did not encounter bypass systems, as a fraction of fish tagged. Reach-specific baseline survival data would contribute to understanding of the results.

Experiments under the preceding conditions would require not only more PIT-tag detectors at existing downstream passage bypasses, but adult detection equipment. They would also require placement of large numbers of PIT-tags in hatchery and wild juveniles.

Effects on homing upstream from point of transport collection:

Spawning grounds for wild fish were surveyed in the Snake River basin when spring chinook marked during transportation studies in 1975 were expected to return. The overall TBR for transportation, as evaluated on observed return at Lower Granite Dam, was 1.62-2.58%. Control groups were released at Clarkston, Washington, upstream from Lower Granite Dam, hence passed through eight projects, hence the TBRs do not compare with TBRs obtained in later years in which controls were released at Little Goose tailrace. However, our point in discussing the 1975 experiments is less the TBR than the effect of transportation on homing. The NMFS spawning ground surveys in 1978, when ocean age .3 fish would return, recovered 22 carcasses from the 1975 experiments. Twenty of the 22 carcasses had been transported as smolts; the remaining two were controls. This evidence should not be used in comparisons of TBRs at various points in the river migration, but suggests that truck transport did not reduce the ability of wild fish to find spawning areas upstream from the point of inriver collection of downstream-migrating juveniles. Recoveries of transported fish outnumbered control recoveries at hatcheries; seven transported fish and two controls were recovered at Kooskia and Rapid River hatcheries. Recoveries in 1977 of ocean age .2 chinook totaled 44 on spawning grounds and at hatcheries. Of these, 30 were fish transported as smolts and 14 were controls. Eleven of the 44 were recovered on spawning grounds, but no breakdown of transport and control fish among the 11 fish on spawning grounds is available in Park et al. (1978).

Using the data in Park et al. (1978) and Park et al. (1979), we find that spawning surveys detected 33 test or control fish; hatchery recoveries totaled 42. Of the 75 fish examined, 57 had been transported and 18 were controls. These data do not suggest failure of fish transported at Snake River dams to successfully reach spawning areas. Furthermore, absence of recoveries of wire-tagged chinook of hatchery origin in natural spawning areas during spawning ground surveys leads us to postulate very low straying rates of hatchery fish during periods when mass transportation was underway on the Snake River (1977-1989). Of 642 carcasses examined in the Middle Fork Salmon River, none contained a wire tag from hatchery releases (Chapman et al. 1991). About 80% of the carcasses were examined 1985-1989. We examined wire tagging records to see how many wire tags were released in the mid- to late-1970s in the Salmon River basin. We found that in brood years 1974-1976, 351,675 summer and 617,025 spring chinook were wire tagged in the basin. Those fish would have returned mostly from 1978 through 1980, a period that coincided with extensive spawning-ground surveys 1977-1980. At 0.3% return rate, we should expect about 1,000 summer chinook and 1,800 spring chinook to return to Idaho from the wire-tagged groups. Spring chinook from Rapid River appeared neither at the South Fork Salmon River rack where summer chinook were collected, nor did summer chinook appear at Rapid River trap.

Spawning ground surveys were curtailed to a token effort in the period when test and control fish returned from transportation experiments in 1976 (Park et al. 1980). However, data are available from Kooskia and Rapid River hatcheries. For the 1976 experiments, 26 transport and two control fish were recovered at the hatcheries in 1979; 19 transport and nine controls in 1978. Thus, 45 transport and 11 controls were recovered at the two hatcheries as ocean ages .2 and .3. More test and control fish were recovered at hatcheries than observed at Lower Granite Dam, which demonstrates that only part of the adults that pass Lower Granite Dam are observed for marks. Still, the recoveries at hatcheries do not support a failure of transported fish, as compared to control fish, to find their way upstream past the point at which they had been transported as smolts. Only two returns on spawning grounds are recorded for transportation tests in 1986; both were transported fish (Matthews et al. 1990). Recovery efforts on natural spawning areas were not sufficient to detect presence of more tags (G. Matthews, NMFS, personal communication).

Ebel (1980) evaluated straying in mostly wild chinook and steelhead for fish transported from Little Goose Dam to Dalton Point downstream from Bonneville Dam. All groups were trucked. Ebel states: *The homing ability of the adult fish was not significantly diminished.........survival was increased from 1.1 to 15 times as compared with control fish which passed by seven mainstem low-level dams and reservoirs.* Ebel reported spawning ground surveys in wild-fish spawning areas in 1972, 1973, 1974, and 1976. During the surveys, 14 marked fish were recovered; 12 transported and 2 controls. Hatchery-marked fish were not recovered on wild-fish spawning grounds. Ebel notes that checks of hatcheries and spawning grounds in the upper mid-Columbia region did not reveal straying of transported Snake River fish. However, in 1990, two Clearwater River (Idaho) steelhead were recovered in tributaries of the Wenatchee River (Table 31), one in Nason Creek and one in Icicle Creek. In 1989, one CWT-tagged Snake River spring chinook was detected in Icicle Creek, tributary to the Wenatchee River downstream from Lake Wenatchee (Hays and Peven 1991). Ebel (1980) found 16 chinook from Snake River groups at Pelton Dam on the Deschutes River in Oregon. Of those, 10 were from transported juveniles, 2 from controls, and 4 could not be identified as being of transport or control origin. He says:

> *These recoveries indicate that the homing behavior of a portion of the chinook salmon transported as juveniles may have been adversely affected. However, the proportion of the transported groups affected to this degree must have been small; 857 chinook salmon ....were identified at Little Goose Dam from the same release groups. The homing behavior of these fish obviously was not damaged.*

Ebel was mistaken in one respect. The recovery at Pelton Dam of transport and control fish was roughly in the proportion that one would expect, given the higher survival of transported fish. Thus, the first sentence of his italicized quote is incorrect. In discussion of this matter, Dr. Ebel agreed that the sentence was incorrect as written (W. Ebel, personal communication, Dec. 13, 1994). The ratio of transported to control fish is not disproportionate. Dr. Ebel also noted that had the marked chinook not been captured at Pelton Dam, they might have returned to the main Columbia River to continue their upstream migration. Dr. Ebel's report is primarily of value in relation to homing and straying. With respect to relative survival of test and control fish, the studies that he reported had a bias in them against control fish for all releases. Controls were trucked upstream from Lower Granite Dam and released in Lower Granite Dam pool. Thus, controls had but one hour in the tank truck to recover from stress, while transported fish had six hours.

Furthermore, Little Goose Dam was a serious obstacle for controls in at least 1973. It has been estimated that 50% of downstream migrants that reached the dam died in passage across the dam. This high loss in controls in 1973 is reflected in the very high T/C ratios for chinook and steelhead in 1973 (Ebel 1980), and in observed control survivals in 1973 that were much lower than in 1971 and 1972. G. Matthews (NMFS, personal communication) found trashracks completely covered with trash and at least 0.25 mi of trash backed-up against the dam in the forebay in 1973. The trash likely contributed to the high mortality rate at Lower Granite Dam in that year.

Submerged traveling or bar screens in turbine intakes

Fish that enter turbine intakes tend to concentrate toward the intake ceiling, rather than distributing themselves equally throughout the water column. The design of deflection screens, which are deployed at the bottoms of turbine gatewells, adapts to that behavior. The screens project downward into the turbine intake at an angle, guiding fish upward into the gatewell. The screens intercept only the upper portion of the water column in the turbine intake. *Fish guidance efficiency* (FGE) of screens equals the percentage of fish entering the turbine intake that are diverted by deflection screens. USACE (1992) summarizes FGE for yearling chinook at mainstem Columbia River dams as 75% at McNary Dam, 72% at John Day Dam, 43% at The Dalles Dam, 42% at Bonneville Dam PH1, and 19% at Bonneville Dam PH2.

In prototype bar screen testing at Priest Rapids Dam, Grant County PUD has obtained FGE of 84% (personal communication, D. Zeigler, Grant County PUD). FGE at Rocky Reach Dam in prototype screened intakes has been extemely low, averaging 15.1% in 1994 (Peven and Abbott 1994). At Rock Island Dam PH1, FGE has been higher, averaging 70.8% in 1994 (Peven and McDonald 1994).

Because of the location of spill bays directly over turbine intakes at Wells

Dam, deflection screens cannot be used there. A surface spill is provided, and results in fish passage efficiency (FPE) that has been estimated as about 90%, based on hydroacoustics sampling (Skalski 1993; Sverdrup Corporation and Hydroacoustic Technology, Inc., 1994).

Gessel et al. (1994) evaluated effectiveness of extended-length screens at Little Goose, McNary Dam, and The Dalles Dam. They report improved FGE with the extended-length screens. At Lower Granite Dam, FGE was nearly 85% for yearling chinook that encountered either extended-length bar or traveling screens. At The Dalles Dam, extended screens produced higher FGE than extended traveling screens or standard-length traveling screens (Brege et al. 1994). At McNary Dam, extended traveling screens produced FGE=88%, extended bar screens yielded FGE=81% (McComas et al. 1994). Extended-length screens produce higher FGE than standard screens.

Assessment of descaling in yearling chinook that encounter extended-length screens has yielded different results in different sites. At Lower Granite Dam, extended traveling screens caused significantly more descaling (12% descaling rate) than extended bar screens (9%) or STS (7%). Descaling in the latter two devices did not differ significantly (Gessel et al. 1994). At McNary Dam, observers found no significant differences in descaling for the extended traveling, extended bar, or STS (McComas et al. 1994). Brege et al. (1994) found no differences in yearling chinook descaling caused by extended screens and the STS. These data do not mean that screens cause no descaling. They indicate that the various types of screens do not cause differences in rates of descaling.

Peven and Abbott (1994) examined FGE at Rocky Reach Dam to determine if guidance was correlated with independent variates of river discharge, water transparency, water temperature, length of FGE test, and date. They reported that FGE was significantly correlated with streamflow during the guidance tests ($r^2 = 0.46$). However, their analysis included all species and life stages of spring migrants. We analyzed the FGE data for chinook yearlings alone, omitting data points based on fewer than 100 fish in samples (this eliminated two data points, one based on 15 fish, the other on three fish). We found that the r^2 for flow dropped to 0.26, and the regression depended heavily on a single point at 182 kcfs. Without that point, the r^2 for flow dropped to 0.044. Inasmuch as the data on FGE in Peven and Abbott (1994) were obtained over a period of 24 days from 18 April (first quarter moon) to 12 May (just after new moon), with four night tests included with 12 daytime tests, we are doubtful that one can infer anything about effects of river discharge on FGE. Peven and Abbott were also doubtful about their results, stating:

> *Other factors, such as level of smoltification, may explain the increase in FGE over the season....Other investigators have related increases in FGE to increases in smoltification (e.g., Giorgi et al. 1988), but no physiological testing of smolts has been done at Rocky Reach. Again, this point is moot considering the overall success of the prototype, but it may explain at least some of the increase in FGE estimates for chinook yearlings over the season.*

We correlated FGE with time in a manner somewhat different from that used by Peven and Abbott (1994), who placed test dates in a numeric code from one to nine. We used "number of days after April 15" as the independent variate. With removal of FGE data for two tests with 3 and 15 fish per test, FGE correlated significantly with time at $r^2=0.76$ ($t=3.98$, $p=0.002$), and not with flow ($r^2=0.22$, ns, $p=0.08$). Degree of smoltification may partially control the response of migrants to deflection screens.

Vertical slot "surface" bypass

Olson (1984b) found at the Wells Dam hydrocombine that spill significantly reduced the number of smolts caught in fyke nets in the turbine intake. This behavior led to development at Wells Dam of a bypass system based on the propensity of fish to pass into turbine intakes high in the water column and to pass in spill (with spill bays directly over turbines). Provision of an avenue for fish to reach the spill bays, and limited spill to pass them downstream, proved to offer efficient fish passage at Wells Dam.

Individual project characteristics and morphology probably preclude direct export of the Wells Dam bypass system to other dams. USACE et al. (1994) make this point by stating:

> *The Wells Dam design, however, is considered only a starting point. Each of the Corps projects are both unique and different from the Wells Dam's hydrocombine design. The program starts by focusing on and studying the behavior of juvenile fish as they approach each project and comparing this to existing river hydraulic flow patterns. Prototype surface bypass and collection designs (using existing/new concepts and utilizing fish behavior at specific projects to accentuate system performance) will be identified, evaluated, and tested, if feasible.*

Vertical slot surface collectors

At Wells Dam, a hydrocombine with spill bays directly over turbine intakes, a bypass system has been devised and implemented that takes advantage of the propensity of smolts to travel relatively high in the water column. A passageway is provided for fish to enter a limited amount of spill without sounding to full turbine intake depth. Hydroacoustic work to evaluate the efficiency of the bypass system in 1990-1992 indicated that the system diverted about 89% of the downstream migrants available for diversion (Skalski 1993; Sverdrup Corporation and Hydroacoustic Technology, Inc. 1994). Grant County PUD proposed to install a prototype system at Wanapum Dam that would duplicate desirable features of the Wells Dam system. It would consist of an independent steel channel attached to the forebay side of the powerhouse. The channel would offer flexibility in numbers and locations of slots, and of individual slot flow rates. It would occupy the uppermost 50% of the water column. A series of vertical inflow slots would extend from the bottom of the channel up to just under the low design forebay level. In full installation, if prototyping is successful, the channel would extend across the existing ten units and deliver fish through a pipe with 280-500 cfs to the tailrace through a spillbay. Additional attraction flow would be provided by pumps, and fish would be screened out of pump intakes for delivery to the bypass pipe. In prototype, the system will encompass only units 7-9.

Another protoype slot system will be tested in 1995 at Rocky Reach Dam in the cul-de-sac. A vertical slot 16 ft wide and 60 ft deep will be used to guide fish. Attraction flow will be provided behind a screened area inside the slot, and a pipe down the west bank fishway will carry fish in about 20 cfs to a separator and sampling facility located well down the fishway (C. Peven, Chelan PUD, personal communication).

The concept of vertical slot bypasses is attractive because it does not force smolts to sound to enter turbine intakes. If turbine flows can be maintained at full capacity while fish divert through vertical slots, spill can be minimized, thus reducing likelihood of excessive TDG supersaturation. Delivery of smolts to the tailrace will remain a potential problem, as for conventional bypass systems. For example, the bypass outfall at Wanapum Dam would deliver fish from slots across the entire powerhouse to the tailrace. Just as in conventional bypasses, those fish would be delivered in 500 cfs or less. Even if they are carried by pipeline to a point of high river velocity, predators will likely key on their concentration at points downstream from the outfall.

Spill

Spill offers an attractive fish passage route for smolts because it kills relatively few fish as they pass across the concrete (Schoeneman et al. 1961). However, as noted elsewhere in our report, that dam survival may come at a price in system survival because of increases in TDG. It may also lead to delayed passage of adult salmon because fish fail to locate fishway entrances promptly.

USACE et al. (1994) suggest four operational regimes that may help reduce gas supersaturation: (1) uniform spill bay operation would pass an equal amount of discharge over each spill bay, thus reducing air entrainment caused by concentrating flow at any one spill bay; (2) at some structures, concentration of spill in one or a few bays may reduce air entrainment; (3) where some bays are equipped with deflectors, spill at only those bays may reduce entrainment (no mid-Columbia dam is equipped with spillbay defllectors, so this solution would not suffice at present in the region); and (4) spill based on effective spill deflector range.

Flow augmentation and/or drawdown

As noted earlier, we find that flow has no discernible effect on travel time for hatchery spring chinook smolts. Level of smolt development is a key factor in control of travel speed. Some work shows that flow plays a secondary role. Our analysis reveals no flow effect in mid-Columbia spring chinook smolts. We have stated that if one wishes to adopt the generalized flow response indicated in FPC models, then increasing mid-Columbia flow from 120 to 200 kcfs would decrease median travel time at the rate of one day per 20 kcfs. We have also noted that average velocity of water movement through the mid-Columbia region exceeds that through the Snake River system.

We also suggest elsewhere in this report that transportation is the most effective way to speed movement of spring chinook smolts. If arrival of smolts at sea with minimal delay is desired, transportation is potentially more effective than flow augmentation. For example, smolts transported from McNary Dam reach the estuary in less than 18 h.[33]

Drawdown of reservoirs has been proposed as a means of increasing speed with which juvenile salmon and steelhead move through reservoirs. Underlying this mitigation proposal is the fact that water velocities increase as reservoir depth and cross-section decrease, and the assumption that fish that move faster will be exposed to predation in the reservoir for a shorter time and reach the sea sooner.

The data for the late 1960s and early 1970s were obtained before bypasses were fully installed, when turbines were not operated with needs of fish in mind, when dams were being constructed and resident pool communities of animals and plants were in transition, when debris was not managed appropriately, and when downstream migrant smolts were mostly wild. Survival across one dam, Little Goose, was only 50% from forebay to tailrace in at least one of the years, largely because of debris accumulations. Yet the survival data for that year from uppermost dam to The Dalles Dam were included in the model used to predict effects of flow on survival. Recent critical reviews have recommended that the early data not be used to predict survival as associated with travel time under current river conditions and management of hydro projects.

Recent work with tagged fish in the Snake River demonstrates, for the first two years of study, that although fish do move faster with higher flow, they do not survive through the uppermost two Snake reservoirs at higher rates as flows rose during the spring. In fact, the data indicate that survival in the pools is near 100%. However, survival through turbines at Lower Granite Dam was lower than

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[33] As we prepare this report, the NMFS Biological Opinion on river operations for Snake River listed fish would terminate transportation at McNary Dam.

previously thought. Most mortality appears to occur in passage through and close to the dam, not during pool passage, at each project. Thus, it appears wise in the Snake River situation to concentrate on improving survival across the concrete rather than through the pool. Similar baseline reach survival studies have not been completed at dams downstream from Lower Granite and Little Goose, or in the mid-Columbia region. It is imperative that those reach-specific estimates be obtained in pools of the lower Snake and lower Columbia rivers, and in the mid-Columbia before any extensive testing of drawdown as a mitigation tool. Various experts have recommended that four years of baseline, reach-specific (each pool, and each route through the dam) survival estimates be obtained to cover a spectrum of river conditions.

Spring drawdown has not yet been evaluated with respect to effects on summer-migrating juvenile chinook, which rear in each pool after they emerge from the gravel as fry. No one knows what the effect of drawdown will be on smolt mortality in turbines, wildlife communities, food production by aquatic insects and plankton in reservoirs, predation by squawfish and walleye (*Stizostedion vitreum*) on smolts, or ease with which adult salmon find and pass fishways (adults must pass upstream while smolts migrate downstream).

Drawdown applied to pools at collector dams (or dams that potentially could be equipped with collection and transport facilities) would preclude transportation by barge in the Snake and Columbia rivers, and transportation has been shown to improve survival of smolts over that attainable in in-river migration. If drawdown were used and turbines not operated, spilled water would likely increase dissolved gases to dangerous supersaturation levels for salmon smolts and adults. In summary, much remains unknown about whether drawdown would help or harm salmon.

In summary, we believe discussion of drawdown in mid-Columbia pools is premature. We recommend acquisition of reach-specific survival data for mid-Columbia projects before drawdown is seriously evaluated as a mitigation option.

In any event, such data are a part of any test of drawdown in the region, for no controls are feasible for drawdown. Thus, any evaluation must be based on before-and-after comparisons of reach-specific survivals.

Dam removal

Some individuals have proposed that Columbia or Snake River dams be removed or that alternate openings through the dams be constructed so that the river will flow at historical river grade for part or all of the year. The assumption behind that plan is that salmon will survive at high rates once again if they can migrate through one or more projects at river grade.

The removal of mainstem dams between spawning areas and the sea will not necessarily lead to salmon runs similar to those of, for example, the 1950s. Certainly increased survival and runs are likely. However, many factors have changed in the river system since the middle of the century; factors that will prevent return to pristine or even 1950s run sizes. River flows have been altered by Canadian storage so that more water passes through the lower Columbia in winter and less in late spring and summer. Flood flows have been reduced, water clarity has increased, and temperature regimes altered. This has changed the Columbia River estuary and altered the mix of plants, micro- and macro-invertebrates, and of fish. Non-native species like shad and walleye have increased greatly in abundance. Squawfish have increased. Sediments have collected behind dams in the Columbia River. Density-dependent interactions at sea alter survival of chinook salmon from that observed in early time periods.

Dams cannot be removed or altered in major ways instantaneously. Many years are likely to be required for removal. Destruction or modification both will have environmental costs not yet evaluated. Examples include accelerated sediment movement, possible adult migration disruption, and increased predation by squawfish, walleye, and other predator fish. Summer-migrating chinook fry use reservoirs as rearing areas. The value of these rearing areas must be balanced against possible increased survival in the long term (or mortality in the short run). If dams are altered from upstream to downstream, predators from downstream pools may concentrate at the incoming river-grade flow from the altered upstream project, consuming smolts at increased rates. Time would be required for predators and other aquatic community elements to stabilize after dam removal. Effects of sediments carried by river grade flows from deposits in former pool areas will constitute a water quality problem of probable negative effect on downstream communities and, if all dams were removed, on the estuary. Salmon stocks as we know them today may be put at risk by the removal or alteration of dams. It is uncertain whether the genetic groups that would survive would be the same as those now present.

Most visions of dam removal see a Columbia River almost instantaneously returned to conditions that once existed. They do not envision effects on the aquatic ecosystem during the transition. They do not predict how long it will take for fish runs to respond to change, or the effects on ecology of the new system. These questions should be evaluated carefully and deliberately if regional authorities elect to pursue dam removal as a mitigation option.

Predator control

Predator control research has been suggested for the mid-Columbia region (Sauter et al. 1994). Predator indexing in the region has demonstrated that abundance of northern squawfish equaled that in many of the mainstem reservoirs of the Columbia and Snake rivers. Consumption indices were generally highest at tailrace boat-restricted zones, with one of the highest indices found at Rocky Reach Dam tailrace. Sauter et al. (1994) note that predation indices in the mid-Columbia region were less than those in John Day Dam reservoir in 1993, and lower than those for the remainder of the Columbia River. However, Predation indices for the mid-Columbia lie within the same range of those in the lower Snake River. Juvenile salmonids appear to be a significant component of diets of northern squawfish in the mid-Columbia reservoirs, especially in tailrace areas.

Information on high abundance of squawfish in the Rocky Reach Dam tailrace led Chelan PUD to recommend and support a predator control program in the tailrace. Welsh et al. (1994) reported capture in the program of 9,633 squawfish, with an aggregate weight of 5,403 kg, by two crews of four persons each. Catch per unit of fishing effort remained high for an extended period, but slowly declined after June. Highest catch rates were obtained in the evening, and squawfish were taken at night as well as in daytime. At the end of the tenth week of fishing on July 29, mark and recapture analysis indicated a population of about 32,000 fish. Mean weights of squawfish declined from about 0.82 kg to about 0.45 kg over the nine weeks of fishing. The experimental program at Rocky Reach Dam tailrace demonstrates that very large numbers of squawfish reside in the tailrace, and that their activity increases in the evening. Declines in mean weight and catch per unit of fishing effort indicate that the population of large fish can be reduced in key areas where predators concentrate. A similar predator control program will be implemented at Rock Island Dam in 1995.

Welsh et al. (1994) calculated costs of the squawfish control program at Rocky Reach Dam as \$8.41/fish removed. They compared the cost to \$12.26 per fish under the 1992 sport-reward program of the WDW, \$28/fish in the CRITFC-administered angling program, and \$180/fish caught by the ODFW-administered longline fishery downstream from Bonneville Dam.

One might expect squawfish activity to be considerably more important in early summer than in spring, because waters warm with time and daily ration increases. However, appended to Burley and Poe (1994) is a table of coded wire tag codes from spring chinook recovered from northern squawfish digestive tracts from the mid-Columbia River in 1993, a spring in which temperatures in the mid-Columbia River were lower than normal in spring (Sauter et al. 1994). The codes show predation on yearling chinook from several production releases in the mid-Columbia region.

Access to the Similkameen River

Chapman et al. (1994a; 1994b) detailed Canadian objections to introduction of salmon and steelhead to the area upstream from Enloe Dam. Although Beak Consultants (1983) estimated potential production of spring chinook as 1.5-4.8 million smolts, the estimates are generally considered too high (WDW 1989). WDW (1989) estimated that the potential production by spring chinook in the Similkameen River could double spring chinook runs from the area upstream from Wells Dam. Whatever the potential production, Canadian assent to passage of anadromous fish appears unlikely.

ARTIFICIAL PROPAGATION CONCERNS

We move now to discuss problems associated with artificial propagation as a tool for compensation or enhancement. For over 100 years, hatcheries have planted salmonids to increase the number of fish returning to natal streams. Most of the planting was to offset effects of overfishing and habitat degradation. Various factors contribute to the success or failure of a hatchery program. Many investigators have documented the deleterious effects of hatchery programs on wild populations (e.g., see Miller et al. 1990). Deleterious effects include:

1) mining wild population for eggs,
2) reducing genetic diversity, with subsequent reduction in fitness,
3) competition with wild fish on the feeding grounds (fresh- and saltwater), and,

4) introduction (or amplification) of disease to wild fish.

Egg mining:

A classic example of egg mining took place at the Little White Salmon NFH (Nelson and Bodle 1990). The hatchery was built in 1896 to supplement the run of "tule" fall chinook. The egg-take peaked in 1917, and juvenile releases in 1914. Initially, fish were released as unfed fry until 1908, when increasing numbers were reared for later release. Egg-take declined between 1917 and 1944, then rebounded until reaching a second peak in 1958. After 1958, the hatchery increasingly relied on exogenous egg sources. Finally, by 1968, over 50% of the fish released were from non-native sources. By 1985, the number of native tule stock was so depressed that artificial propagation was abandoned. Nelson and Bodle conclude,

> *Although well intentioned, the efforts to perpetuate a stock of salmon led instead to its demise. It would be convenient to solely blame the construction and operation of Bonneville Dam for causing the extinction, but in the 30 years from 1939 to 1968, the stock-recruitment ratio was >1 in each of 17 years, and the egg take exceeded 11 million on 16 occasions. Therefore, the causes for extinction of this stock of fall chinook salmon apparently included the introduction of different stocks, which altered their genetic fitness and introduced diseases, and the management decision to rear fish longer, which decreased their survival both in the hatchery and after release.*

While Nelson and Bodle (1990) conclude that introduction of non-native fish and longer rearing in the hatchery were the underlying factors that eventually led to the extinction of the tule fall chinook, continual taking of eggs from a stock that was not replacing itself (after 1968) probably contributed.

Genetic effects:

Genetic effects of hatchery fish have been covered in another section, and will not be repeated here.

Competition with wild fish:

Competition of hatchery fish with wild fish has been demonstrated. For example, Nielsen (1994) found that when hatchery-reared coho were introduced into a California stream, wild coho fry were displaced from their usual microhabitats, and they also shifted their foraging behavior.

Decrease in size and increase in age of adult salmonids returning from the ocean also suggests that, at least in some years, ocean feeding may be limited, a possibility discussed in other sections of this report. Increases in hatchery production over the last 30 years (Figure 32) may increase competition in the ocean.

Disease concerns:

Hatchery fish may introduce or amplify disease by horizontal or vertical transmission. For example, if fish released from a hatchery have a higher incidence of BKD than wild fish, they may transmit the disease when they come into close association, for example in a bypass system or transport vehicle. Hatchery fish may become carriers of a disease at a higher rate than wild fish and return to spawn naturally with wild fish, thus vertically transmitting the disease to the next generation in possibly higher levels than would occur naturally.

The preceding only cursorily reviews hatchery influences, and the reader should review other documents for additional information.

Supplementation

Considering the above, managers in the Columbia Basin now embrace the concept of supplementation, defined by Miller et al. (1990) as,

> *Planting all life stages of hatchery fish to enhance wild/natural stocks of anadromous salmonids,*

or by Cuenco et al. (1993):

> *. . . the stocking of fish into natural habitat to increase the abundance of naturally reproducing fish populations.*

Inherent in the supplementation concept is that the activities under the program will maintain the long-term genetic fitness of the supplemented population, while keeping the genetic effects on nontarget populations within acceptable limits (Cuenco et al. 1993). One of the major differences between the supplementation concept and traditional hatcheries is that one of the major focuses is to maintain the unique biological characteristics of the supplemented stock, and not to create a new "hatchery" stock. Hatchery stocks have been traditionally raised to augment harvest, and not to conserve wild gene pools.

Miller et al. (1990) and Steward and Bjornn (1990) conclude that if done properly, supplementation could increase the number of spawning adults in a particular stream. From Steward and Bjornn:

> *Based on principles of population genetics and a limited number of empirical observations, offspring of matings between hatchery x wild spawners would be expected to perform less well on average than pure wild-strain progeny, unless the hatchery fish are indistinguishable from the wild fish.*

Hybridization can break down complex genetic adaptations to specific environments, and thereby reduce the fitness of progeny of hatchery x wild matings. Many fisheries geneticists, therefore, recommend that locally adapted wild fish be used to start and replenish hatchery brood stocks. Management practices that promote genetic or phenotypic divergence between hatchery and wild stocks are discouraged where the hatchery fish are going to be used to supplement wild stocks of fish. Gene flow into non-targeted stocks due to straying should also be minimized to maintain and strengthen the adaptation of stocks to their environment. . . Once released from the hatchery, stocked salmonids interact with their environment, including wild fish, through competition, predator-prey, parasite-host, and pathologic relationships. Hatchery and wild fish have similar ecological requirements and therefore are potential competitors, but the competitiveness of hatchery fish varies with broodstock, hatchery history, fish health, and environment. . . Hatchery fish stocked as smolts tend to fare well because of reduced competitive pressures, if they are healthy and migrate to the sea soon after release. . . Whether hatchery fish significantly alter the behavior, growth, and survival of wild fish remains a controversial subject. Recently introduced hatchery fish, even those poorly adapted to the environment, may elicit high levels of activity and stress among wild fish. . . Survival of hatchery-produced fish in stream depends on the match of the stocks with environmental conditions, rearing procedures, the method of stocking, stocking densities, size or age at release, and time and location of release. Supplementation managers must consider stocking densities and schedules in light of program objectives and resources, the carrying capacity of the ecosystem, the proportion of limiting resources used by competitors, and the viability (survival and reproductive success) of hatchery-produced fish.

Erho and Bugert (1995) point out some of the major "critical uncertainties" of supplementation that the evaluation plans for the MFHC and RIFHC will address (see Appendix 6 and 7). Two of the "uncertainties" addressed by Erho and Bugert are whether the program will conserve the genetic integrity and long-term fitness of the naturally spawning populations, and whether (and somewhat related) fish released from the hatchery adversely affect natural production.

Under the first concern above, some of the questions raised pertain to spawning success of hatchery fish, habitat use, allele frequencies, effective population size concerns, bilateral meristic asymmetry differences, and progeny to parent ratios. Under the second concern above, some of the questions raised pertain to excessive straying of returning adults of hatchery origin, wild fish impacts from hatchery releases in the river, and whether the natural production of the donor stocks will be diminished after hatchery fish begin to become more numerous on the spawning grounds.

Because the evaluation plans just begin in the next few years, there are limited baseline (pre-supplementation) data for comparison purposes. While this may not limit the efficacy of the evaluation, some of the "observed differences" that may become apparent in time may have happened whether a population was supplemented or not. Without previous information of the rate of change of some of the parameters looked at, some of the conclusions may be false.

One of the concerns for the supplementation programs is whether the returning adults will use the available habitat in the same manner (places) as the naturally produced fish. In the Chiwawa, Methow, Twisp, and Chewack rivers, adults are trapped and juveniles released downstream from most of the spawning grounds (Peven 1994; Scribner et al. 1993). While no specific recommendations have been made (S. Hays, personal communication), if returning adults are not utilizing the best (based on previous observations) spawning habitat, then possible changes in releases practices might occur. In the Tucannon River, the spawning distribution of the returning adults appears to have been altered since hatchery fish began returning in significant numbers in the late 1980s (see below). On the South Fork of the Salmon River, broodstock collection for the McCall Hatchery has virtually eliminated spring chinook that formerly spawned in the Stolle Meadows area (W. Platts, Don Chapman Consultants, personal communication). Fish that were destined to return to the Stolle Meadows area were captured for broodstock, reared at the McCall Hatchery, and then released downstream of the area where they would have spawned. Subsequently, over the years of hatchery development, few fish return to the Stolle Meadows area and more fish spawn in areas downstream, where historically the population was "summer" chinook.

Tucannon River Spring Chinook Supplementation Project:

Bumgarner et al. (1994) report findings of the Tucannon River spring chinook project, which is similar in many regards to the spring chinook supplementation programs in the mid-Columbia. Adults are collected from a weir on the Tucannon River, eggs and early rearing take place at the Lyons Ferry Hatchery, and juveniles are returned to the Tucannon River for final rearing and release. The evaluation program has continued since 1985. Bumgarner et al. (1994) list several observations and concerns from the evaluations over the years that they feel need to be addressed.

Many fish died before spawning, especially hatchery fish. The hatchery weir has been suspect in some years, but pre-spawning mortality has been observed in other sections of the river as well.[34]

Bumgarner et al. (1994) report that the spawning distribution in the river is different now from what it was before hatchery fish started returning. Mendel et al. (1993) compared redd counts in an index section of the Tucannon River that

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[34] In the three years of returns of adults to the Chiwawa, pre-spawning mortality has not been observed to any significant extent (S. Hays, personal communication). Cooler temperatures in the Chiwawa may be the main reason.

has been surveyed since 1954. They conclude that the number of redds observed within this index area has declined substantially since 1954, and especially since 1985 (Figure 97). From Figure 97, it appears that the recent decline may have begun before the infusion of hatchery fish in the mid-1980s, and it should also be pointed out that the number of redds observed in the index area has fluctuated greatly over time, possibly a function of the surveys being only once per year. Bumgarner et al. (1994) also point out that the percent of fish spawning downstream of the hatchery weir has increased since the mid 1980s (Figure 98). This may be a function of the increase in hatchery fish since then (Figure 99), or a possibility that the weir affects spawning distribution. Fish of the 1994 brood are being raised in circular tanks at different locations upstream from the weir for release at these sites, which may improve the distribution of the returning adults (B. Bugert, WDFW, personal communication).

Another observation of Bumgarner et al. (1994) is that the returning hatchery fish are younger and slightly smaller for a given age than their naturally-produced counterparts. Smaller females in the population could reduce the reproductive potential of the population by having lower fecundity (Major and Craddock 1962). Indeed, Bumgarner et al. (1994) show that the average fecundity of hatchery fish is 25% lower than that of natural fish over five years. Bumgarner et al. (1994) recommend releasing fish at smaller sizes, so they are similar to size of natural fish, hopefully modifying the age structure to better mimic the natural fish in the river.

In 1993, one pond of HxH juveniles from the 1992 brood was infected with the parasite *Enterocytozoon salmonis.* The parasite was not observed in the pond with the WxW cross juveniles. The disease outbreak was a major concern, and after much negotiation, the fish were brought to the Tucannon and released the following spring (B. Bugert, WDFW, personal communication).

The estimated smolt-to-adult survival for hatchery fish is much lower than natural fish in the Tucannon (5-yr average 0.65% for wild fish and 0.32% for hatchery fish), but the mean return per female spawner has been substantially less for wild fish than for hatchery fish (1.3 (wild), compared to 11.0 (hatchery). These data suggest an 8.5:1 advantage for fish reared in the hatchery. These data also suggest that wild Tucannon River spring chinook are not replacing themselves (the return per female would have to be at least two). In 1994, the run was so low to the Tucannon River, that 100% of the run was captured for hatchery broodstock because of the apparent advantage outlined above (Bugert, personal communication). Similar discussions took place between the members of the Rock Island Coordinating Committee concerning the Chiwawa River run in 1994, but because there are so few data concerning adult returns to date, a more conservative broodstock protocol was followed.

Another concern that Bumgarner et al. (1994) discuss is the low number of fish used for broodstock and the possible resultant genetic risks (the two programs in the mid-Columbia have the same potential problem). Successful attempts to augment wild stocks through supplemental breeding and release programs that involve artificial reproduction of a fraction of the wild population (termed "supportive breeding") carry the risk of reducing the effective size of the total (i.e., wild plus supplemented) population below acceptable levels because of the distortion of family size introduced through the cultured fish (Ryman 1991). Ryman notes:

> *...supportive breeding, particularly when it is successful, may result in a trade off. There is a gain in the total production of offspring, but there is a simultaneous reduction in the effective size of the total population that may result in loss of genetic variability (heterozygosity). In many cases the loss of heterozygosity may not be regarded as very important, and possibly justified considering the gain in overall production. However, when the absolute size of the wild population is small, supportive breeding can lead to serious depletion of genetic variability of the overall population.*

All of the problems outlined above have been considered in the planning of the spring chinook supplementation programs of the mid-Columbia (Appendix 6 and 7). Some of the differences observed in the hatchery fish returns to the Tucannon River basin will be difficult to measure in the mid-Columbia because broodstock collection protocols are different. In the Tucannon River, the broodstock protocol calls for 50% of the adults taken to be of hatchery origin (Bumgarner et al. 1994). This gives hatchery managers the opportunity to collect life history data from the returning hatchery fish, but may also exacerbate the potential dilution of genetic diversity of the parent stock. For both mid-Columbia spring chinook supplementation programs, only naturally-produced fish are kept for broodstock, with fish of hatchery origin passed upstream from collection points to spawn naturally. While this gives managers less chance to ascertain differences between adults of hatchery and natural origin upon their return, it is hoped that this will maintain genetic diversity of the donor populations to a greater degree than other hatchery programs (Appendix 6,7). Other important interactions, such as spawning ground use, will be documented and compared to historical use.

Another potential problem with the supplementation programs is a reduced reproductive potential of the populations once hatchery fish begin returning in significant numbers to spawn naturally. The concern of the Rock Island and Wells Committee members is that production per female may drop after hatchery fish make up a significant proportion of the spawning population. One way to determine this is to estimate the number of parr and smolts produced for a given number of spawners (based either on weir or redd counts). The Rock Island Committee was unable to agree as to which method of enumeration was better; either a downstream migrant trap near the mouth, or snorkel surveys in the rearing areas. It was decided to do both. On the Chiwawa River, WDFW has been running a smolt trap just upstream of the mouth (Petersen et al. 1994), and Don Chapman Consultants has estimated the summer parr standing crop in the upstream rearing areas (Hillman and Miller 1993). From these estimates, it is hoped that we will be able to observe any changes in production after significant numbers of hatchery origin adults begin spawning in the Chiwawa. A similar effort (with a migrant trap near the mouth) is underway in the Chewack River of the Methow Basin (Hubble 1994).

In conclusion, the national fish hatchery programs in the mid-Columbia region have improved as they strove to reach their rearing and production goals, but can improve more. We agree with the use of only hatchery fish in the NFHs and strongly discourage the use of naturally-produced fish for broodstock at these hatcheries. If there were a proven benefit of these hatcheries over natural production, then use of naturally-produced fish for broodstock would make sense. Mullan et al (1992b) found naturally-produced smolts were 13-100 times more viable than hatchery-produced smolts from the three mid-Columbia NFHs. While recent survivals have been relatively high from the Leavenworth facility, the Entiat and Winthrop facilities have not followed suit. Recent changes in production goals, release strategies, and other culturally practices may improve survival rates. These hatcheries should remain as harvest augmentation programs, unless significant straying occurs. If there are years when low returns preclude the hatchery from reaching its production goal, eggs should not be received from other broodstocks, and the hatchery should produce less fish.

The supplementation programs of the mid-Columbia appear to have the highest probability of increasing the naturally reproducing populations of stream-type chinook upstream of Rock Island Dam. Broodstock protocols place maintenance of genetic integrity as a top priority. Lessons may be learned from the Tucannon program, and more monitoring of the returning hatchery fish (for life history information) may help us to learn if fish returning from the program are biological equivalents of the naturally-produced populations.

ALTERNATIVE HATCHERY STRATEGIES

Accelerated smoltification

Zaugg et al. (1986) found that by decreasing the photoperiod of spring chinook adults held in a controlled facility, they could increase the rate of maturation and subsequent initial feeding of juveniles by 4-5 weeks. This was attempted to decrease the pre-spawning mortality of spring chinook in the hatchery, since they have to be held for up to four months before they are spawned. Zaugg et al. (1986) observed that progeny of the earlier matured adults exhibited signs of smoltification approximately one year earlier than juveniles that are normally reared for approximately 18 months. They state:

> *Conclusions as to how successful the controlled photoperiod program is in producing 0-age spring chinook salmon smolts that will survive to contribute to the fishery must await adult returns. However, data showing elevated gill Na^{+}-K^{+} ATPase activity, good movement to the estuary, and recapture of significant numbers of migrants are optimistic observations. Should a 0-age smolt program prove successful, it would become possible to rear three to four times as many smolts at less expense in the same hatchery facilities, a cost-effective means of increasing the resource.*

In the mid-Columbia River basin, accelerated smoltification was attempted for three brood years in the late 1980s (Sullivan and Schadt 1989; Sullivan 1991, 1992). This study was undertaken to test the feasibility of accelerating the rearing (and subsequent release) of spring chinook from mid-Columbia hatcheries. By releasing fish up to one year earlier than in normal programs, it was hoped disease incidence of BKD and stress would be reduced, the quality of the fish released would be increased, as would smolt-to-adult survival. The primary objective of the study was to increase the incubation and rearing temperature of the eggs and juveniles, which produced fish of a size that it was hoped would migrate to the ocean. Normal yearling releases were used as controls. From Sullivan (1992),

> *Although several factors may be involved in the development of these smolting characteristics, we considered release size most critical. Therefore, we increased water temperatures during incubation and rearing to stimulate faster growth rates. The physiological characteristics compared included gill ATPase and thyroxine (T_4) which typically peak during the salmonid smoltification process . . . We also compared the migration and survival rates of the two year classes as they migrated to sea, as well as a 120-day saltwater challenge to compare BKD infection rates.*

Migration rates for the first year of releases based on mark recaptures downstream (brands observed at smolt monitoring projects at Rock Island, Priest Rapids, McNary, and Bonneville dams) showed that the subyearlings initially exhibited strong migratory behavior, but eventually took almost twice as long as the yearling group to get to McNary Dam. The largest group of subyearlings were captured in greater numbers than the other subyearling groups, but at two-thirds the rate of yearling fish. Sullivan and Schadt (1989) believed that the recapture rates may have been influenced by fish guidance efficiency differences between yearling and subyearling groups at McNary.

For the saltwater challenge tests, Sullivan and Schadt (1989) found that all groups were infected with BKD, although the yearling group at about a 10% higher incidence. Mortality of the groups was complicated by an outbreak of vibriosis, but the authors still associate the mortality attributable to BKD alone to be 20% higher in the yearling group.

In the second year of the study, recovery rates at McNary were higher, and apparently the fish migrated faster than the first year, although the yearlings were still the faster migrants. Unlike in the first year, yearlings had the lowest overall mortality and lowest incidence of BKD after the saltwater challenge. Artificially increasing photoperiod of the juveniles did not significantly increase the growth rate or improve the migration success of one group of test fish.

In the third year of the study Sullivan (1991) claims that the saltwater challenge tests were confounded by various unforeseen events (e.g., osmoregulatory dysfunction in the 1989 group, a dinoflagellate bloom in 1990) made a comparison of BKD related mortality between yearling and subyearling groups difficult.

Downstream migration rates were slightly accelerated in 1990 for the yearling group compared to the previous years. Faster migration rates where not seen in the subyearling groups, even though flow was higher in 1990 compared to the other years (Sullivan 1991).

Adult returns from the program were dismal (Figure 100). The yearling groups returned at a rate almost an order of magnitude greater. The subyearlings released in 1990 survived at much higher rates than those released in 1988 or 1989, but still at less than one tenth of one percent. Although the yearling release group for this study was not marked in 1990, the normal production release from Leavenworth survived at the highest rates in more than a decade (Table 14, Figure 100), which suggests that juveniles entering the ocean in 1990 survived at higher rates than in the previous dozen years (at least for the Leavenworth NFH). This might help explain the higher rate of survival of the subyearling group released in 1990.

In conclusion, it appears the accelerated smoltification program was successful in producing fish that migrated downstream at reasonable rates, and may have been less susceptible to BKD. The program ultimately failed to produce adults. We find the results unsurprising in light of the small size of the age-0 accelerated fish at release (the largest fish were about 15 g in weight, equivalent to 30 fish per pound, and sizes ranged downward to 63/lb, while yearling "controls" were 16-21/lb [Sullivan and Schadt 1989]).[35] Samplers examined the mean size of accelerated age-0 juveniles at Rock Island Dam and at McNary Dam. Mean size at the latter sampling point always exceeded that at Rock Island Dam, usually by 10-15 mm, or 9-12%. Growth may account for some of this increment, but much is likely explained by predation that culled smaller cohort members.

It may be impossible to bring accelerated age-0 juveniles to yearling size in one year. However, that hypothesis has not been fully evaluated. Not every tool was used in the acceleration experiments. For example, adult broodstock was not subjected to artificially reduced photoperiod, or injected with hormones to speed maturation. Although eggs were incubated at high temperatures, fry were not transported to warm spring waters to accelerate growth, or to artificial control of day length. We believe more research on acceleration is desirable.

Other alternatives

Point-of-origin transport of hatchery fish to a point downstream from Bonneville Dam would increase survival markedly (see section on transportation as a mitigation alternative). Study of point-of-origin transportation was recommended in Chapman et al. (1991) for Snake River stocks. However, we believe homing would be poor. We reject this alternative.

Erho and Bugert (1995) list a number of alternative strategies that may be implemented for the Chewack facility. All of these alternatives are aimed at trying to make the hatchery fish behave more like their wild counterparts. Rearing fish in side channels, or "life skills" training all aim to make the fish less naive to predators

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[35] The yearling releases cannot be considered as controls. A control must satisfy the criterion that it differs from the test only with respect to the variate being tested. That variate was acceleration by one year. Since length also differed in test and control fish, two variates were confounded: length and acceleration.

(use the available microhabitat). Examples include mild electric shock, combined with overhead appearance of bird shapes, or with in-water appearance of squawfish models. Delivery of foods in drift, rather than from overhead, may provide useful training.

MANAGEMENT CONSTRAINTS

We will not repeat here the historical summary of various treaties, conventions, and agreements that affect management of spring chinook in the mid-Columbia region. Neither will we discuss the Columbia River Fish Management Plan (CRFMP) (*U.S. v. Oregon*) and Pacific Salmon Treaty. All those topics are treated in Chapman et al. (1994a). We summarize only the harvest restrictions in the CRFMP.

Interim management goals for upriver adult spring chinook are 115,000 and 35,000 (25,000 wild/natural) fish counted at Bonneville Dam and Lower Granite dams, respectively. No specific wild/natural goal is stated for Priest Rapids Dam. Since the mid-1970s, no commercial fishery in zones 1-5 has targeted upriver spring chinook. Since 1977, no Indian commercial fishery in Zone 6 has targeted spring chinook. Treaty Indian ceremonial and subsistence (C&S) fishing has taken 4,000 to 7,300 upriver spring chinook annually through 1993, an average of 6,300 fish, or 6.7% of the runs.

No provision is available to permit identification of wild or hatchery spring chinook destined for the mid-Columbia region. If they could be identified, and if conventions were designed to protect them, wild chinook caught by gill nets and removed alive would be unlikely to survive after release.

The CRFMP calls for a minimum mainstem C&S entitlement of 10,000 spring and summer chinook. Most of the harvest is to be taken from the spring chinook run. Zone 6 C&S fishing is managed in accord with run size (WDFW/ODFW

1994). Run size is assessed from the total number of adult spring chinook entering the Columbia River and destined to pass upstream from Bonneville Dam. In runs smaller than 25,000, platform C&S fisheries may remain open and gill-net fisheries may occur only if agreed-to by the parties. On runs of 25,000 to 50,000, the combined platform and gillnet C&S fisheries shall not take more than 5% of the in-river run. On runs of 50,000 to 112% of the escapement goal, or 128,800, the combined platform and gillnet C&S harvest shall not exceed 7% of the in-river run. If the minimum C&S entitlement of 10,000 fish is not reached in each calendar year, then the balance shall be provided by the states from the Cowlitz River Hatchery, Willamette River hatcheries downstream from Willamette Falls, or other lower river hatcheries that have fish of equal quality.

RESEARCH RECOMMENDATIONS

Instream flow needs of spring chinook juveniles and adults require study, especially in the Methow River basin. Associated with this effort should be a thorough study of groundwater hydrology and interactions between ground water and irrigation. An inventory of water rights available under a willing-seller, willing-buyer format should be completed. When the various investigations are completed, a list of priority areas for instream flow augmentation, if such augmentation is found to be needed, should be developed.

A small-scale evaluation of the effects of adding woody debris jams on subyearling chinook production in streams or stream reaches lacking wood is needed. Possible treatment sites can be identified using hydraulic analysis like that described in Mikkelsen (1994). Experimental treatments should require low maintenance and look and function like natural log jams. The study design, monitoring, and evaluation should follow techniques described in Fritsch and Hillman (1994).

Additional evaluations of genetic makeup of wild spring chinook populations of the mid-Columbia region are needed. These would help decisionmakers to determine how to lump or split the ESUs upstream from Rock Island Dam. Reciprocal egg lots of Carson and Leavenworth fish need to be reared, tagged and released at both locations to quantify apparent adaptive differences that have evolved in these two recently-diverged stocks.

Reach-specific survival studies with PIT-tags are crucial to best management of the hydropower system to protect migrating spring chinook. Those studies will require placement of a PIT-tag detection system at John Day Dam.

Vertical slot surface collectors deserve continued investigation in the mid-Columbia region. They would, if proven efficacious, take advantage of the propensity of smolts to use the upper portions of the water column.

Research on predator behavior is needed in the region. Information from those studies will help delineate means of delivering smolts to tailrace areas that will thwart predators. The Wells Dam bypass should be evaluated with respect to prey concentrations and predator-related mortality in the tailrace.

Transportation deserves expanded study in the region. The studies conducted at Priest Rapids Dam in the period 1984-1986 were flawed in several ways, and cannot be relied upon as managers decide how best to mitigate for dam-related mortality.

Hatchery evaluation studies now underway in connection with fish culture programs of Chelan and Douglas PUDs should be continued to fruition. They are important components of the mid-Columbia conservation effort.

Mid-Columbia enhancement programs should be evaluated as part of the seamless fabric of ocean ecology. Agency and PUD personnel must come to grips with the broad ecological problems of ocean carrying capacity, interspecific interactions, global temperature changes, and ocean fishing on mixed stocks. These matters are easy to list, but difficult to address in meaningful ways.

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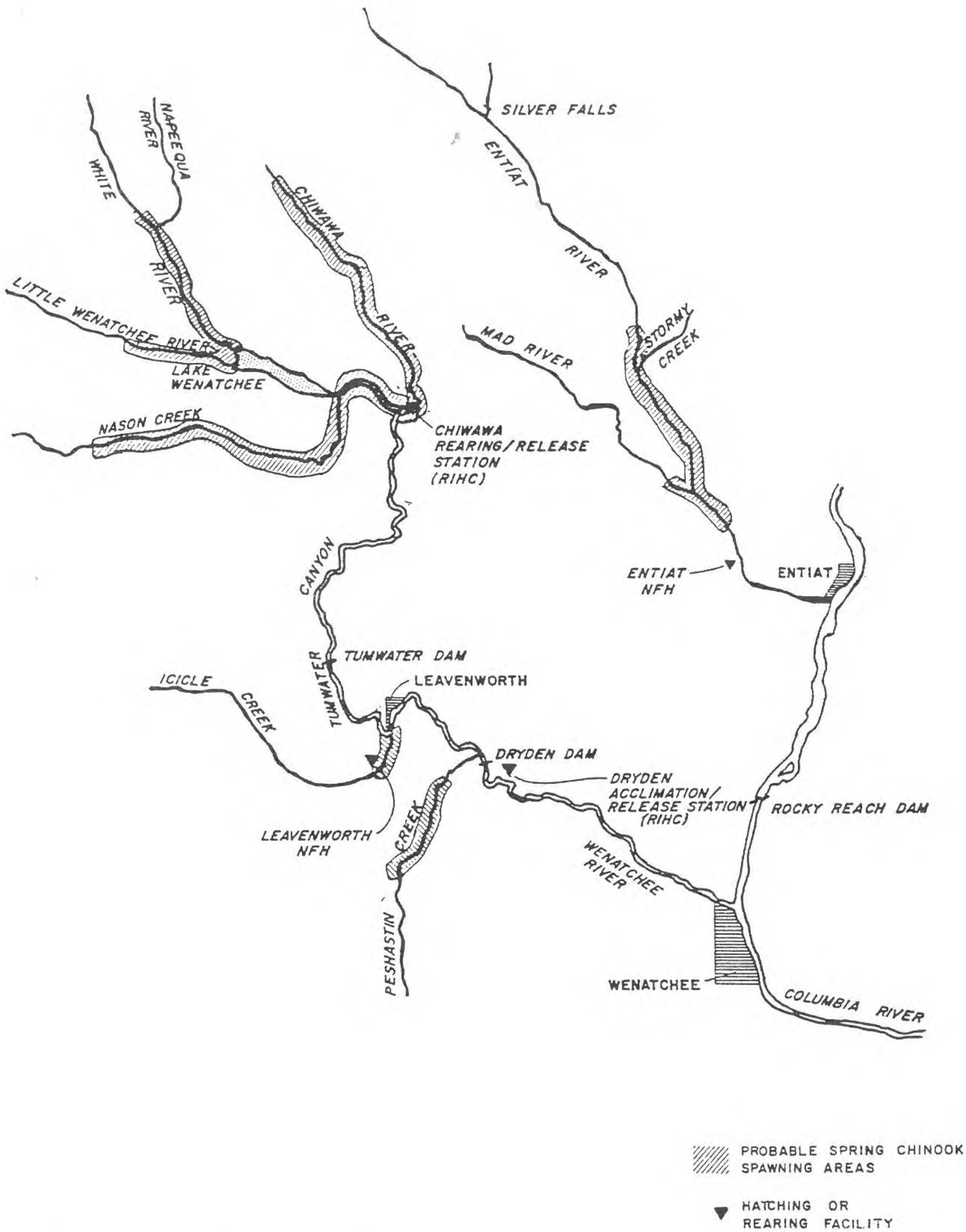


Figure 1. Locations of probable spring chinook spawning areas and hatcheries in the Wenatchee and Entiat rivers.

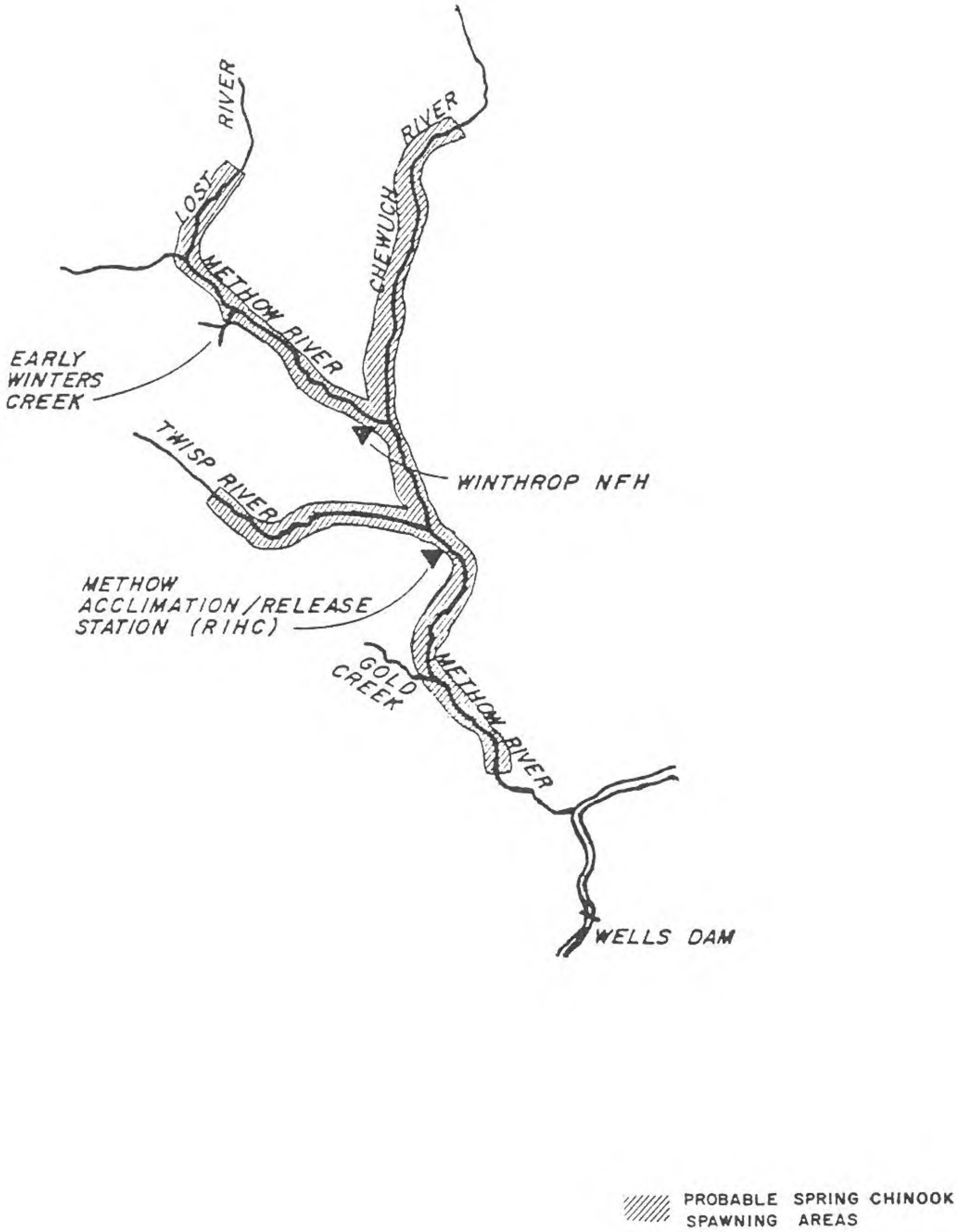


Figure 2. Locations of probable spring chinook spawning areas in the Methow River and Winthrop National Fish Hatchery. Note spelling "Chewuch" in figure is revisionist (our report uses Chewack). Absence of index areas (see Figure 4) downstream from Twisp River suggests little spring chinook spawning in mainstem Methow downstream from Twisp.

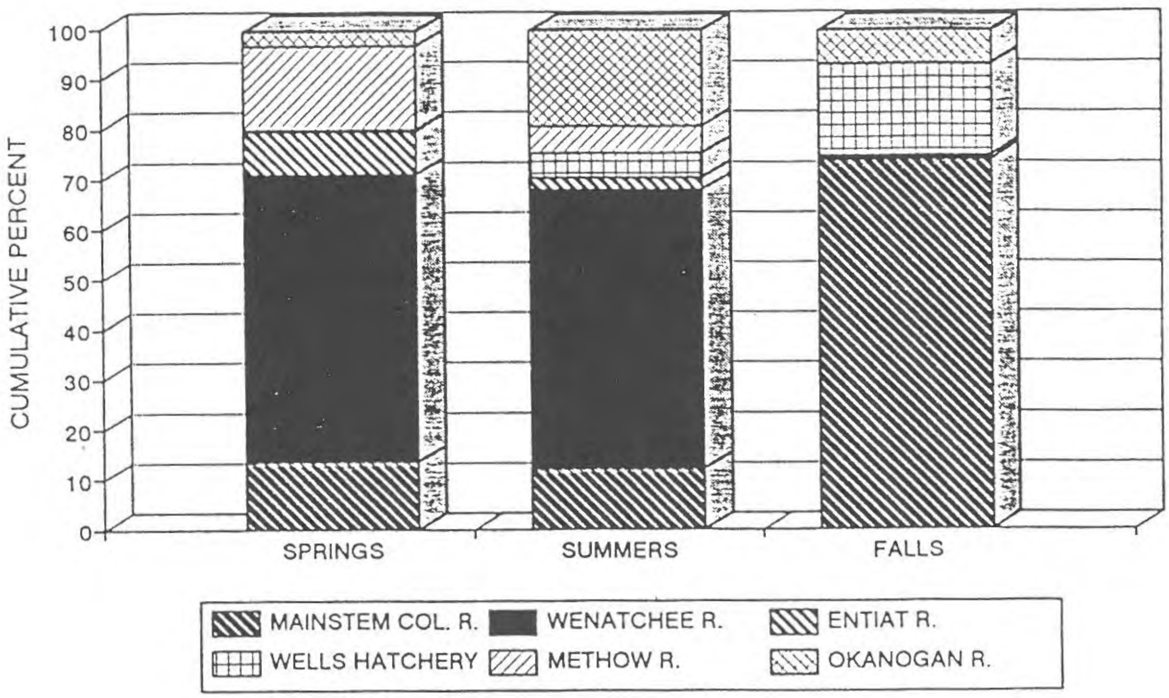


Figure 3. Distribution of radio-tagged spring, summer, and fall chinook upstream from Priest Rapids Dam, 1993, from Stuehrenberg et al. (1994).

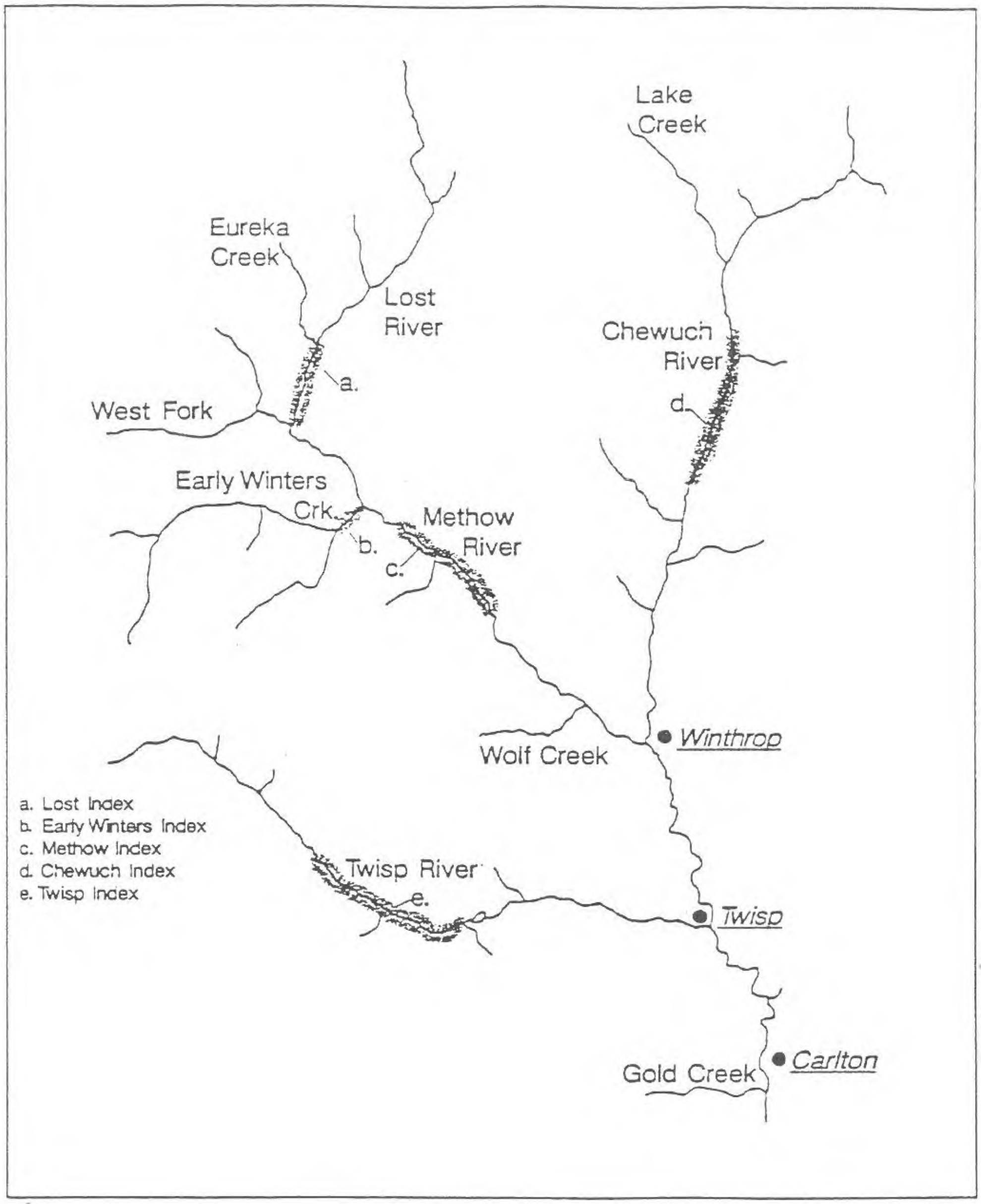


Figure 4. Spring chinook spawning index reaches in the upper Methow River basin. Note that our text uses long-accepted "Chewack" River spelling.

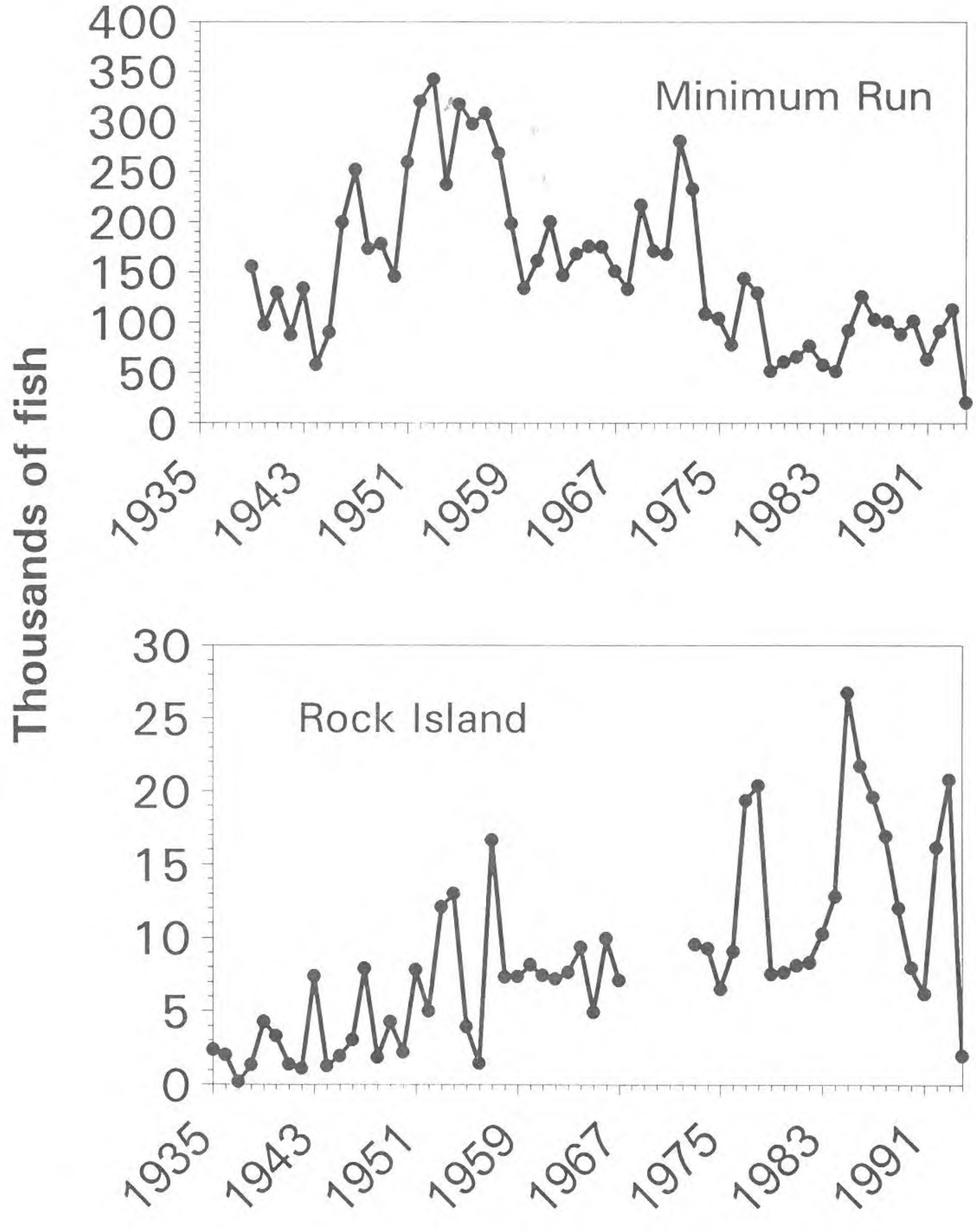


Figure 5. Comparison of the minimum number of upriver spring chinook entering the Columbia River (1938-1993), from WDFW/ODFW (1994) and the number of spring chinook passing Rock Island Dam (1933-1967, 1972-1994), from data of Chelan PUD.

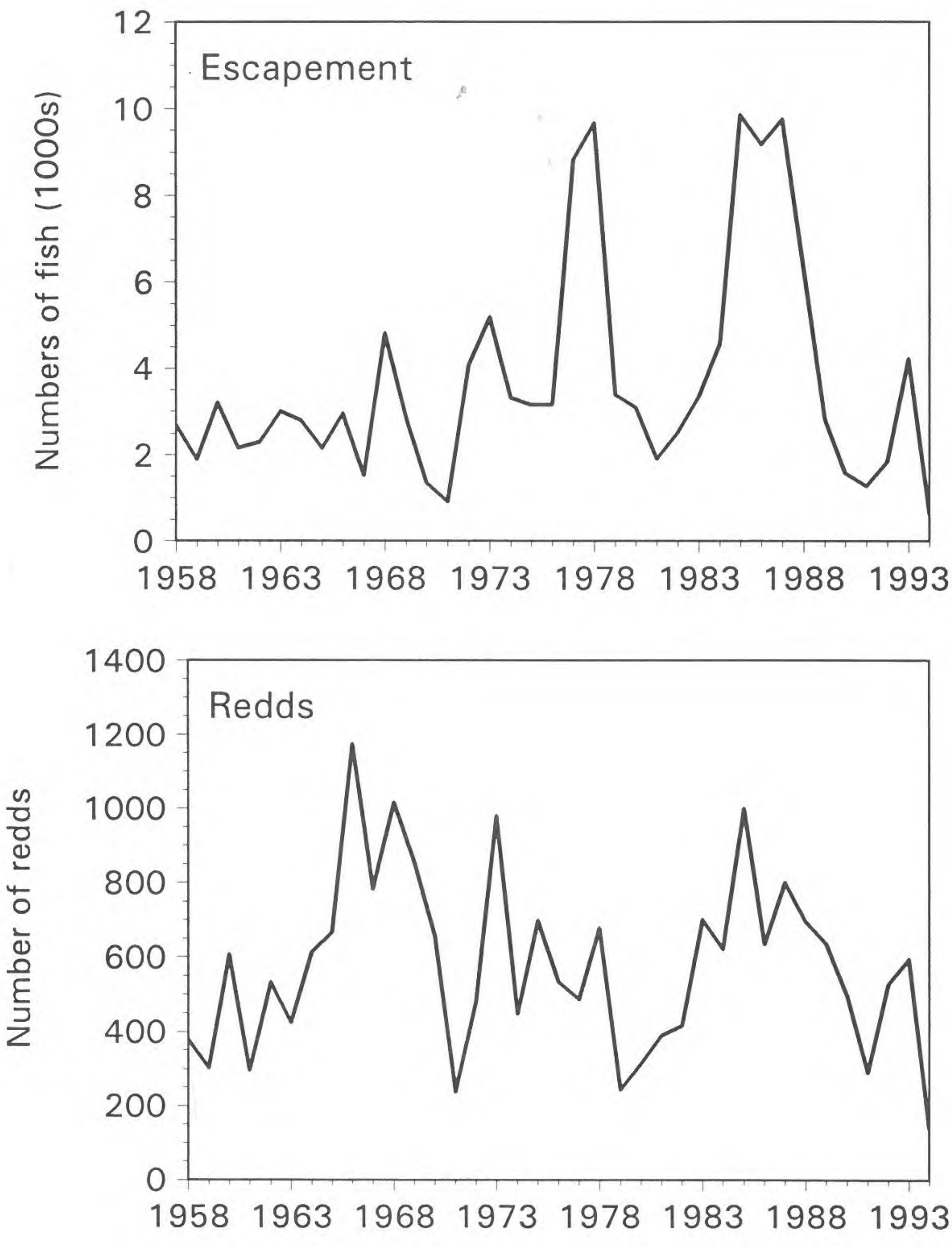


Figure 6. Estimated escapement and number of redds observed in the Wenatchee River, 1958-1994, from Peven and Truscott (1995).

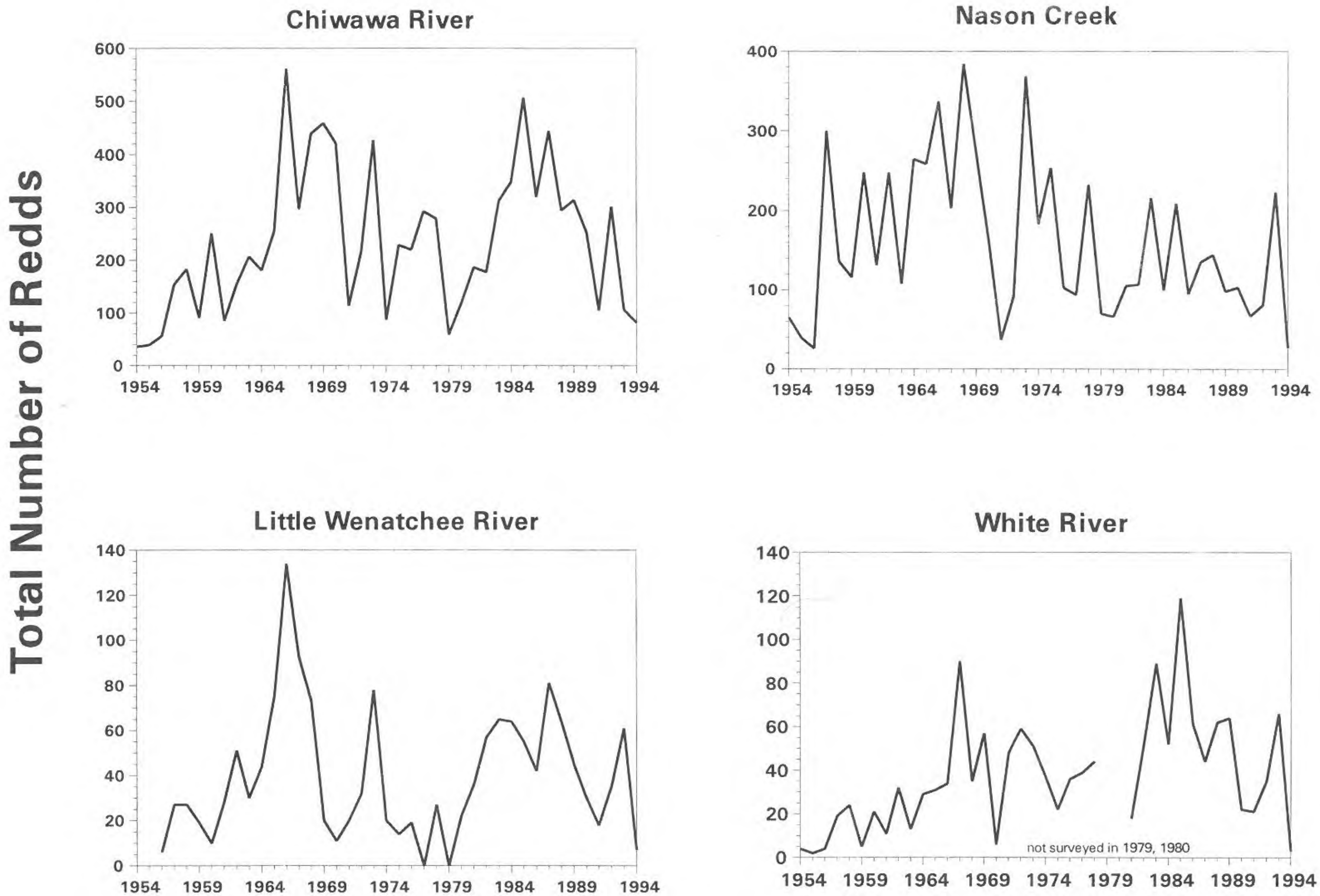


Figure 7. Spring chinook redd counts in the four principal tributaries of the Wenatchee River, 1958-1994 (Note: Between 1958 and 1986, surveys were one-time walks of index areas), from Peven and Truscott (1995).

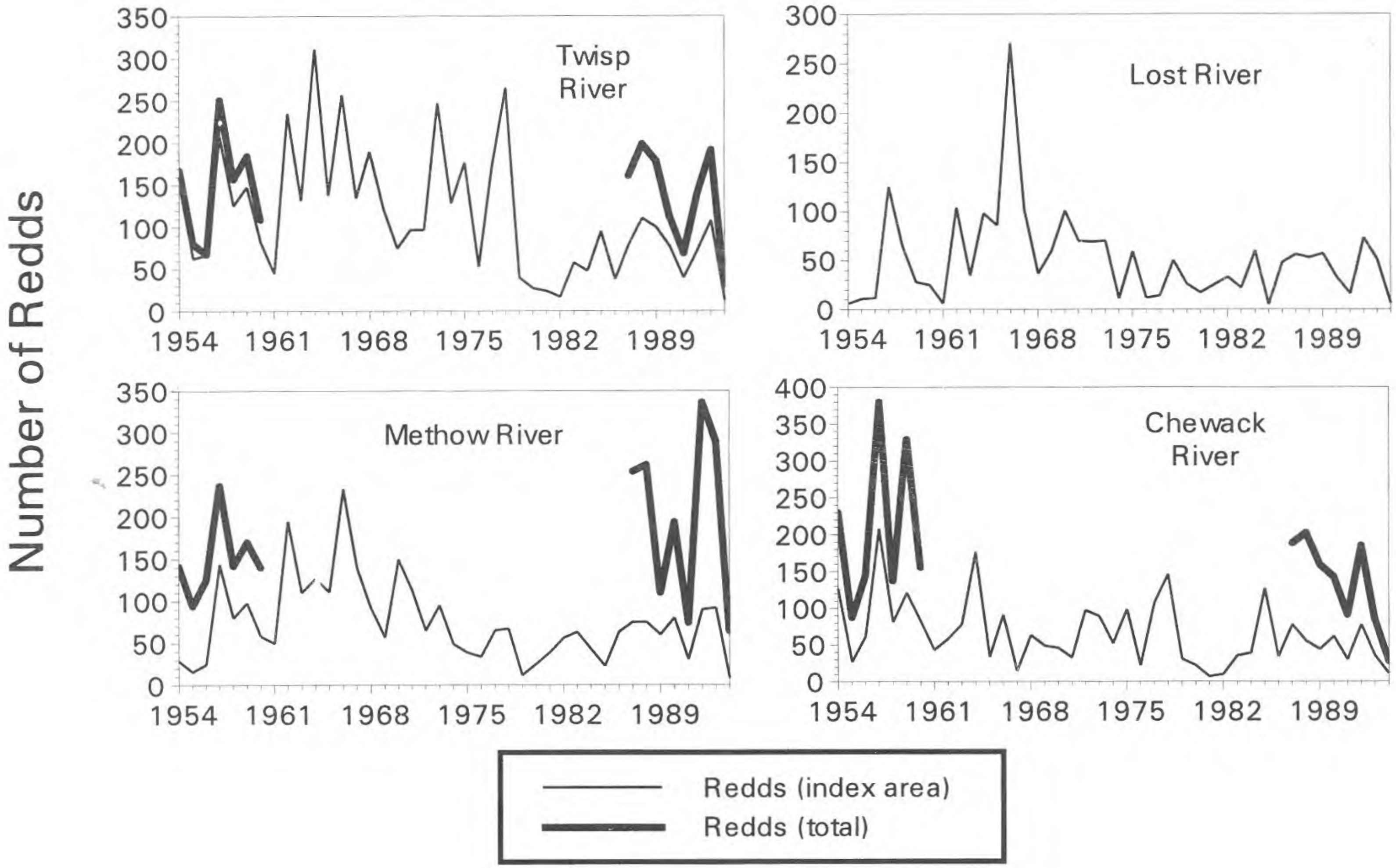


Figure 8. Summary of redd counts upstream from Wells Dam for spring chinook, 1954-1993, from Peven (1992), Scribner et al. (1993), and J. Hubble, YIN, personal communication.

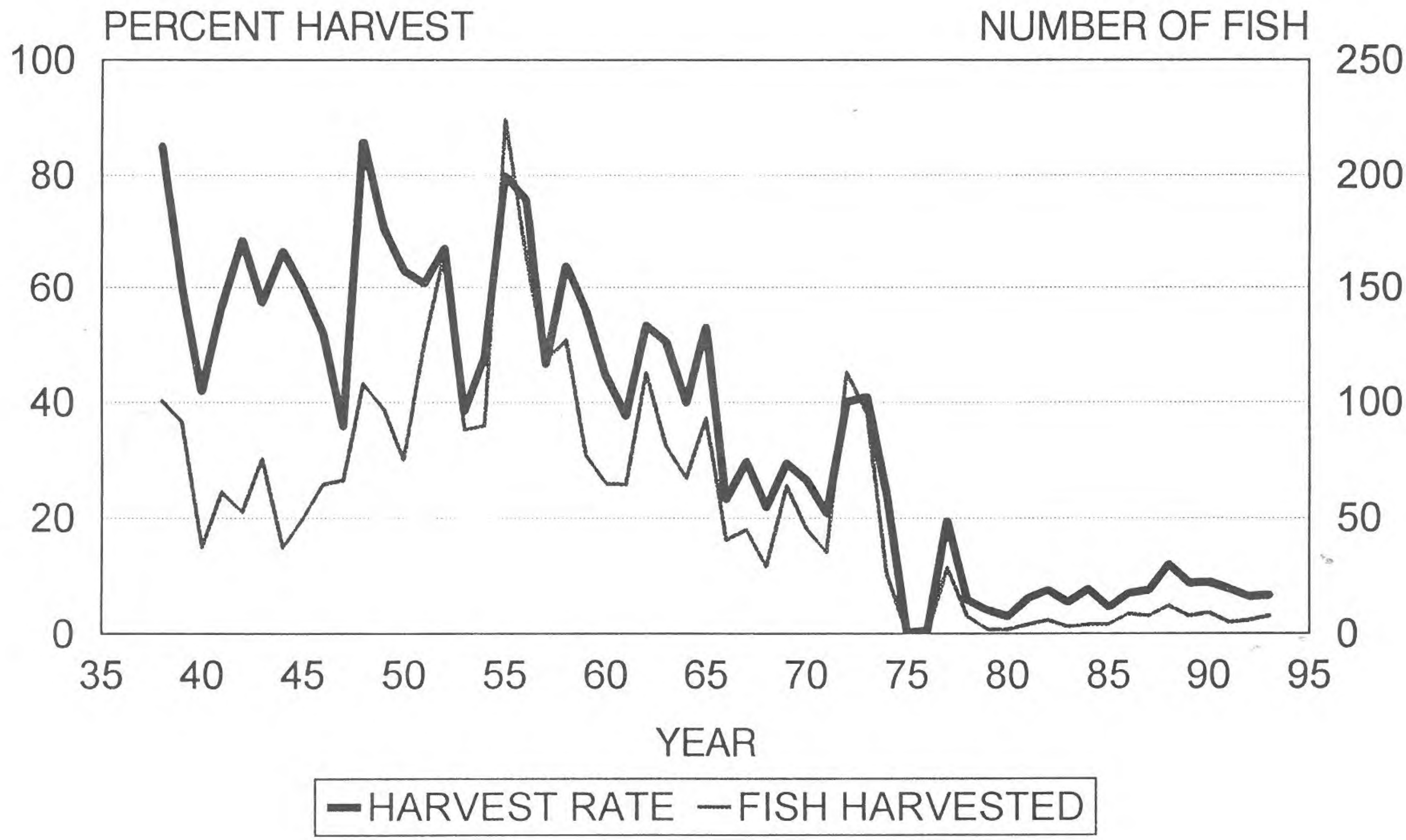


Figure 9. Upriver spring chinook adults harvested, and harvest rate, from WDFW/ODFW (1994).

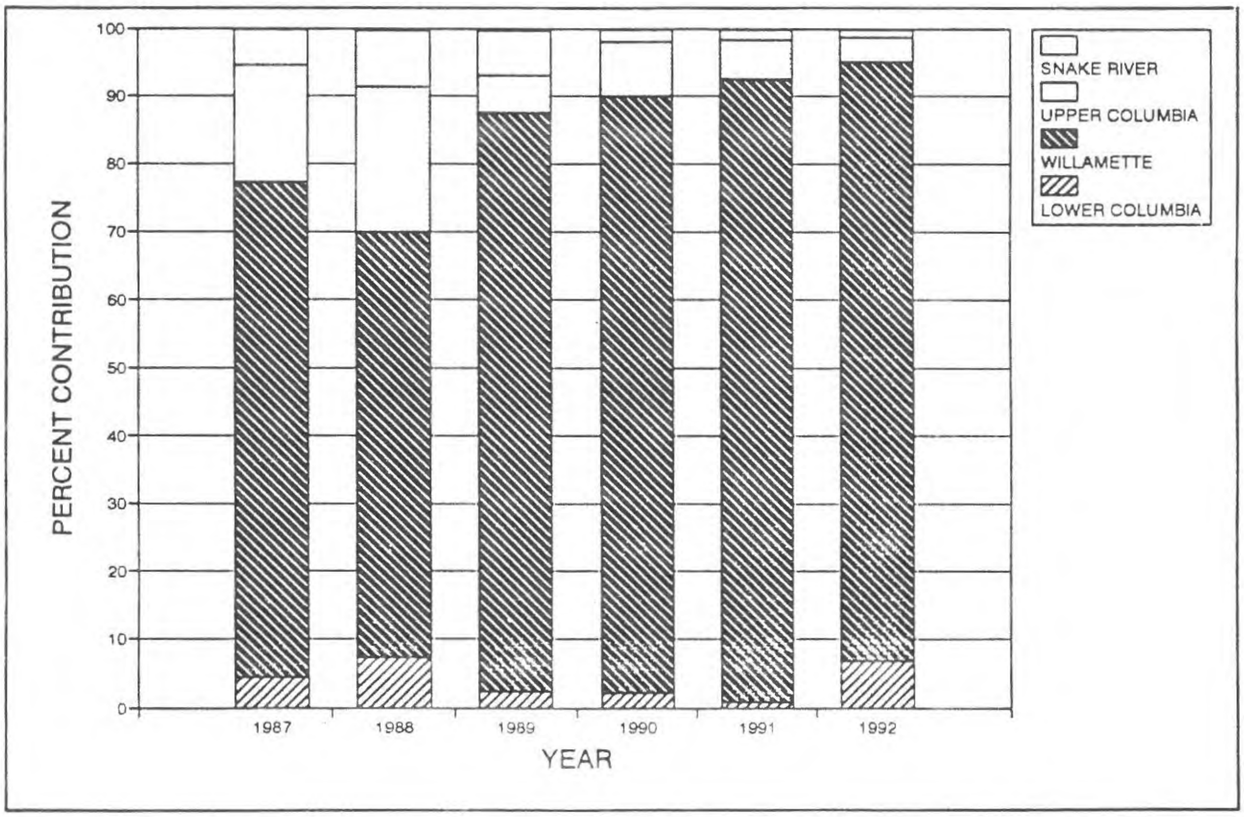


Figure 10. Relative percentages of stock group contributions to the winter gill net fishery for spring chinook in the Columbia River, 1987-1992, from Miller et al. (1993).

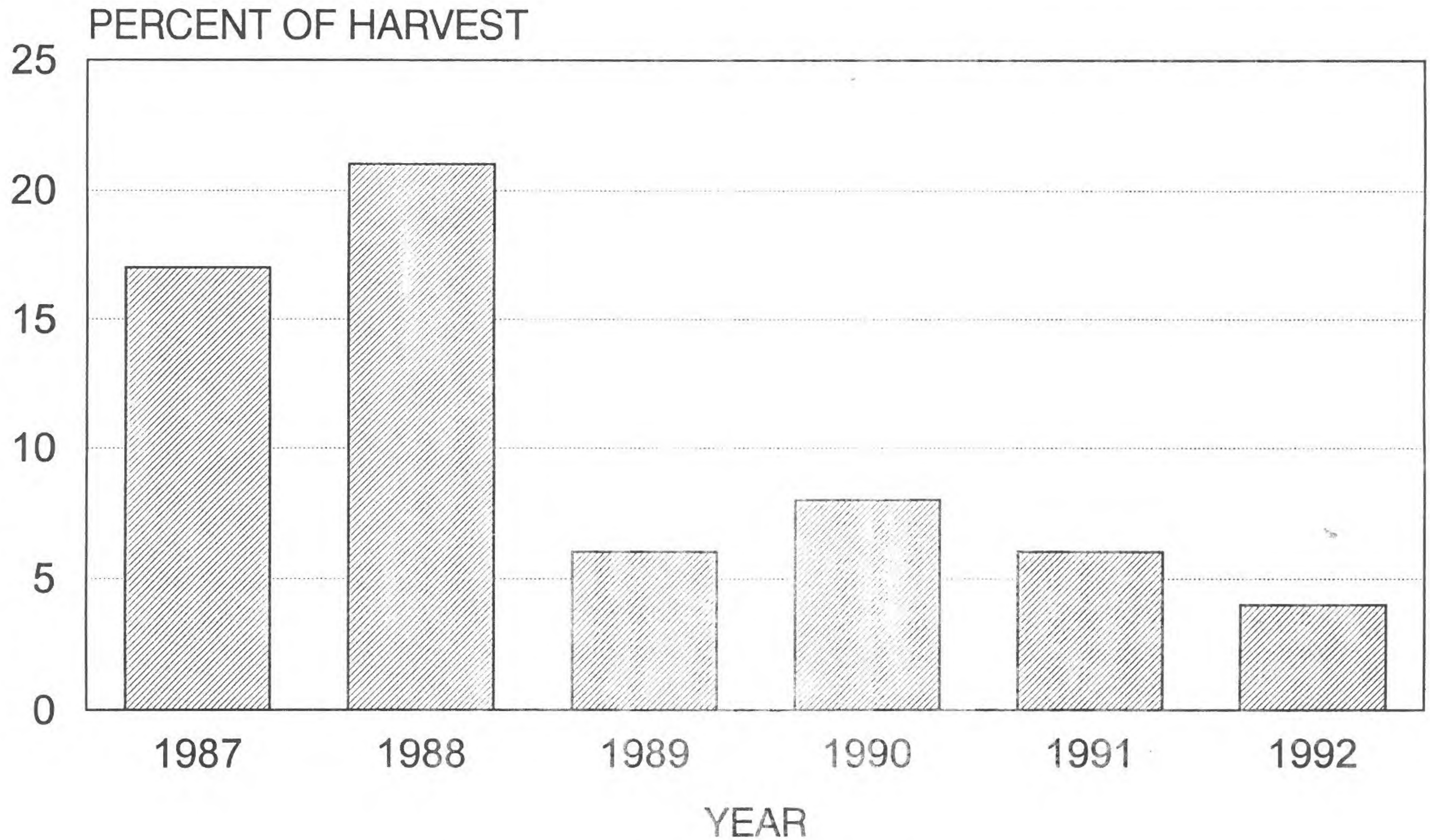


Figure 11. Percent contribution to winter gill net fishery for spring chinook in the Columbia River, 1987-1993, by upper Columbia River spring chinook, from Miller et al. (1993).

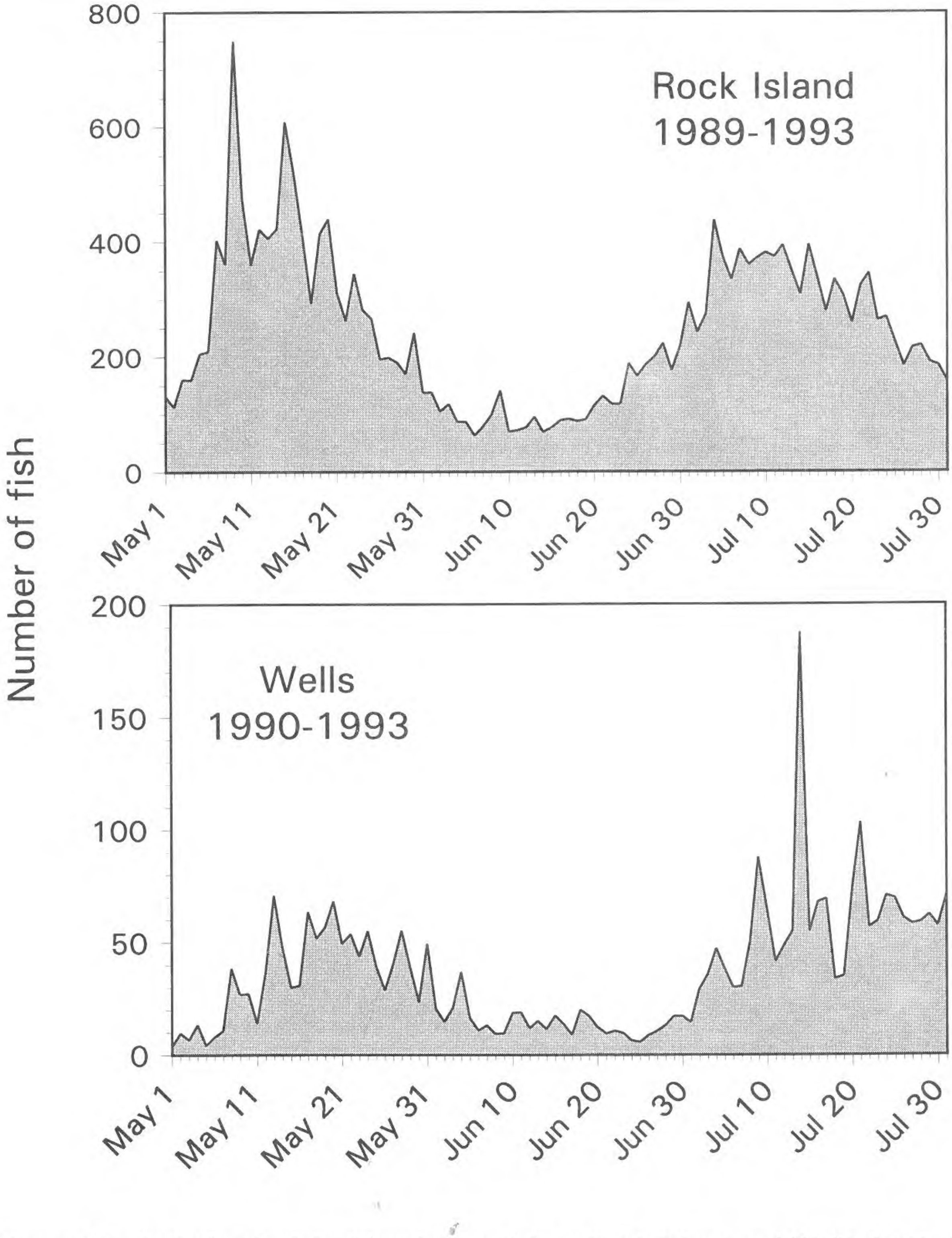


Figure 12. Arrivals of adult chinook May-July at Rock Island and Wells dams, from unpublished data of Chelan and Douglas PUDs.

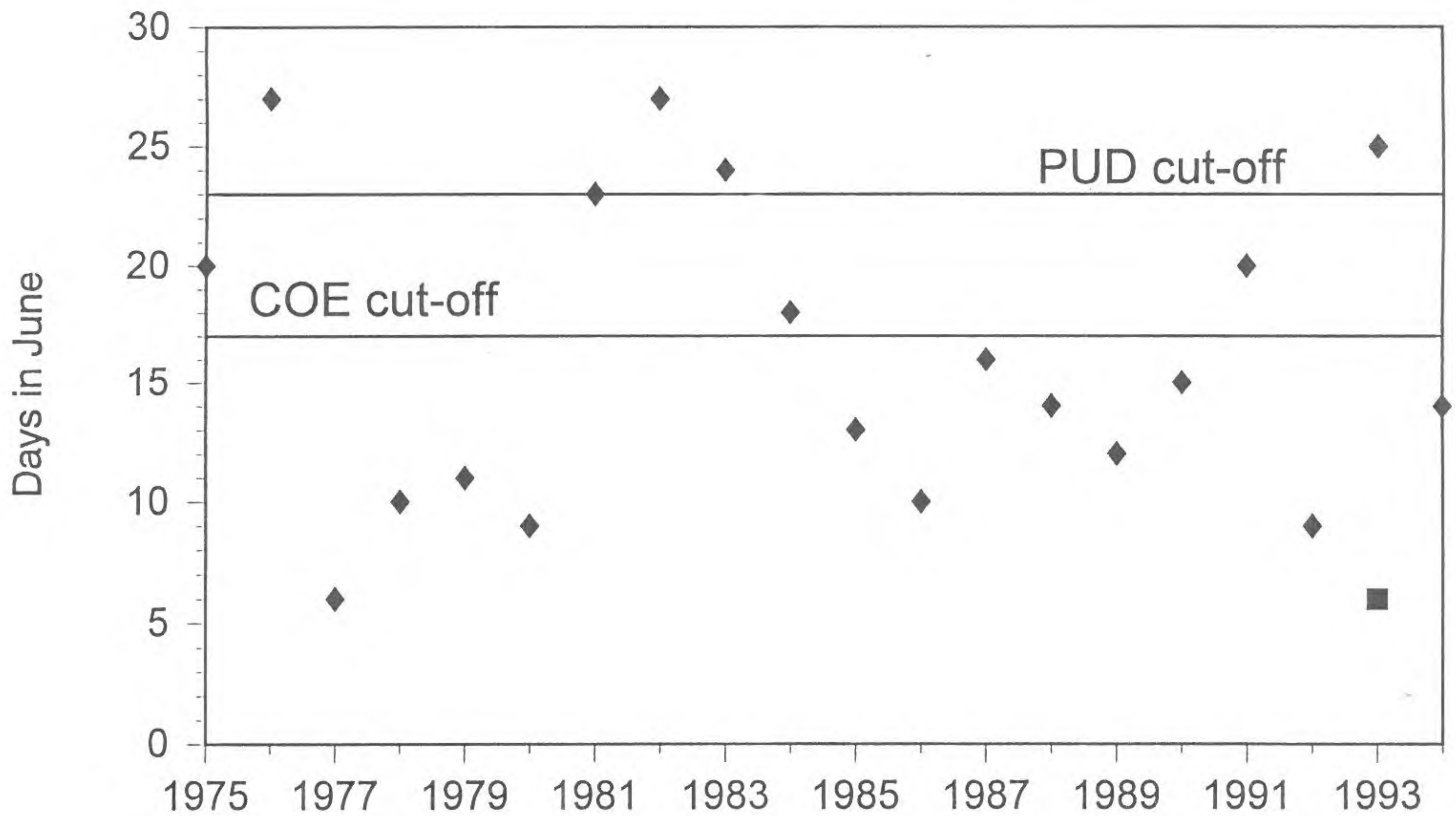


Figure 13. Nadir in arrival of spring chinook at Rock Island Dam, with USACE and Chelan PUD cut-off date for break between spring and summer chinook.

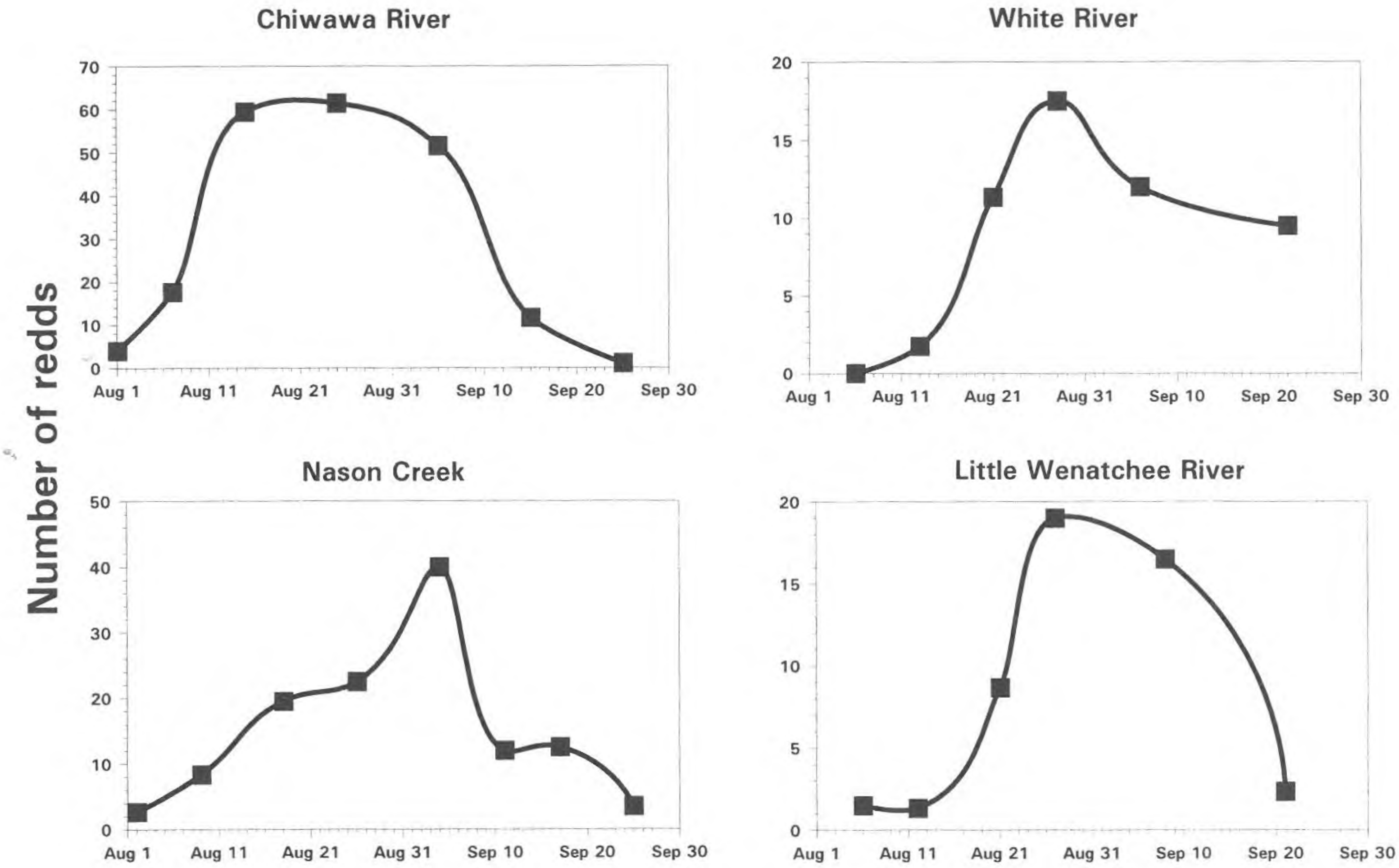


Figure 14. Average timing of spring chinook spawning in the four principal tributaries of the Wenatchee River, 1990-1993, from data of Chelan PUD.

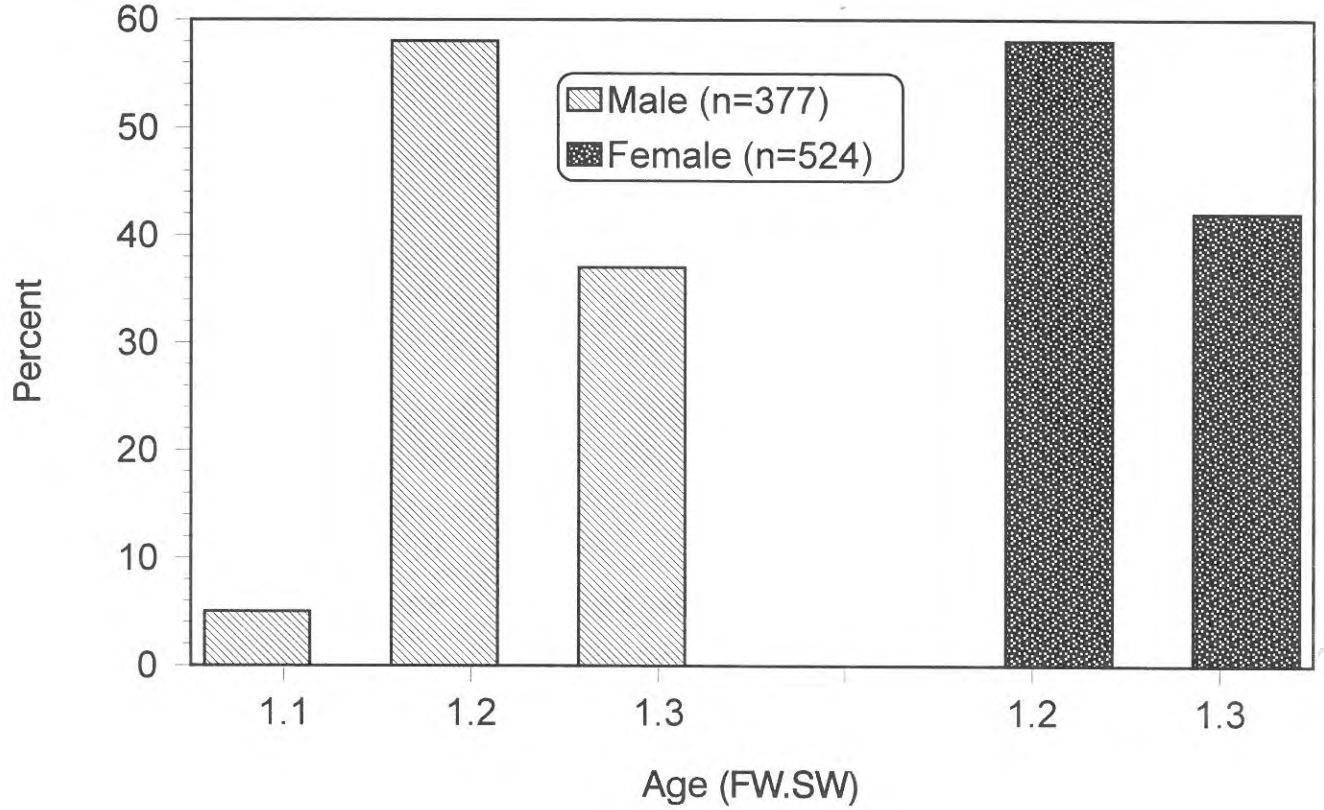


Figure 15. Age composition of spring chinook sampled in the mid-Columbia River basin, 1986-1993, from this study.

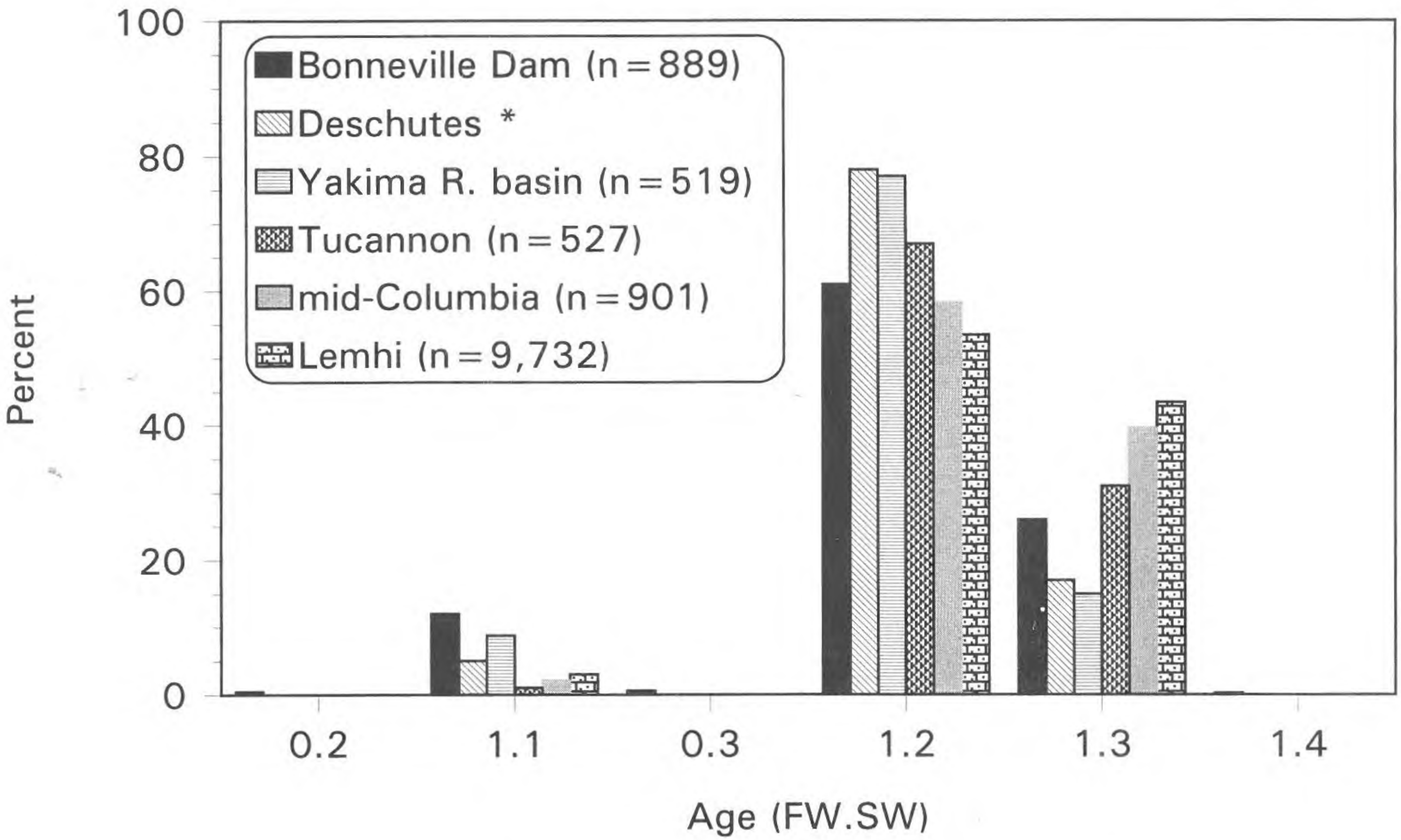


Figure 16. Comparison of adult age composition of spring chinook sampled at Bonneville Dam (Fryer et al. 1992; Fryer and Schwartzberg 1993), Deschutes River (Lindsay et al. 1989), the Yakima River basin (from Howell et al. 1985), the Tucannon River (wild only; Bugert et al. 1992), the Lemhi River (Bjornn 1978), and in the mid-Columbia River basin tributaries (both sexes combined).

* no sample sizes are given by Lindsay et al. (1989) for their age composition.

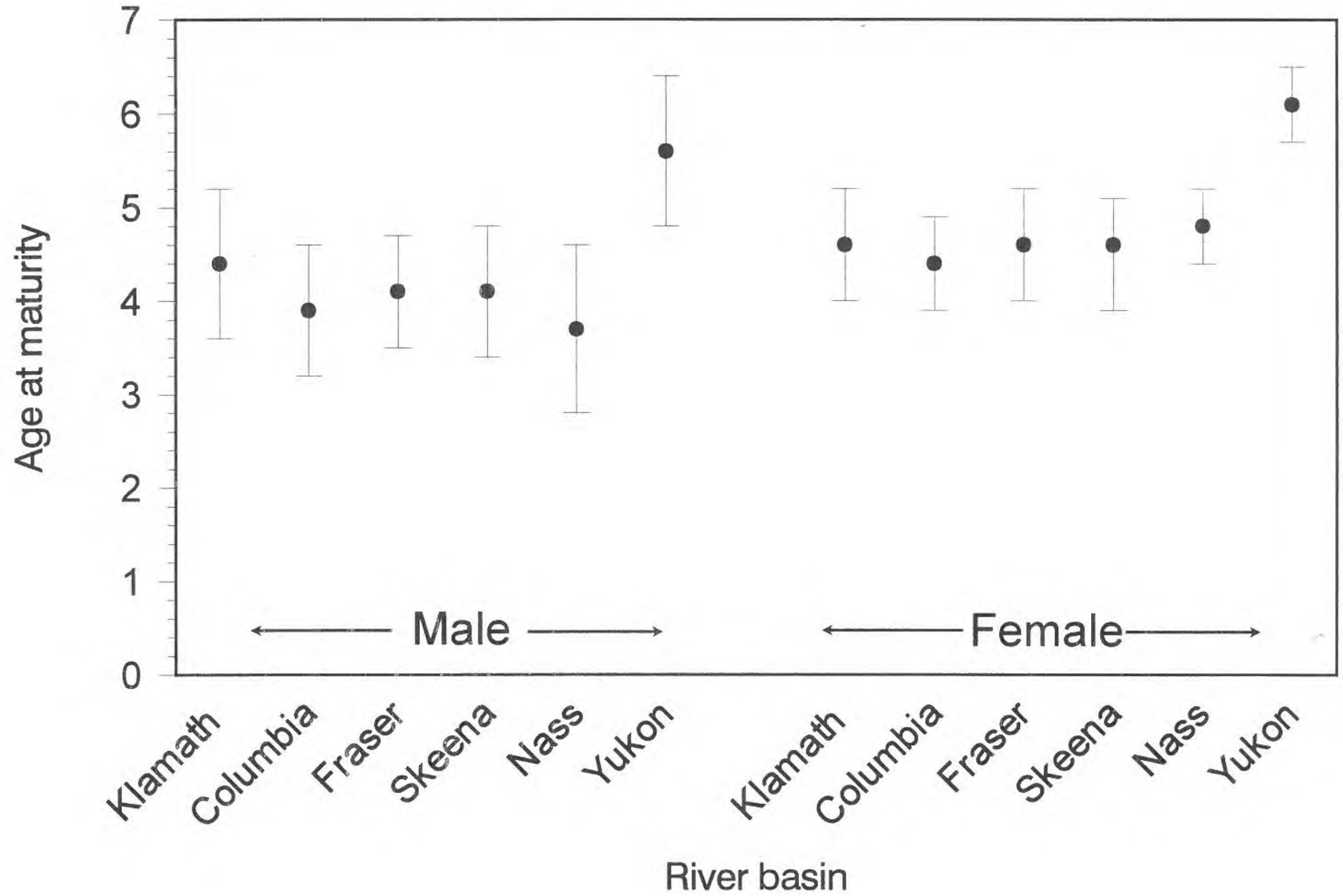


Figure 17. The average (and standard deviation) age at maturity of stream-type chinook throughout their North American geographic range (adapted from Healey 1991).

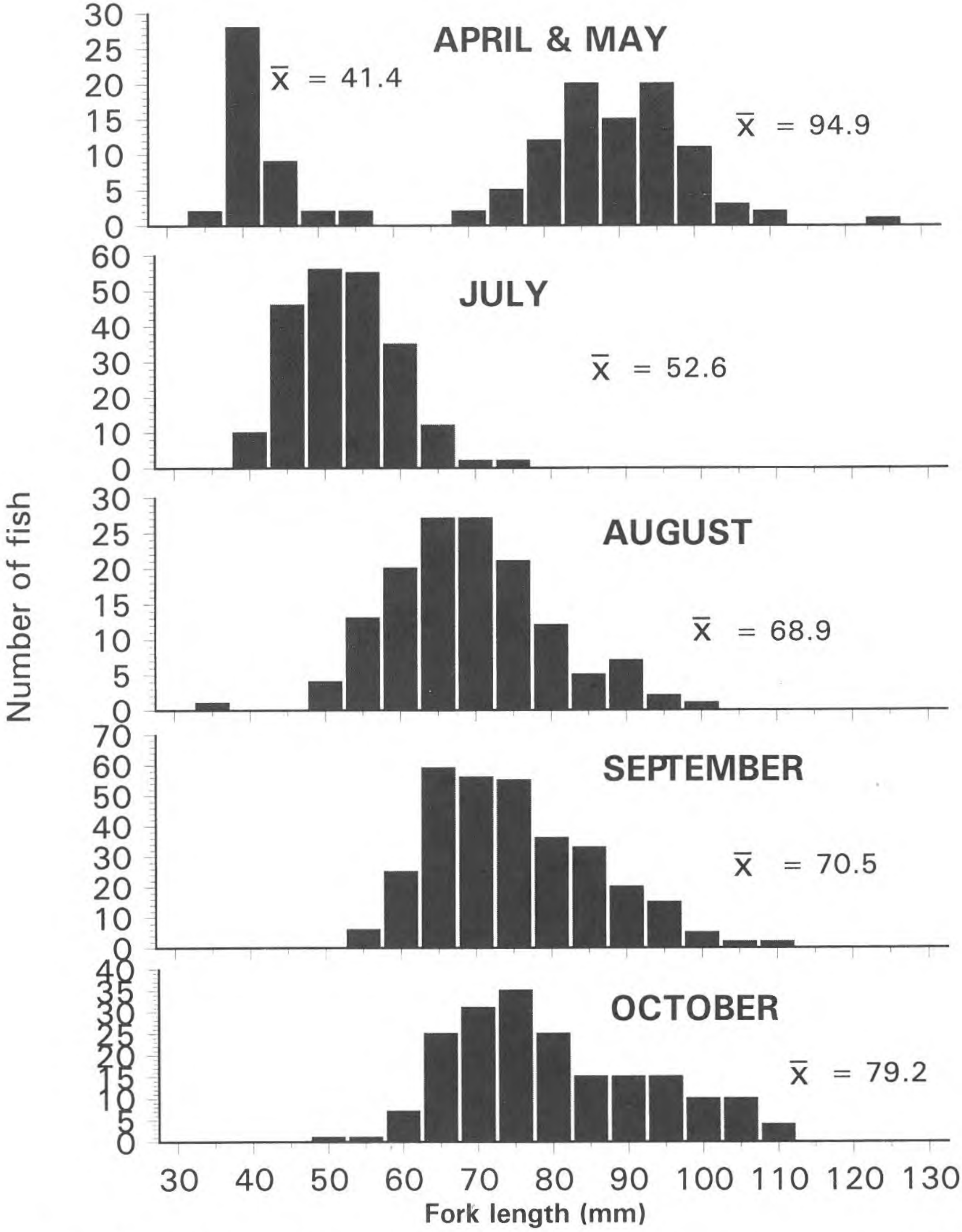


Figure 18. Length frequency of juvenile chinook captured at Tumwater Dam, 1955 (adapted from French and Wahle 1959).

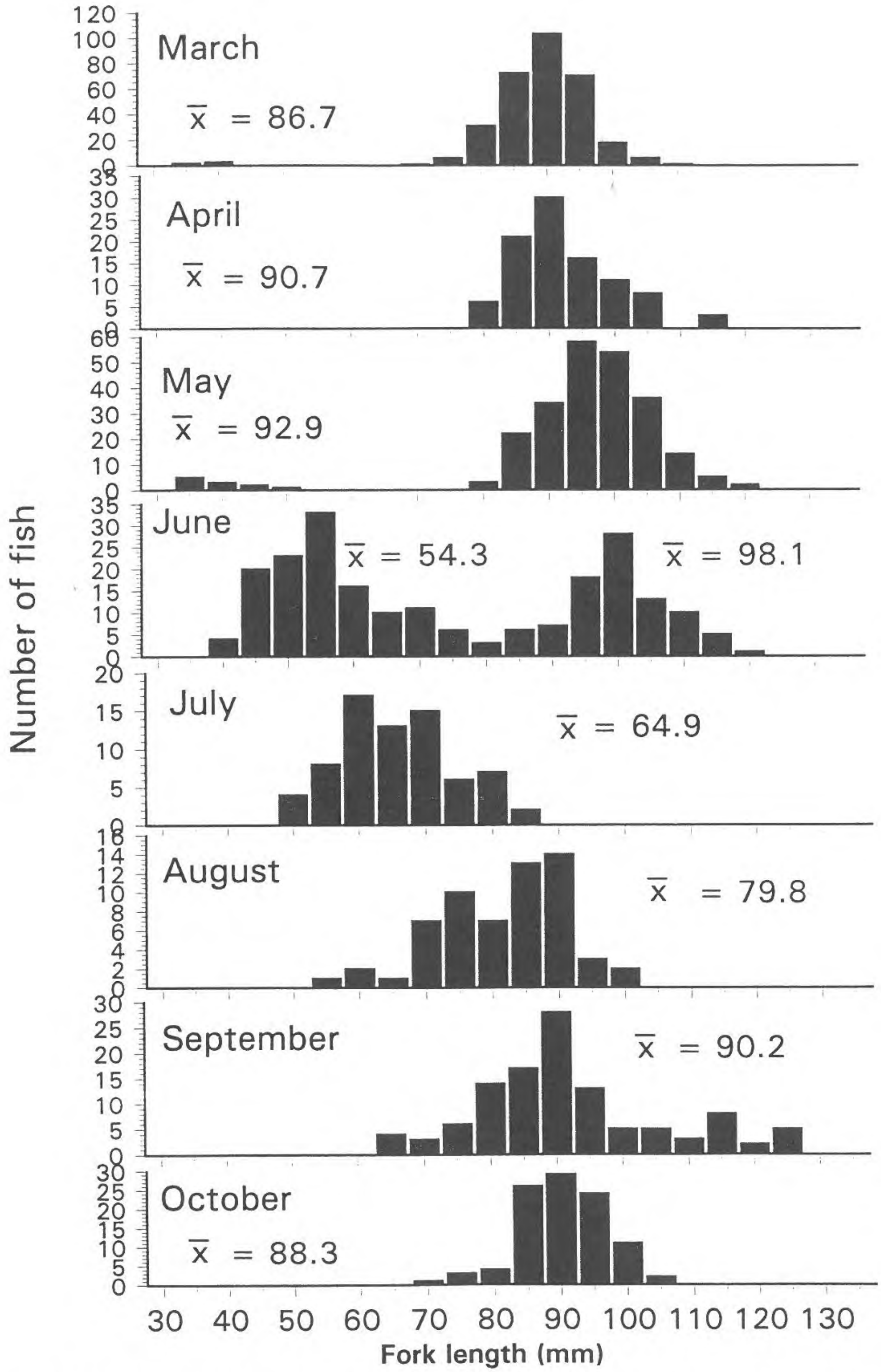


Figure 19. Length frequencies of juvenile chinook emigrating from the Chiwawa River, 1994 (K. Petersen, WDFW, personal communication).

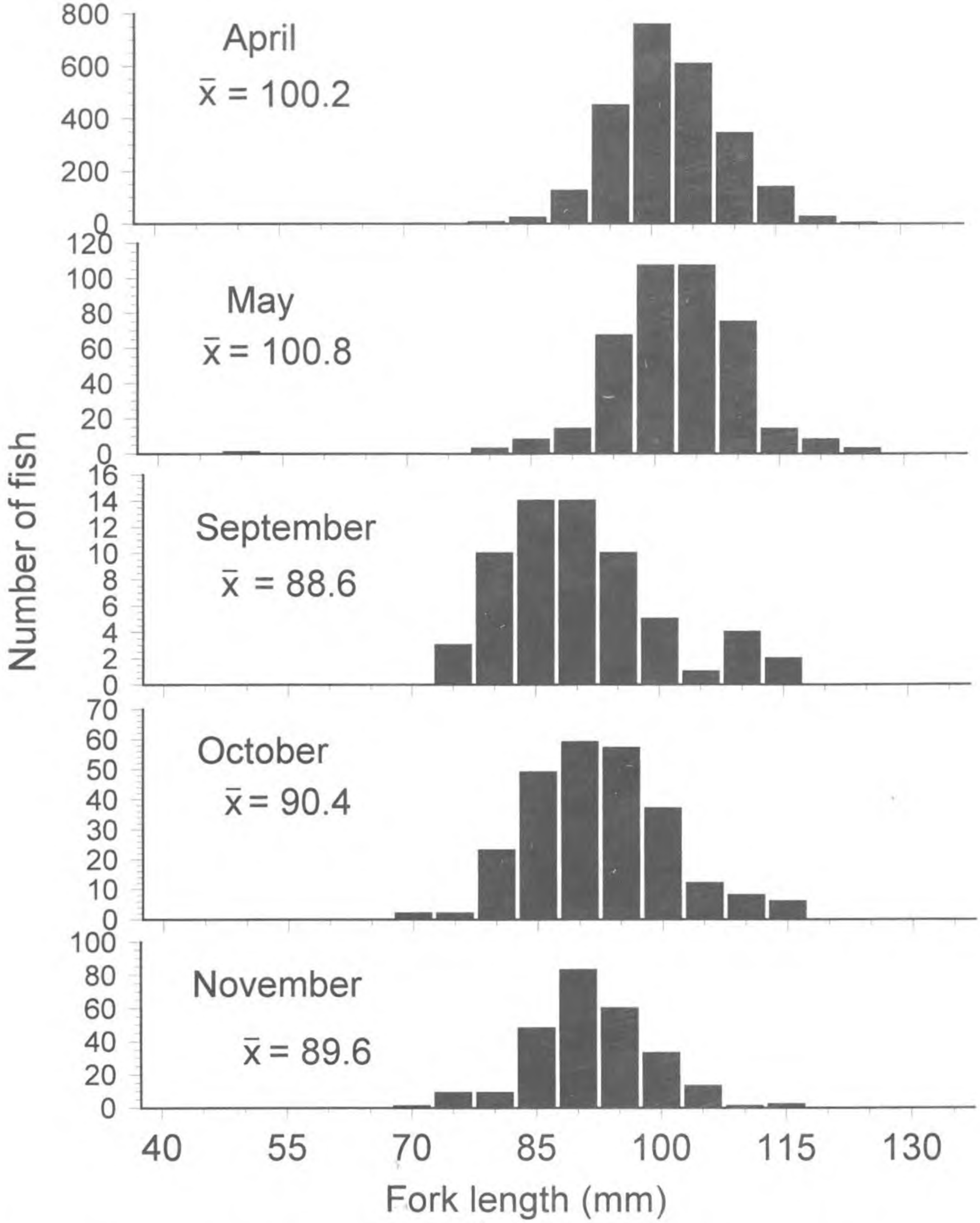


Figure 20. Length frequencies of juvenile chinook salmon emigrating from the Chewack River, 1993 (J. Hubble, YIN, personal communication).

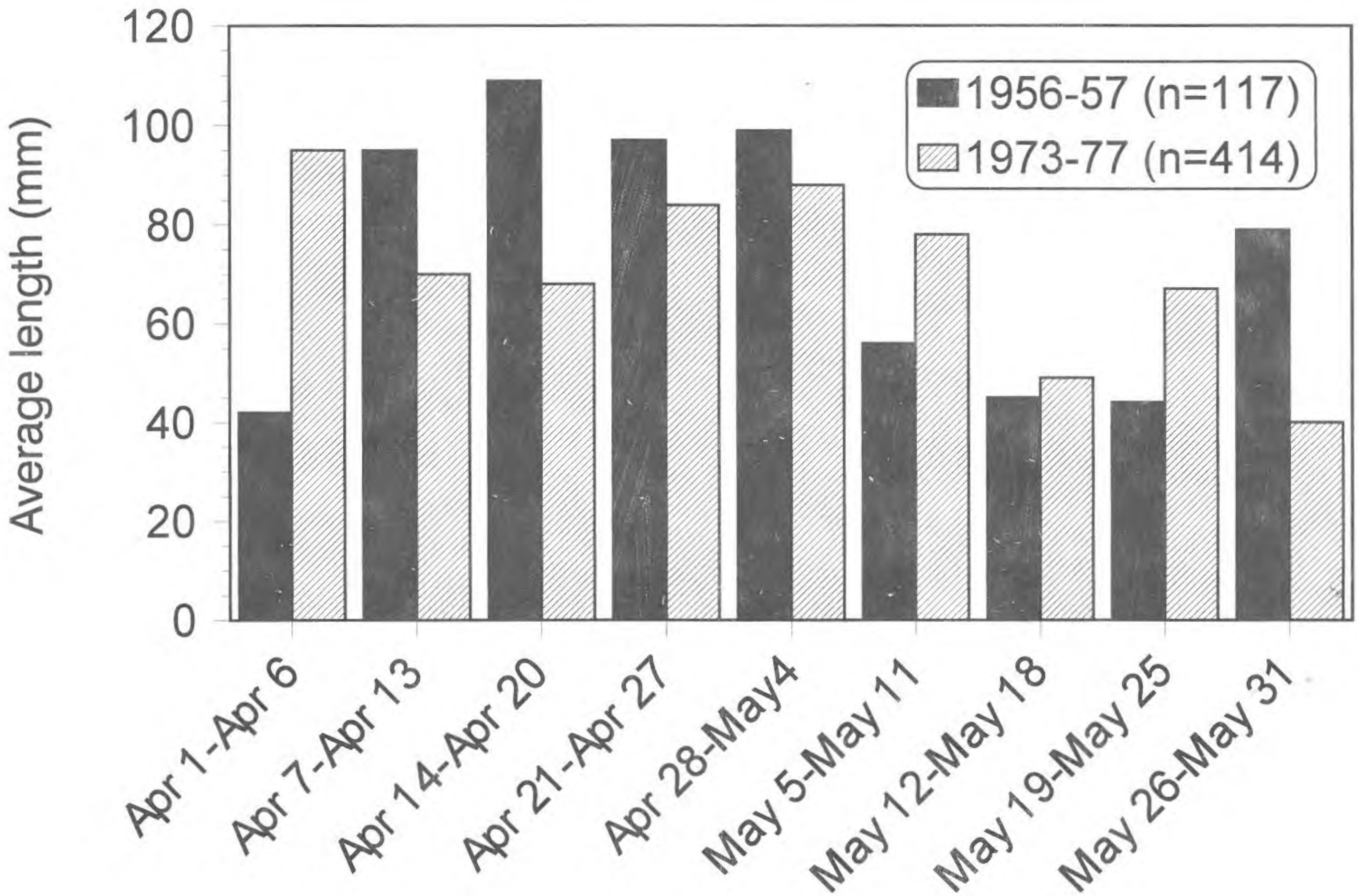


Figure 21. Average length of juvenile chinook sampled at Rock Island Dam cooling water screens, 1956, 1957 (Edson 1958) and 1973-1977 (Chelan PUD, unpublished data).

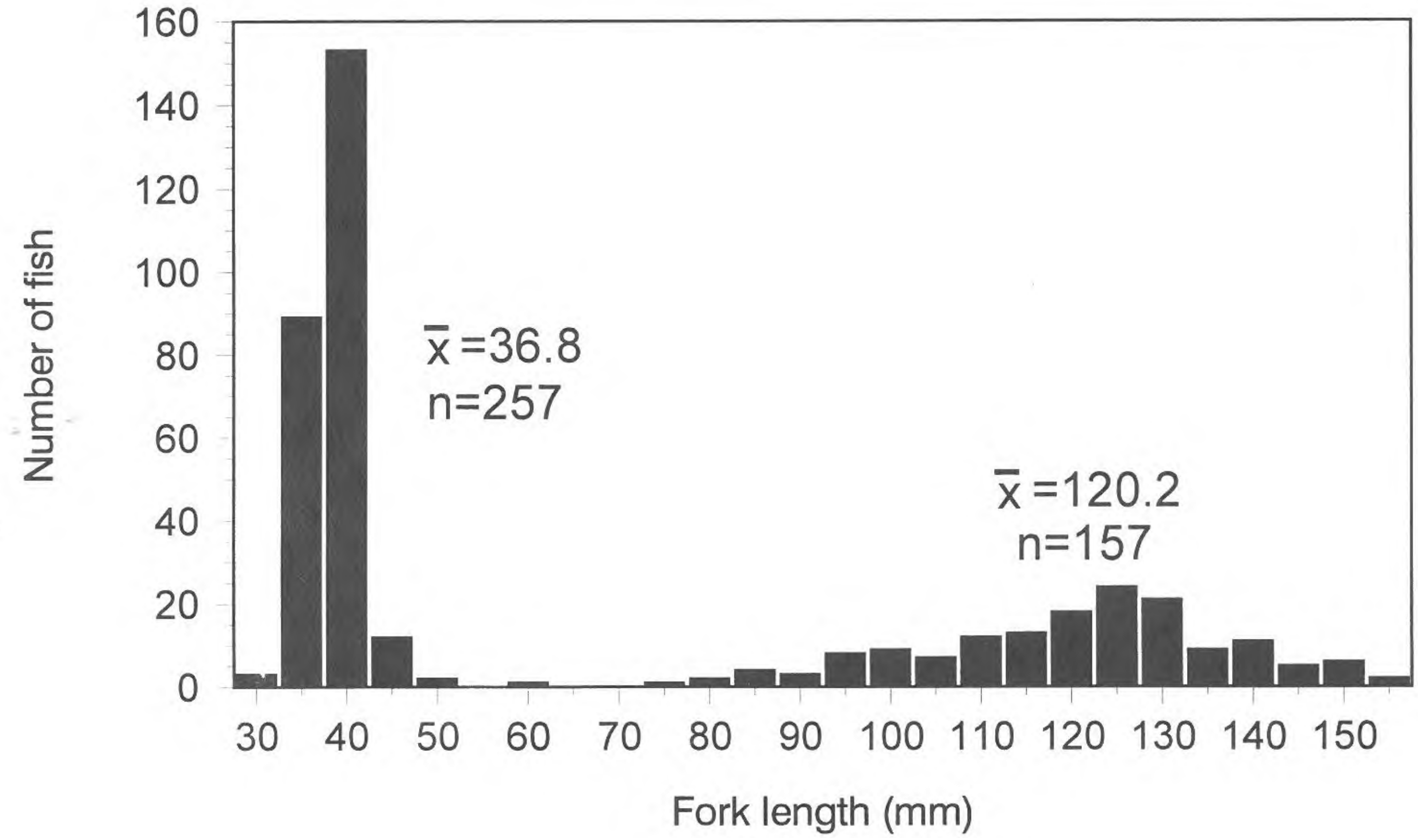


Figure 22. Length frequency of juvenile chinook captured at Rock Island Dam, April and May, 1973-1977, from the water cooling screens (Chelan PUD, unpublished data).

Known hatchery fish excluded.

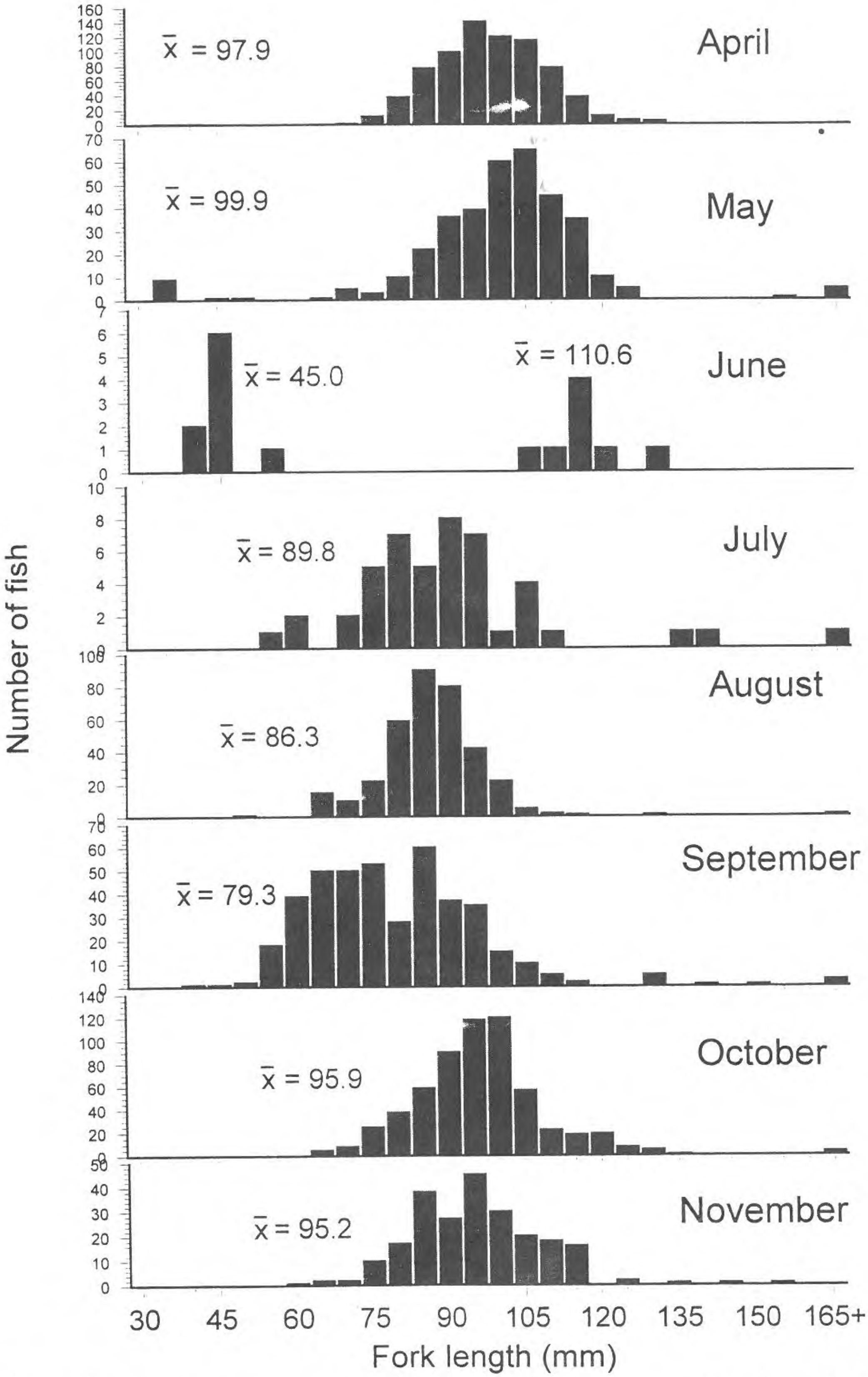


Figure 23. Length frequencies of juvenile chinook salmon emigrating from the Naches River, Yakima River basin, 1985 (recreated from Fast et al. 1986a).

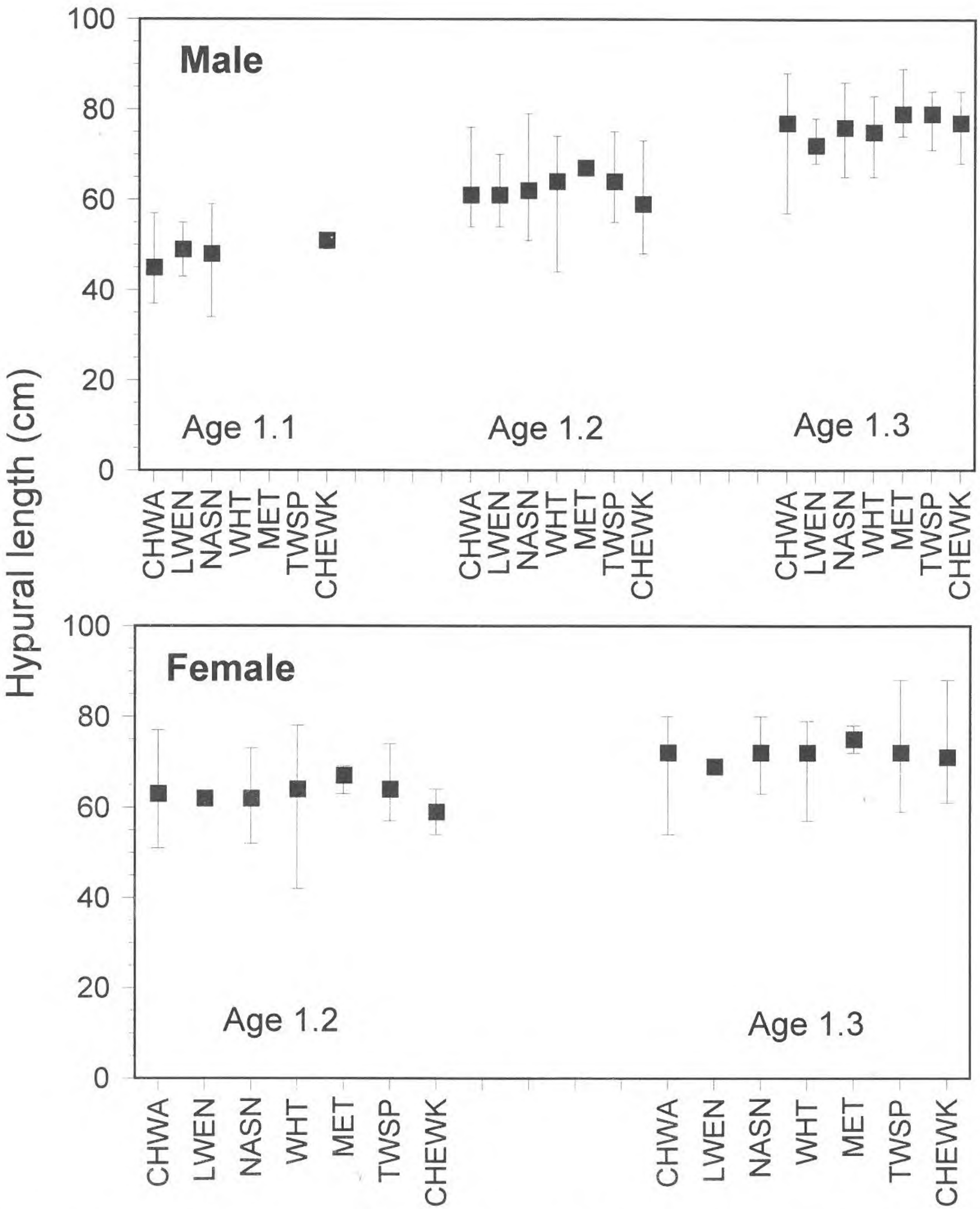


Figure 24. Length at age comparison for spring chinook from the Chiwawa (CHWA) River, Little Wenatchee (LWEN) River, Nason (NASN) Creek, White (WHT) River, Methow (MET) River, Twisp (TWSP) River, and Chewack (CHEWK) River collected from spawning grounds between 1986 and 1993 (data from Chelan PUD).

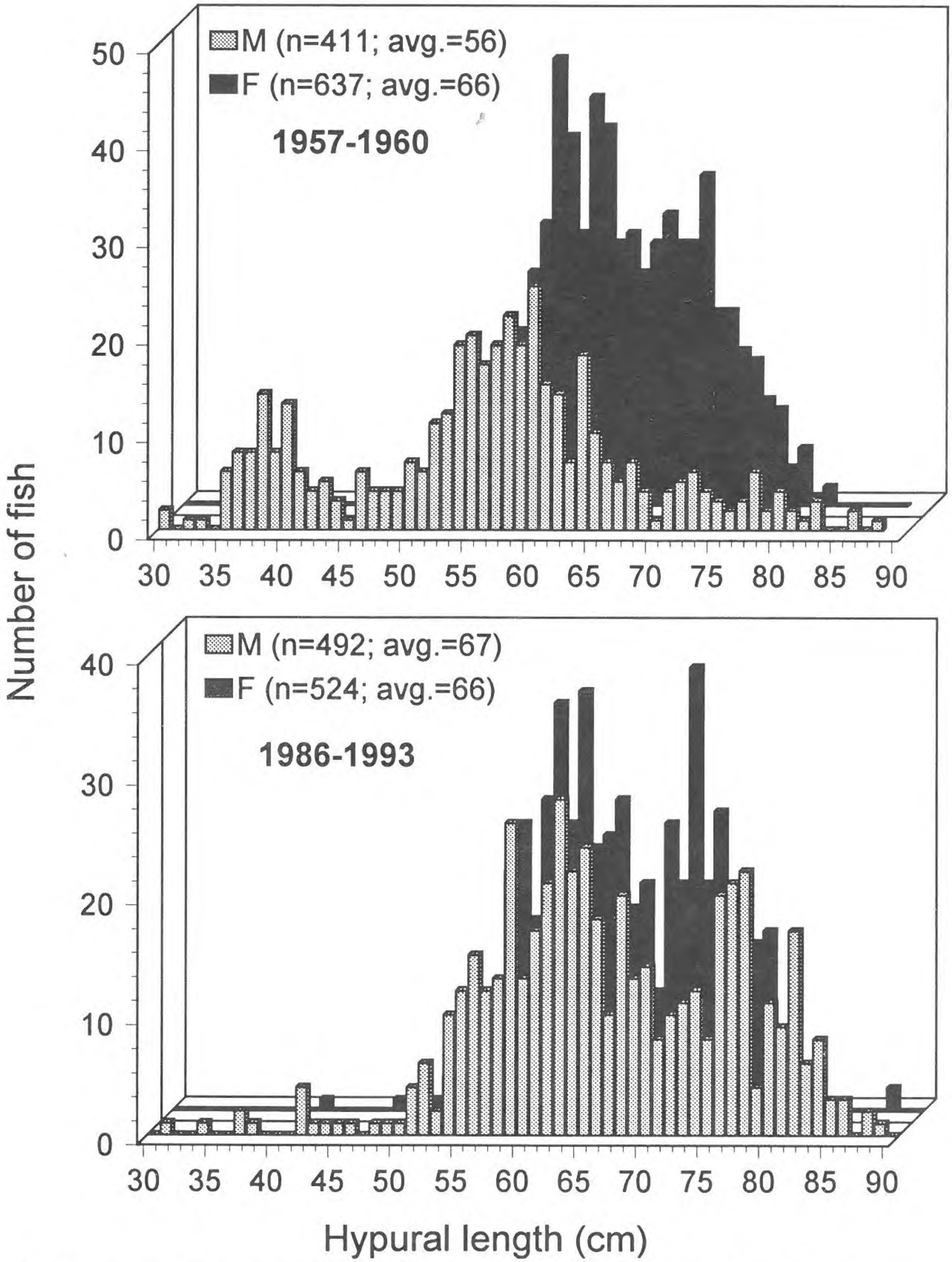


Figure 25. Comparison of the length frequency distribution of spring chinook sampled in the tributaries of the mid-Columbia River basin from 1957-1960 (French and Wahle 1965), and 1986-1993 (present report).

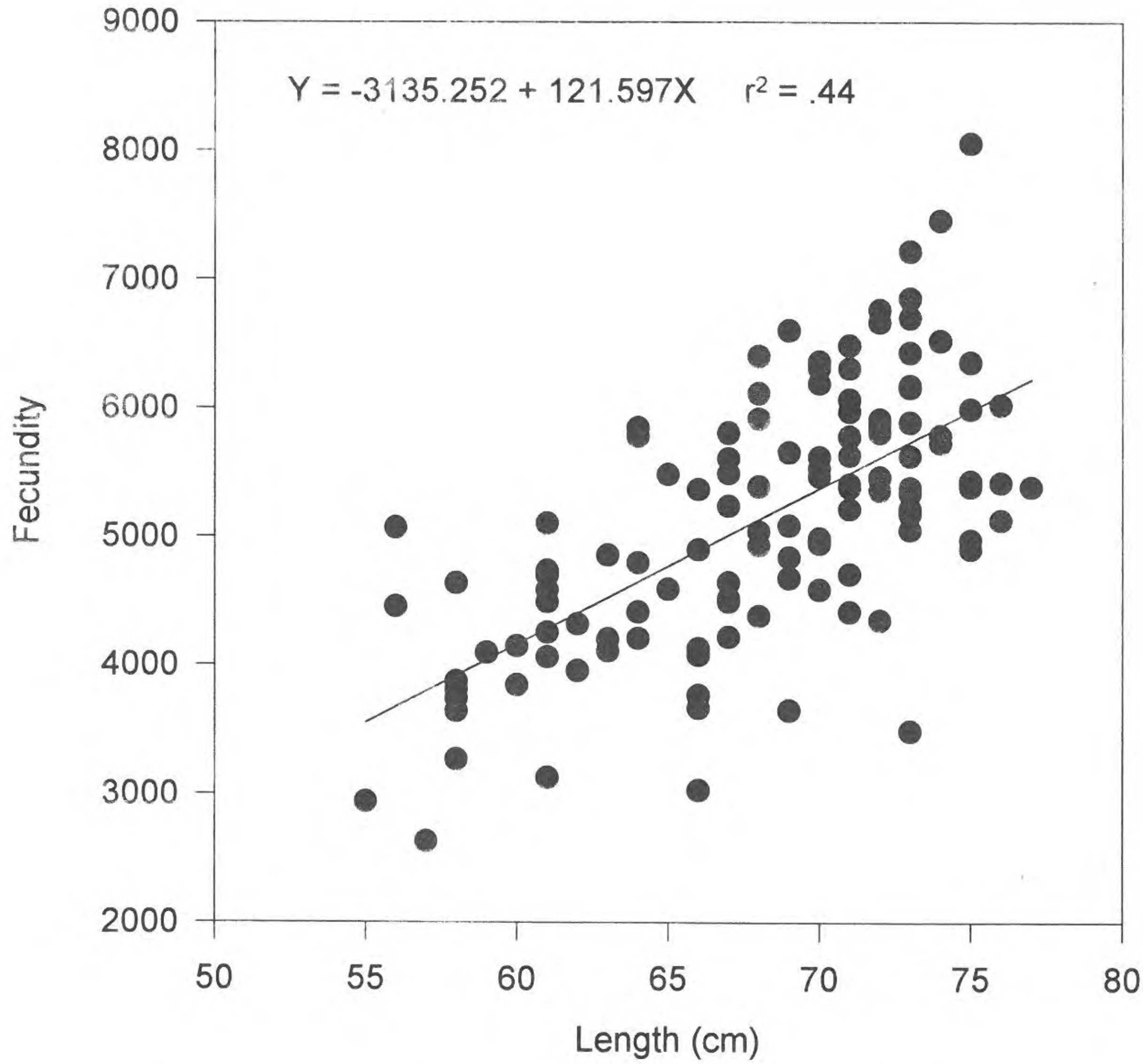


Figure 26. Fecundity-length relationship of spring chinook salmon sampled from the Methow River basin, 1992-1994 (H. Bartlett, WDFW, personal communication).

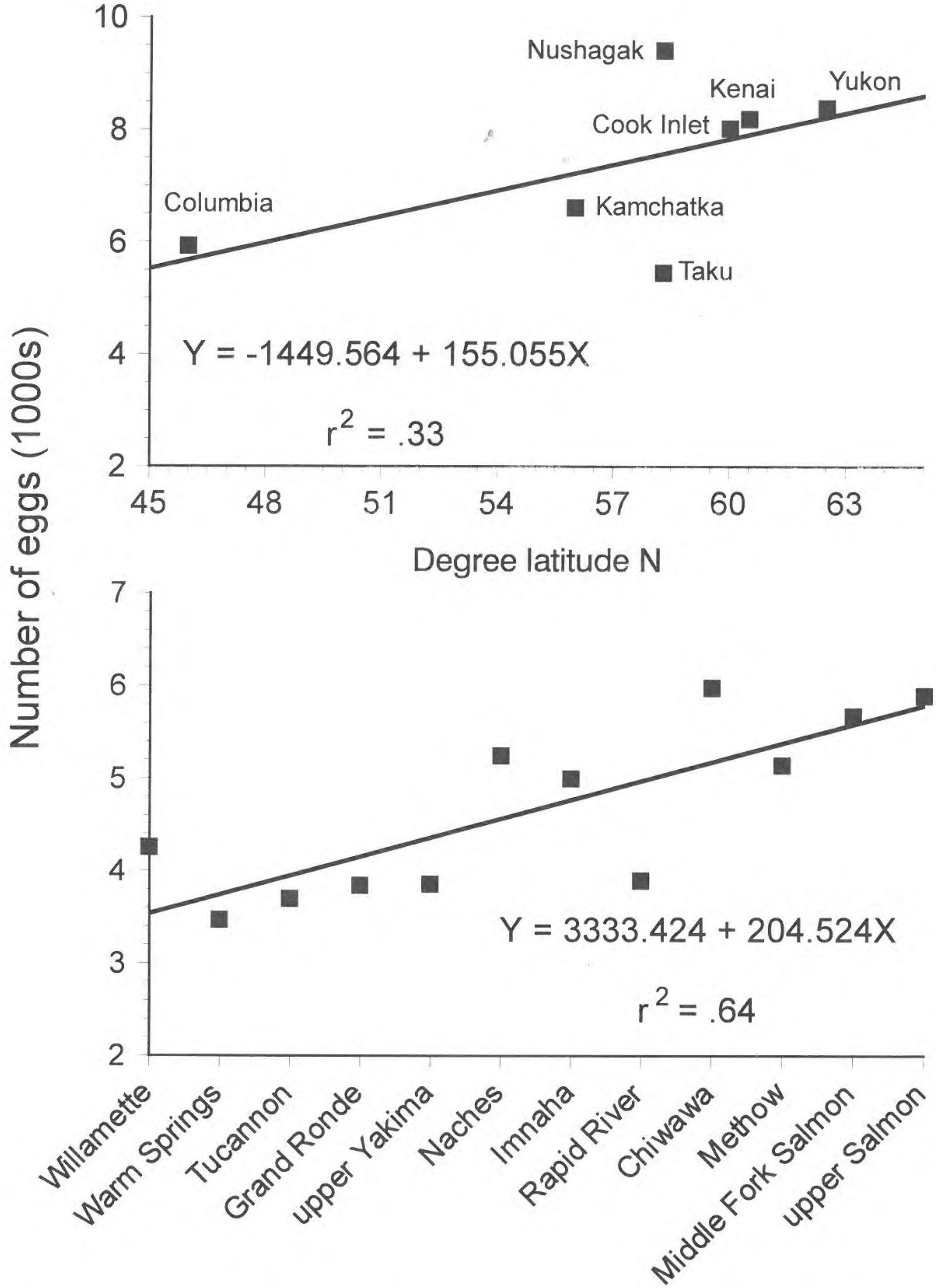


Figure 27. Fecundity in relation to degrees of latitude for various chinook populations (top graph) (see Healey and Heard 1984), and in relation to elevation in the Columbia River (bottom graph)

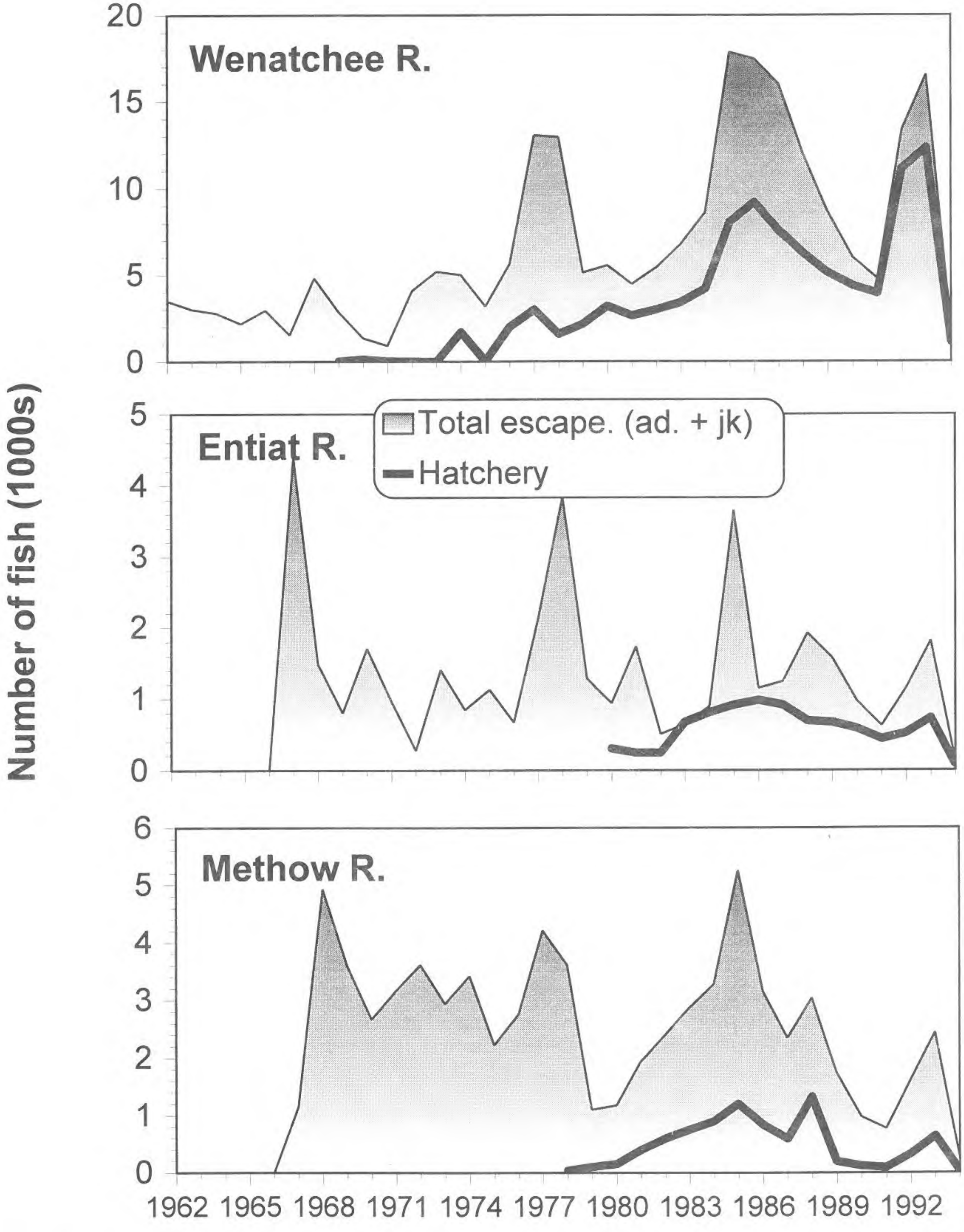


Figure 28. Estimated run composition based on dam counts, Mullan (1987), Pettit (1995), and B. Kelly, USFWS, personal communication.

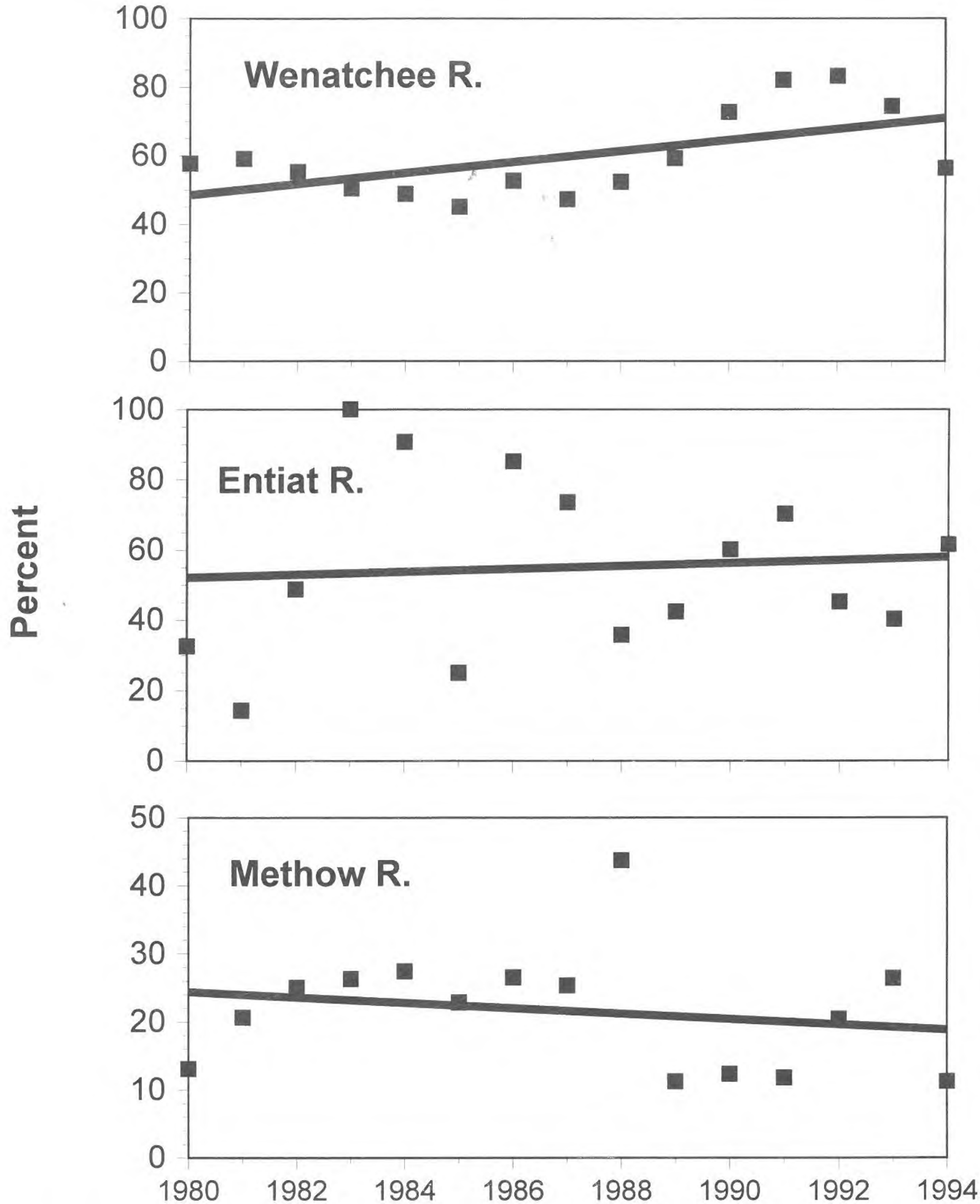


Figure 29. Estimated percent of hatchery fish returning to mid-Columbia tributaries, based on dam counts, sport and tribal take, returns to hatcheries, and natural spawning (Mullan (1987); Pettit (1995); and B. Kelly, USFWS, personal communication).

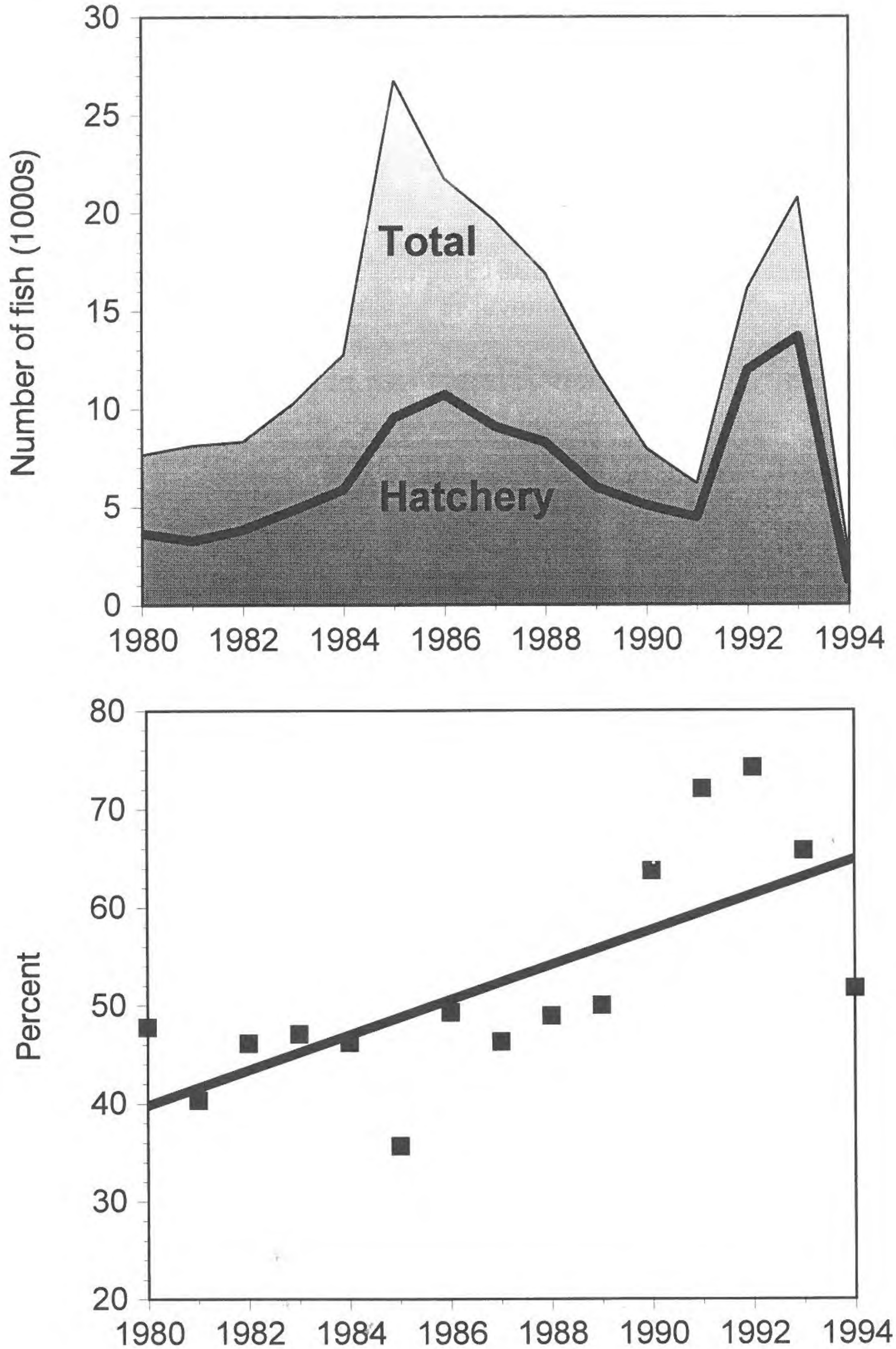


Figure 30. The total number of spring chinook passing Rock Island Dam and the percent contribution of hatchery fish to the run, 1980-1994 (Chelan PUD, unpublished data; Pettit 1995; B. Kelly, personal communication).

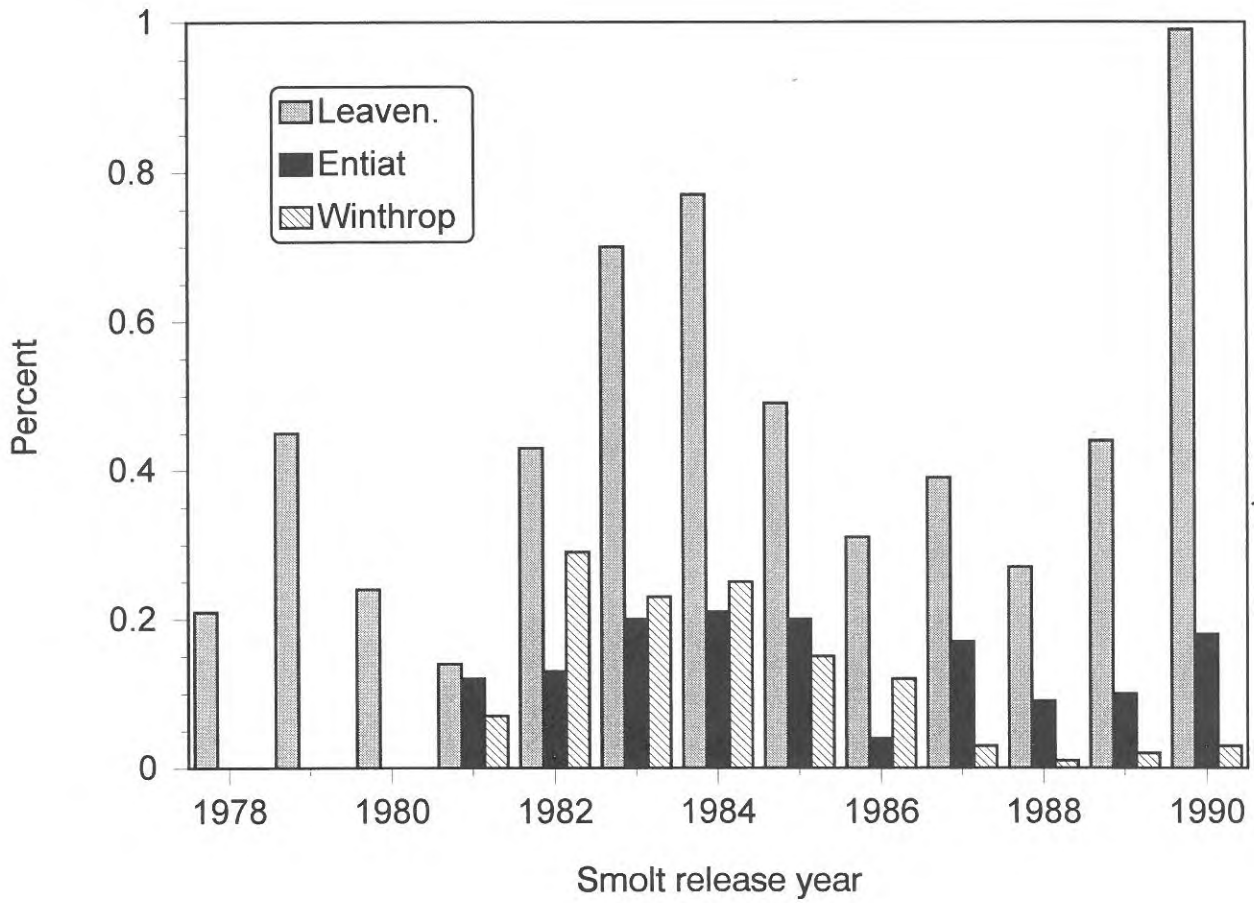


Figure 31. Estimated smolt-to-adult survival of smolts released from the Leavenworth, Entiat, and Winthrop hatcheries (corrected for interdam loss, incidental in-river, and ocean harvest; see text and tables for detail).

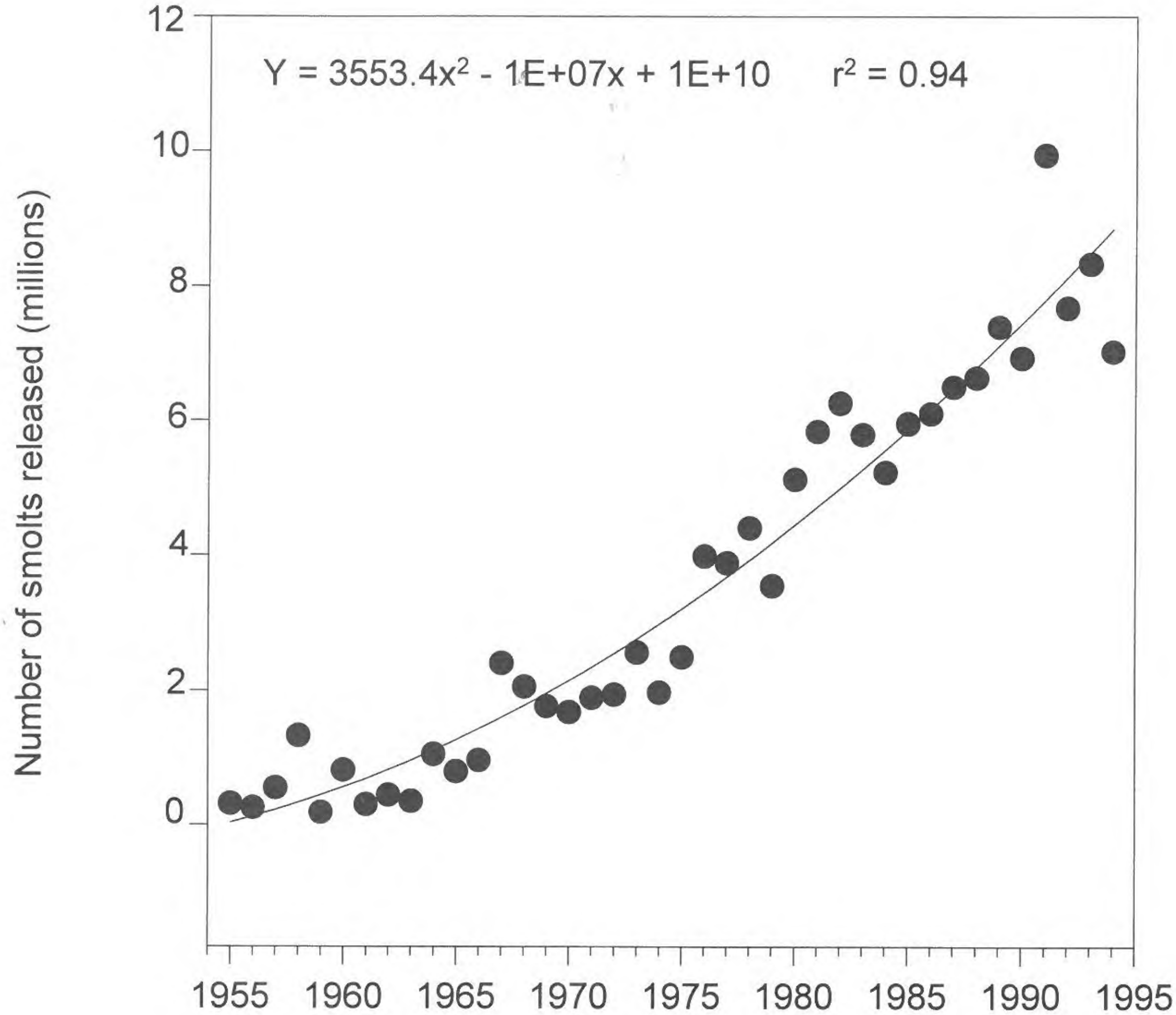


Figure 32. Smolt releases from the mid-Columbia region, 1955-1994 (see Appendix 1-4).

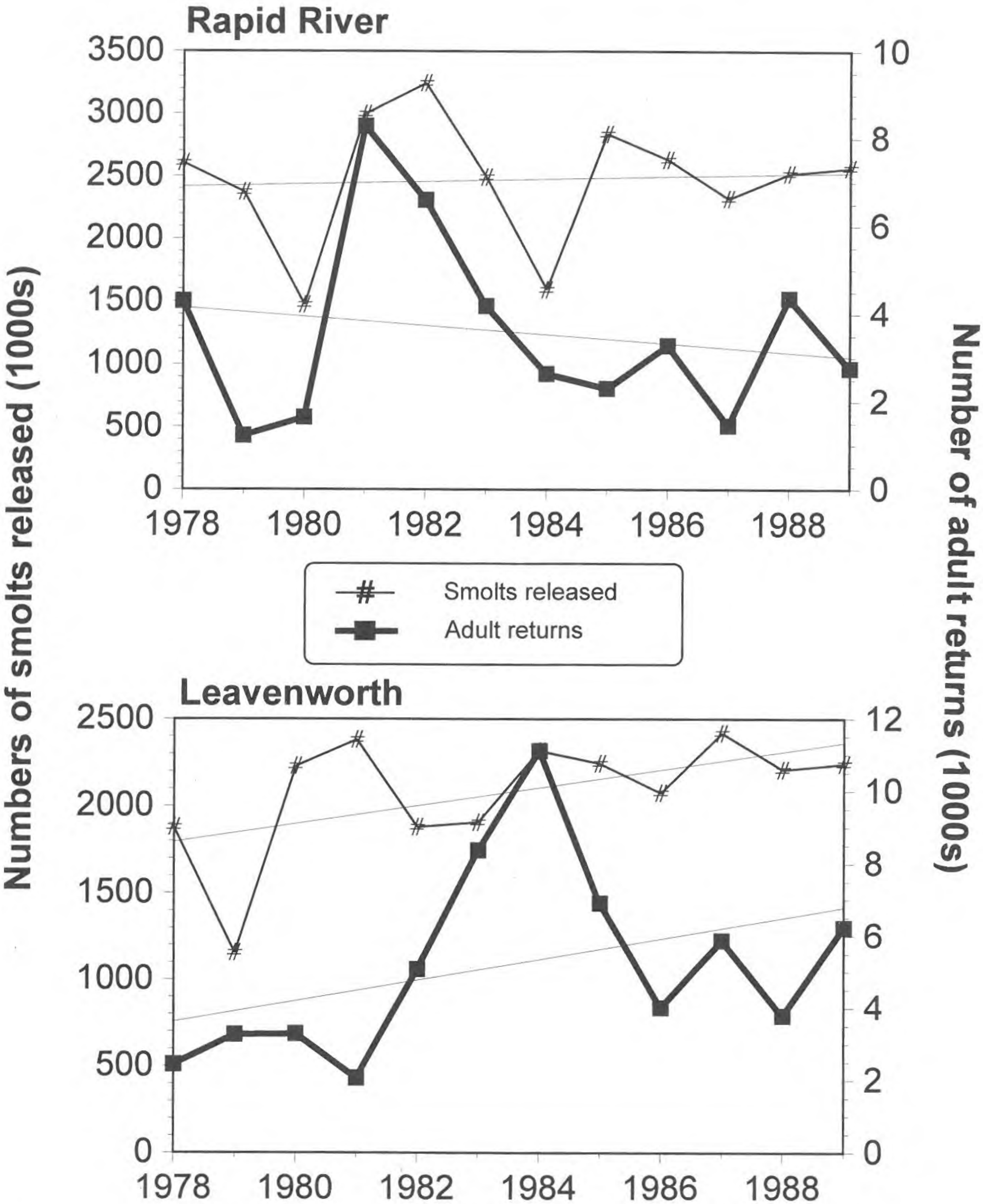


Figure 33. Comparison of smolt releases and subsequent adult returns from the Rapid River and Leavenworth hatcheries (Levendofske et al. 1992).

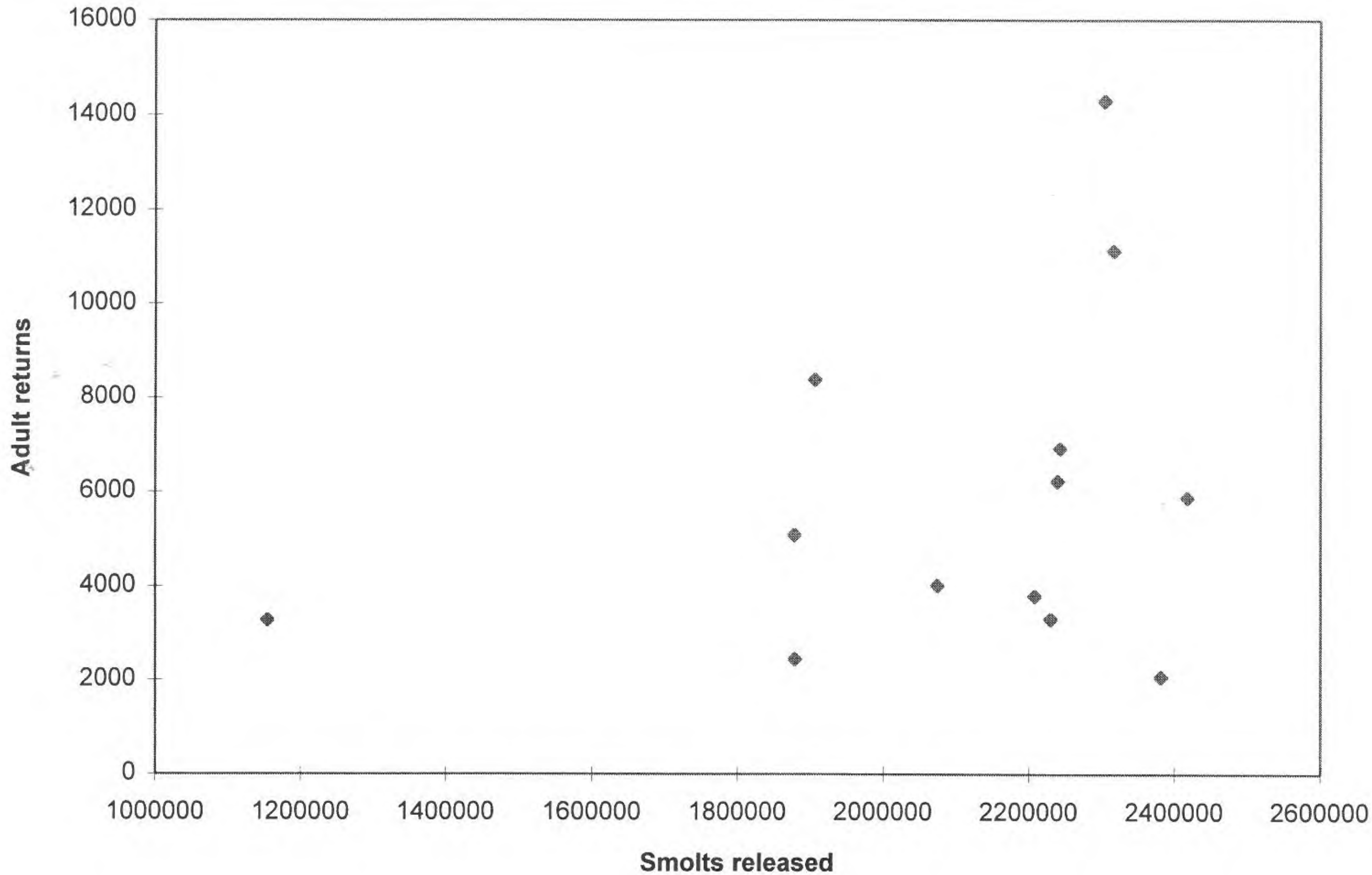


Figure 34. Plot of adult returns per release for Leavenworth NFH, 1978-1990.

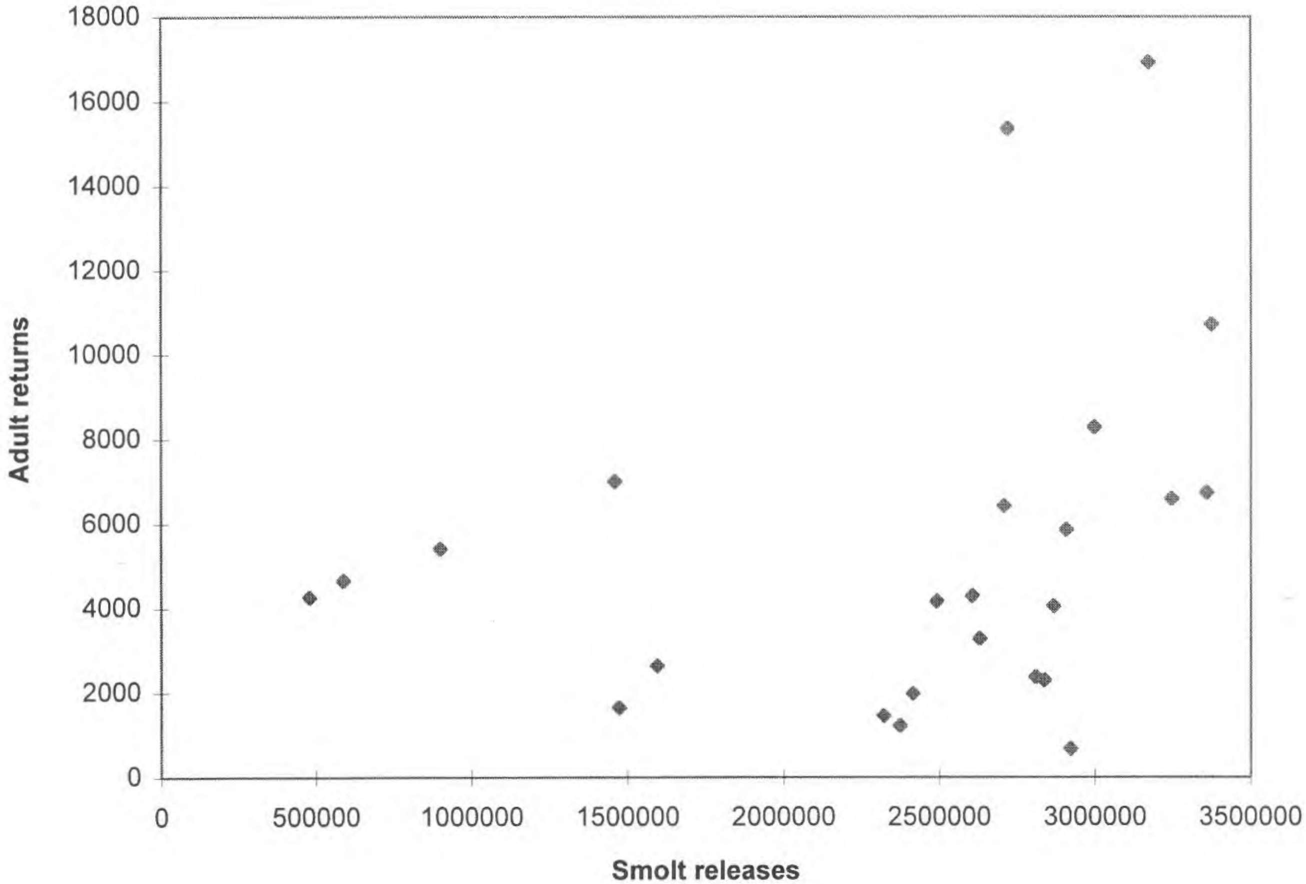


Figure 35. Plot of adult returns per release for the Rapid River Hatchery, 1964-1987 (Levendofske et al. 1992).

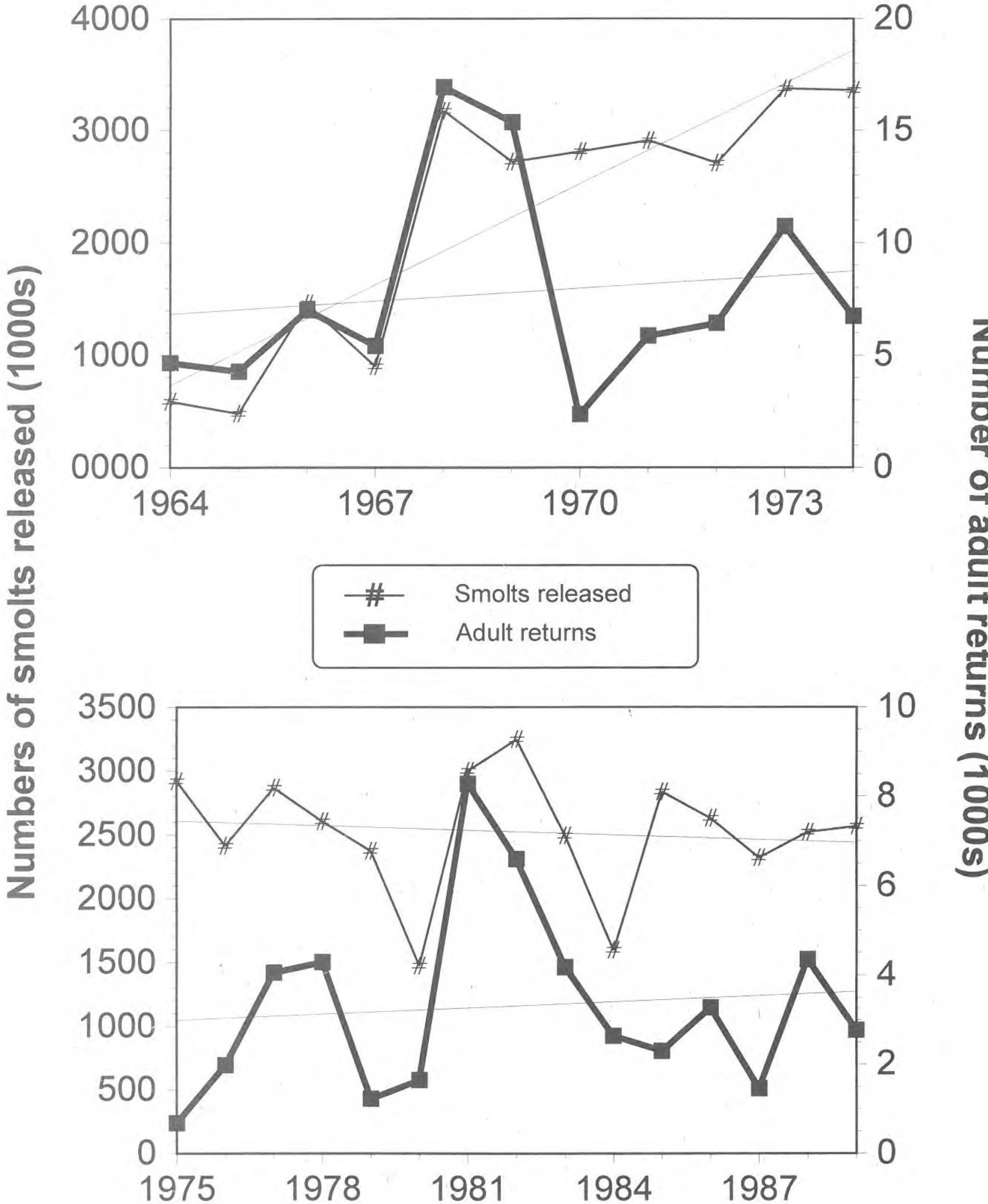


Figure 36. Comparison of smolt releases and adult returns from the Rapid River fish hatchery (Levendofske et al. 1992; R. Steiner, IDFG, personal communication).

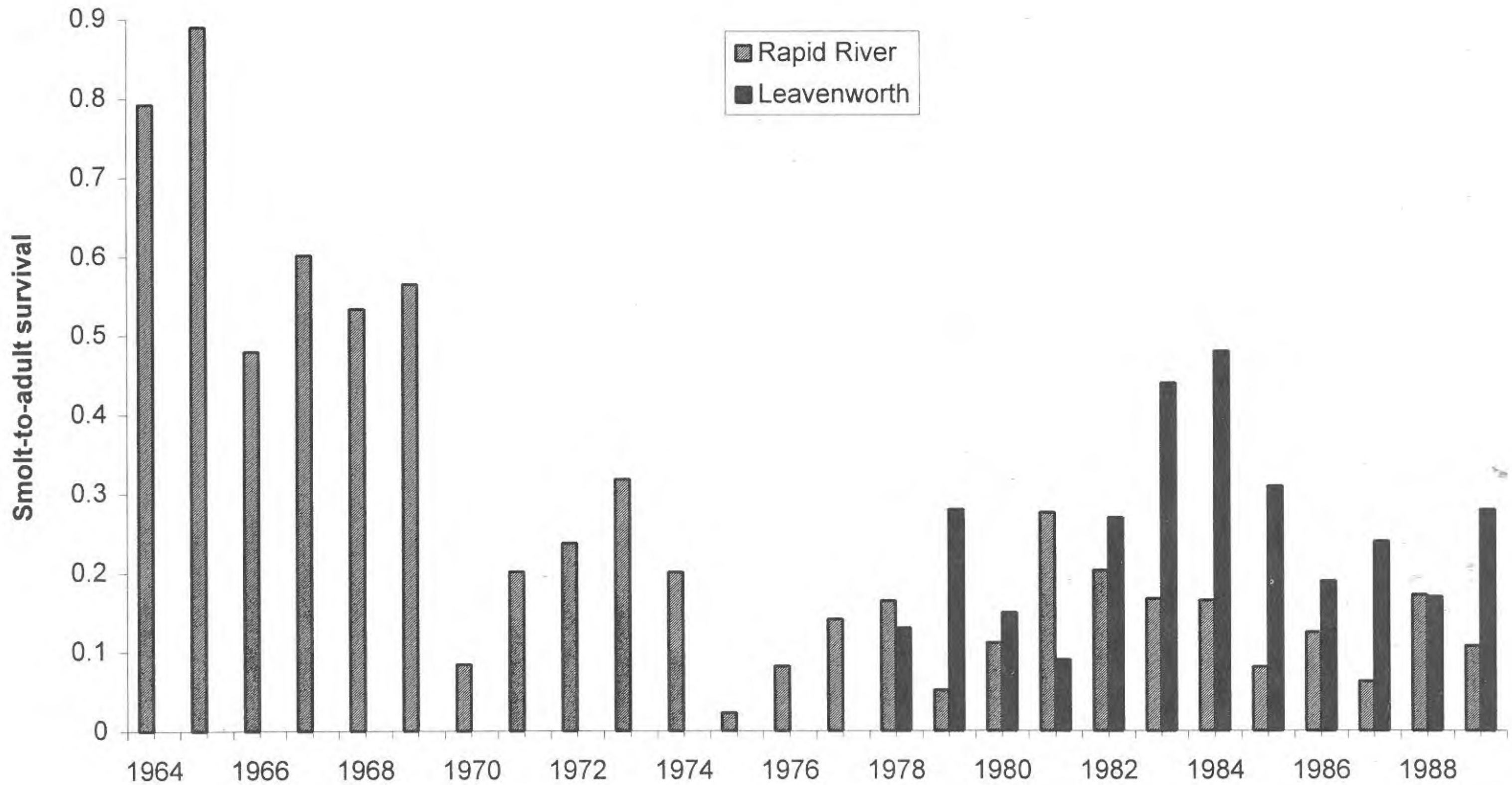


Figure 37. Comparison of the estimated smolt-to-adult survival of fish released from the Rapid River and Leavenworth hatcheries (estimate based on adult returns to the hatchery, or natal river; Levendofske et al. 1992; Pettit 1995; Table 14, this report).

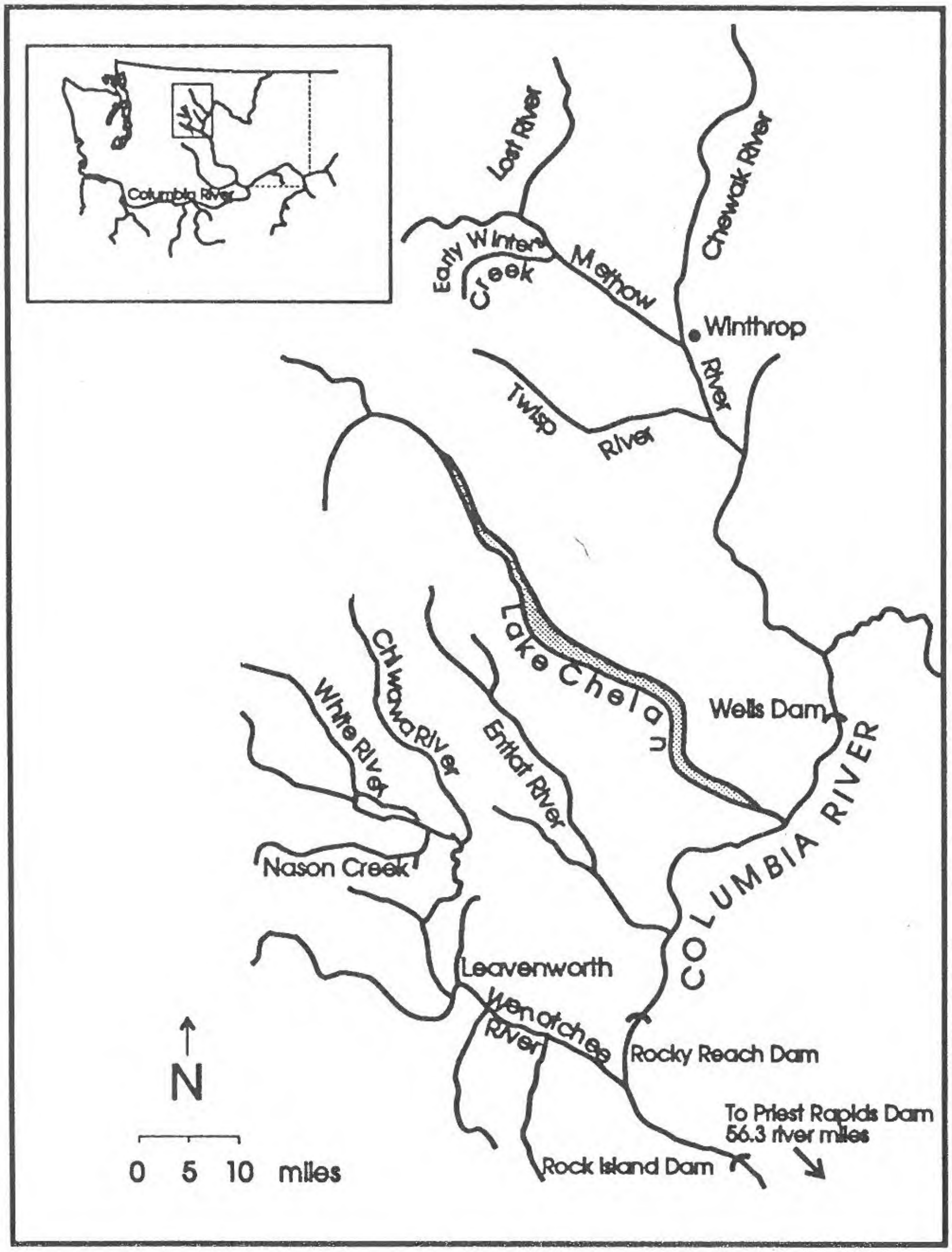


Figure 38. Location of areas in which sampling occurred, or which are discussed in analysis of genetics of mid-Columbia spring chinook.

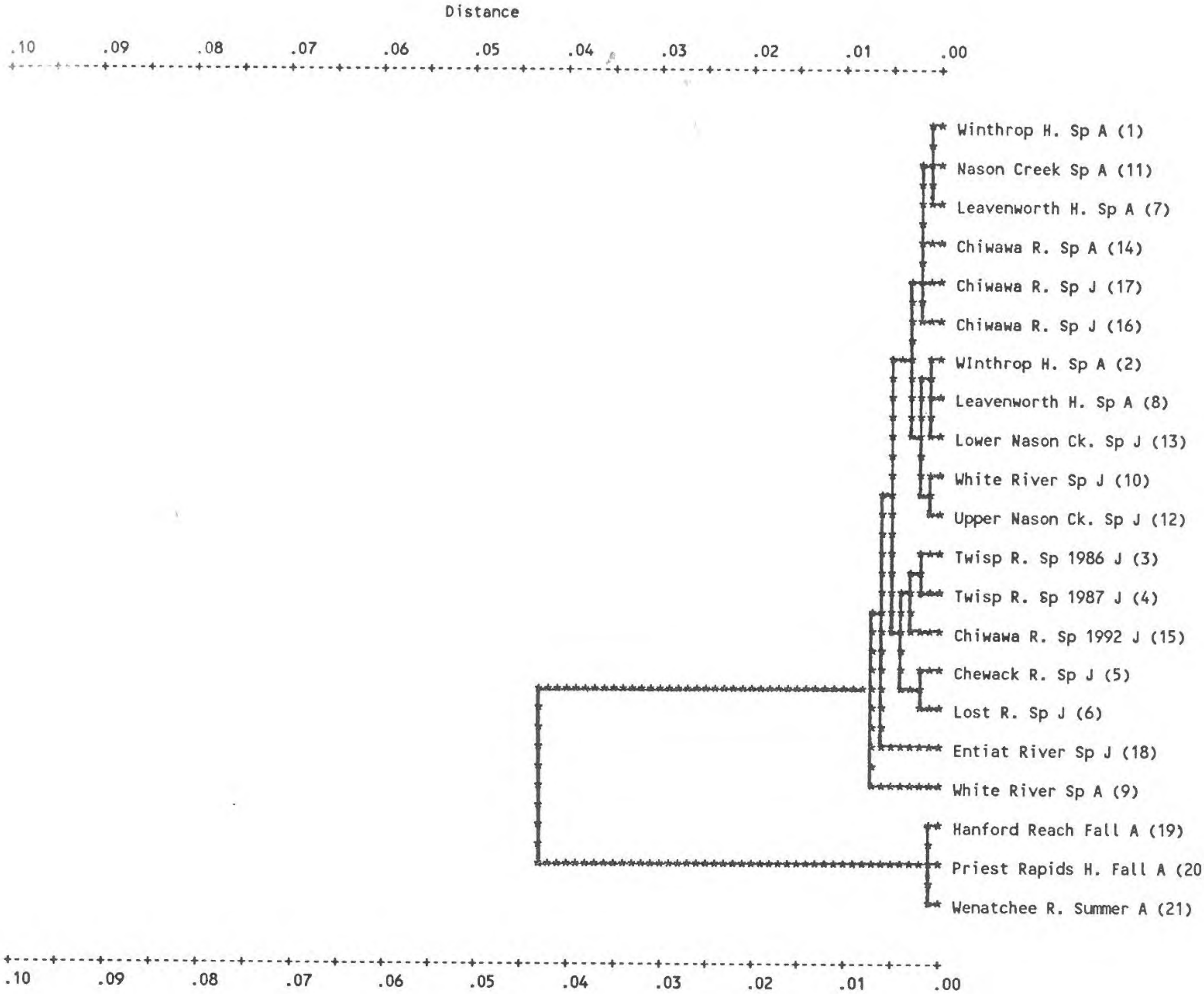


Figure 39. Dendrogram of pairwise genetic distances (Nei 1972) for compatible allele frequency data (16 loci, 21 collections) presented in Hershberger et al. (1988) and Utter et al. (in press).

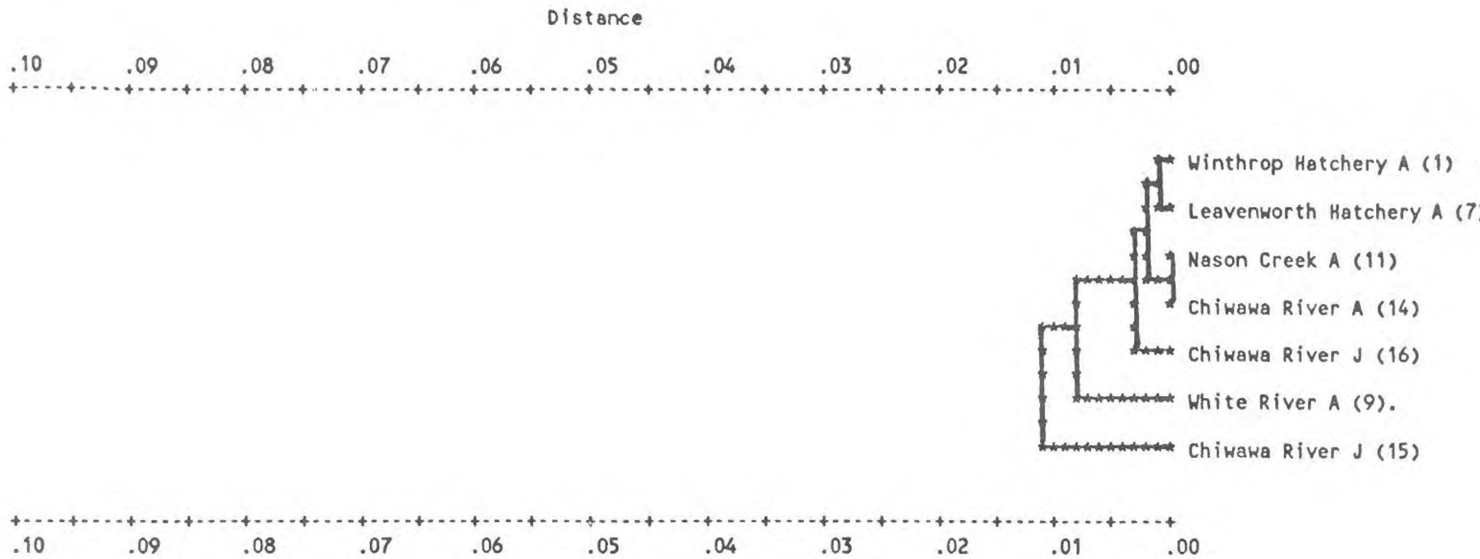


Figure 40. Dendrogram of pairwise genetic distances (Nei 1972) for five polymorphic loci excluded from Figure 38, involving seven spring-run chinook salmon populations included in Utter et al. (in press).

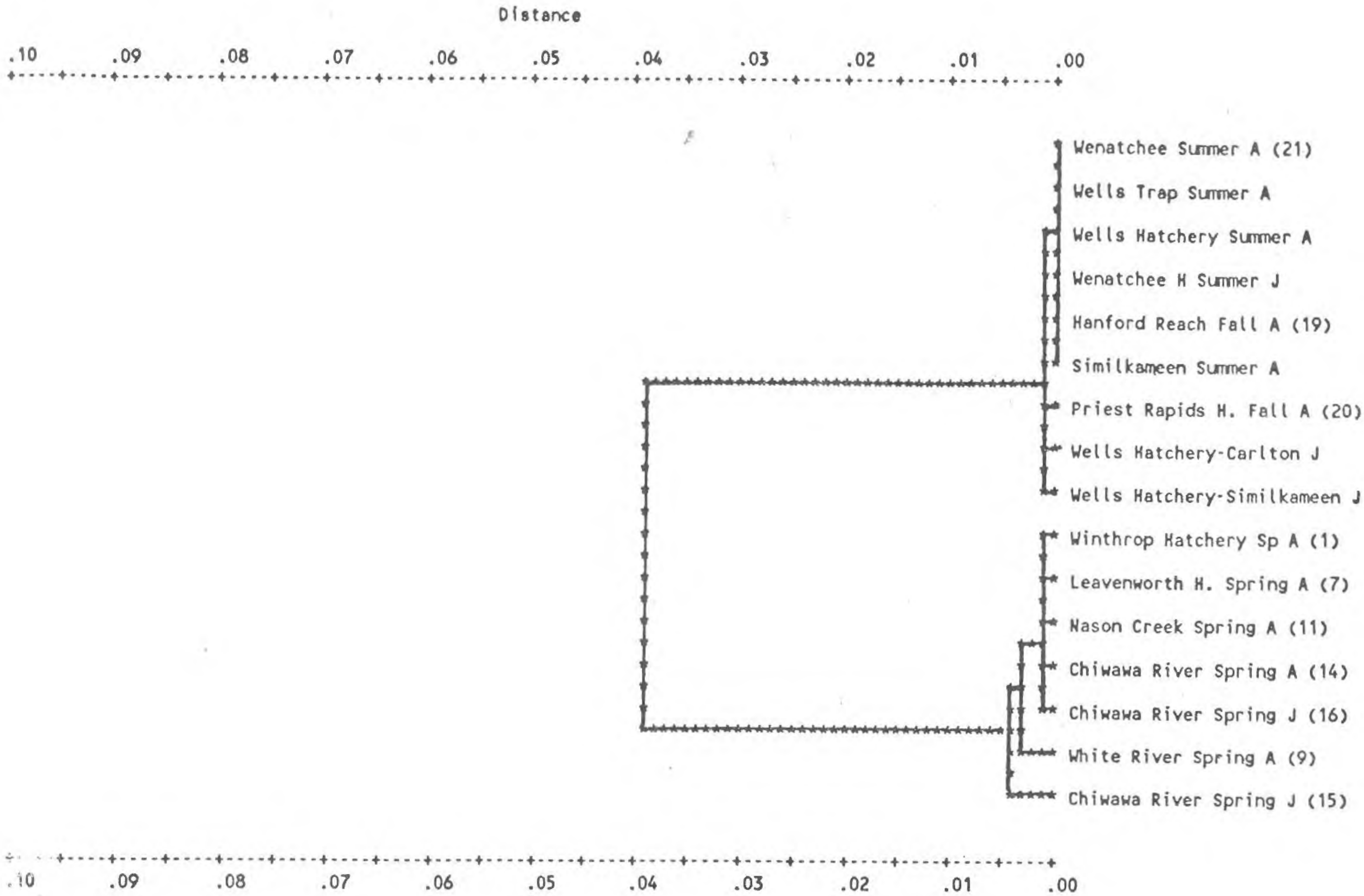


Figure 41. Dendrogram of pairwise genetic distances (Nei 1972) over 33 loci for seven spring-run and nine summer/fall-run populations of the Columbia River upstream from the confluence of the Yakima River (from Utter et al., in press)

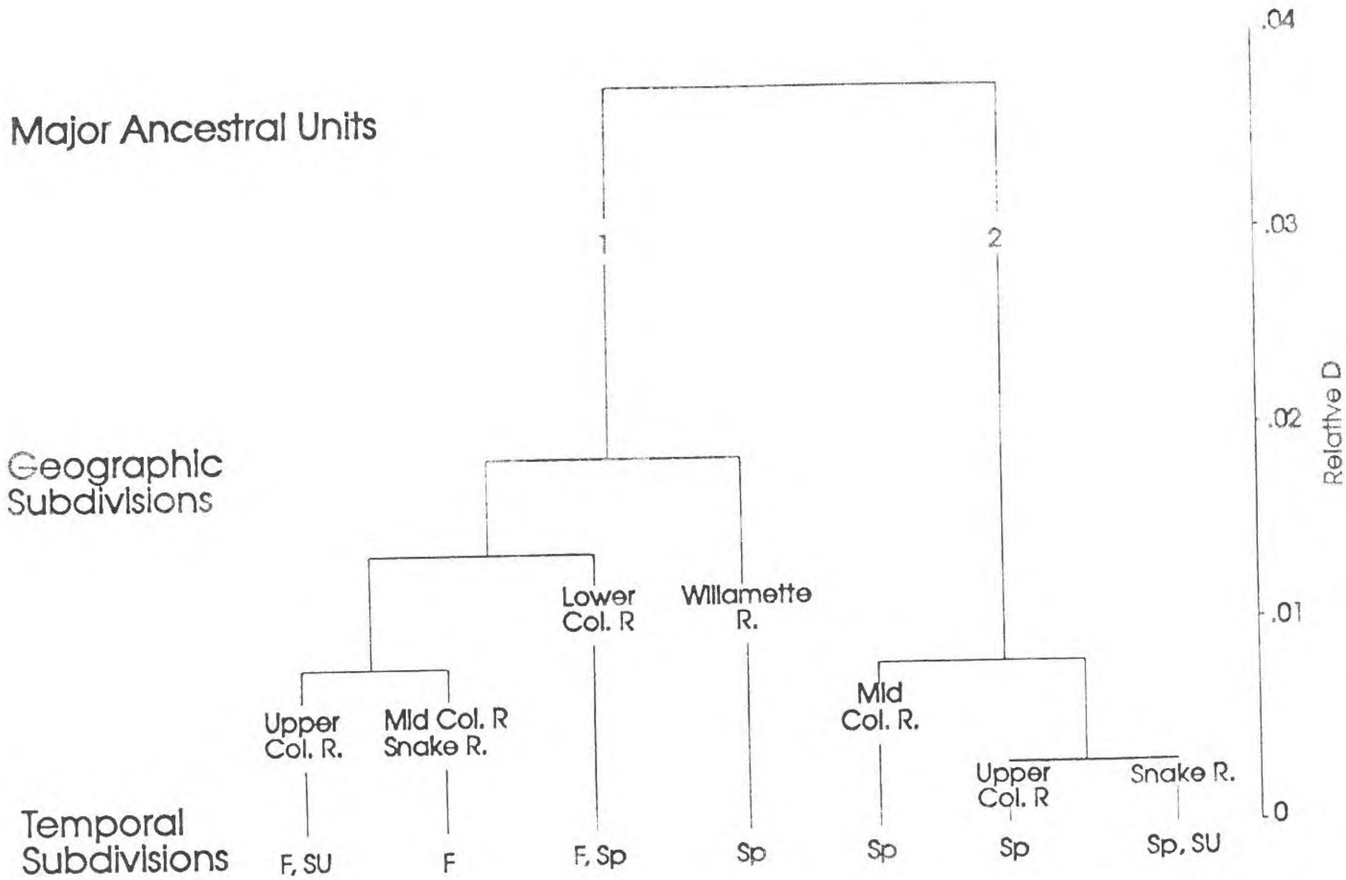


Figure 42. UPGMA dendrogram indicating the hierarchical subdivision of chinook salmon populations of the Columbia River. From Utter et al. (in press) as modified from Waples et al. (1991a). Based on pairwise measurements of genetic distance at 21 polymorphic loci. Multiple temporal subdivisions (Sp = spring-run, SU = summer-run, F = fall-run) included within some geographic subdivisions indicate the absence of distinguishing allele frequency patterns based on run timing. Note: designation of "upper Col. R." here refers to the area upstream from the Snake River.

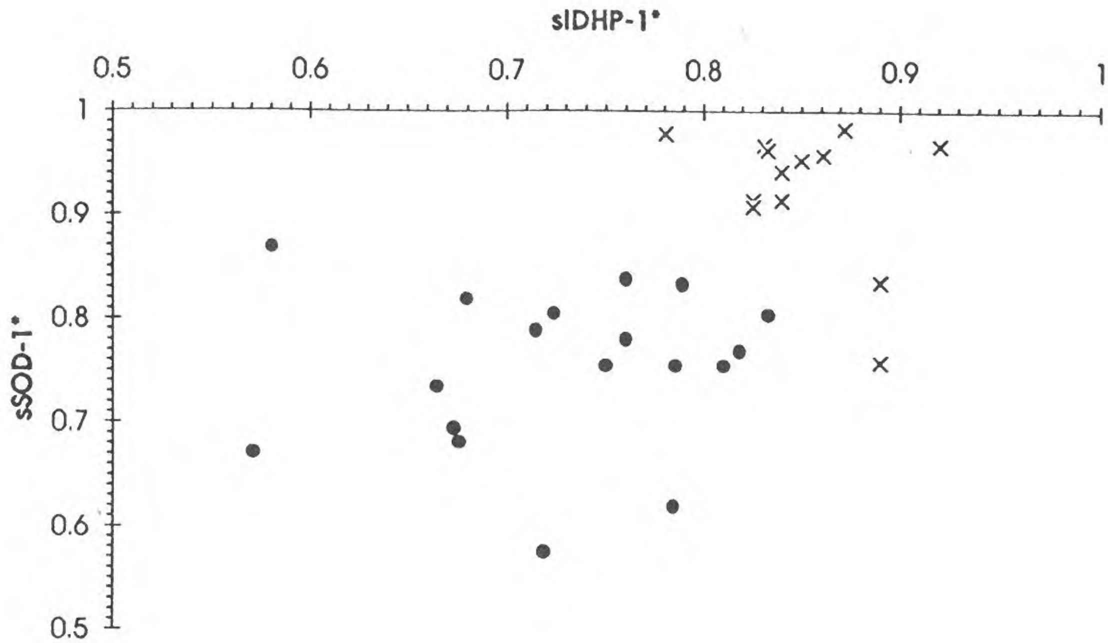


Figure 43. Plot of common allele frequencies for sSOD-1* and sIDHP-1* loci for spring-run chinook salmon collections 1 through 18 of this study (solid circles) and spring/summer-run populations of the Snake River reported in Waples et al. (1993) (indicated by X) where data are averaged for multiple collections from the same locality.

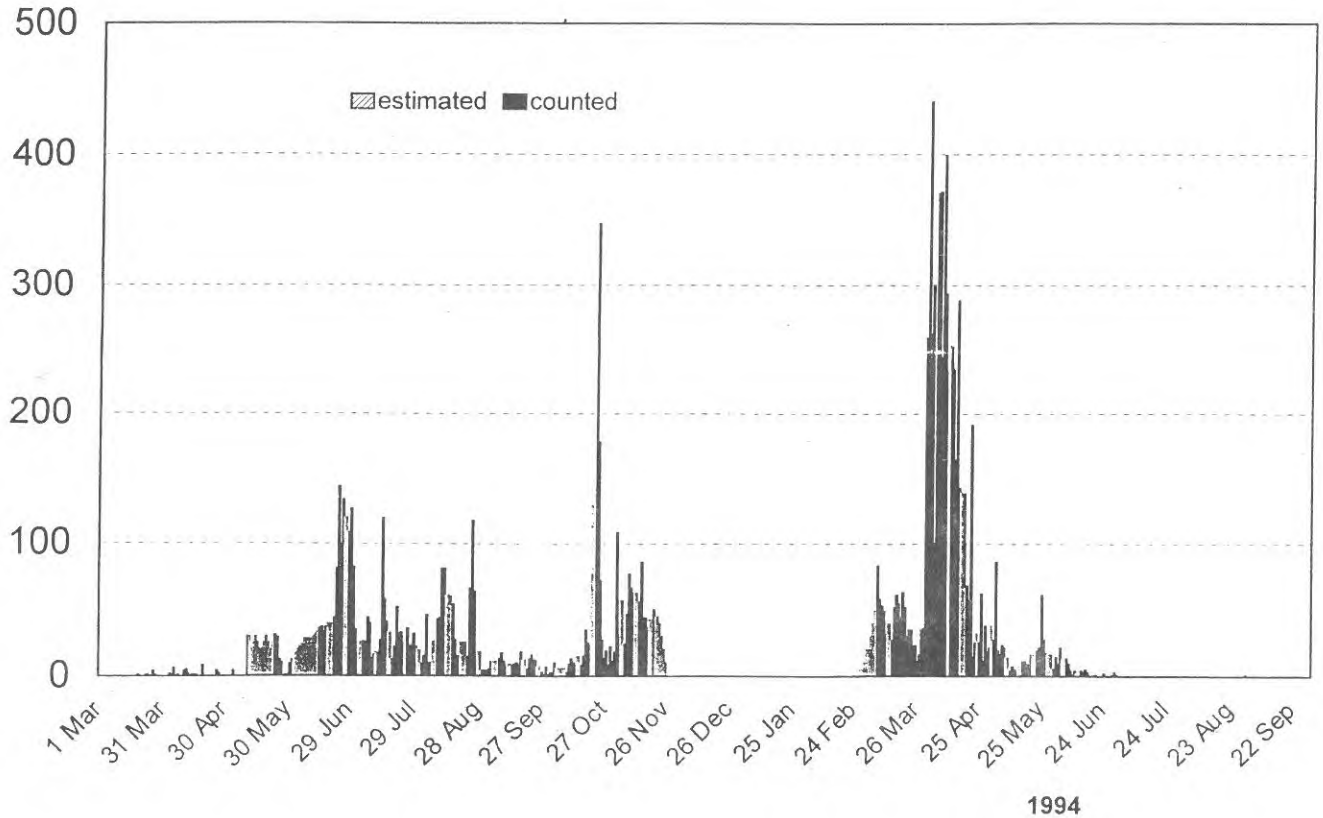


Figure 44. Numbers of spring chinook salmon trapped during 1993 and 1994 in the Chiwawa River by the Washington Department of Fish and Wildlife (Petersen, WDFW, unpublished data). No trapping occurred during most of the winter because of icing conditions.

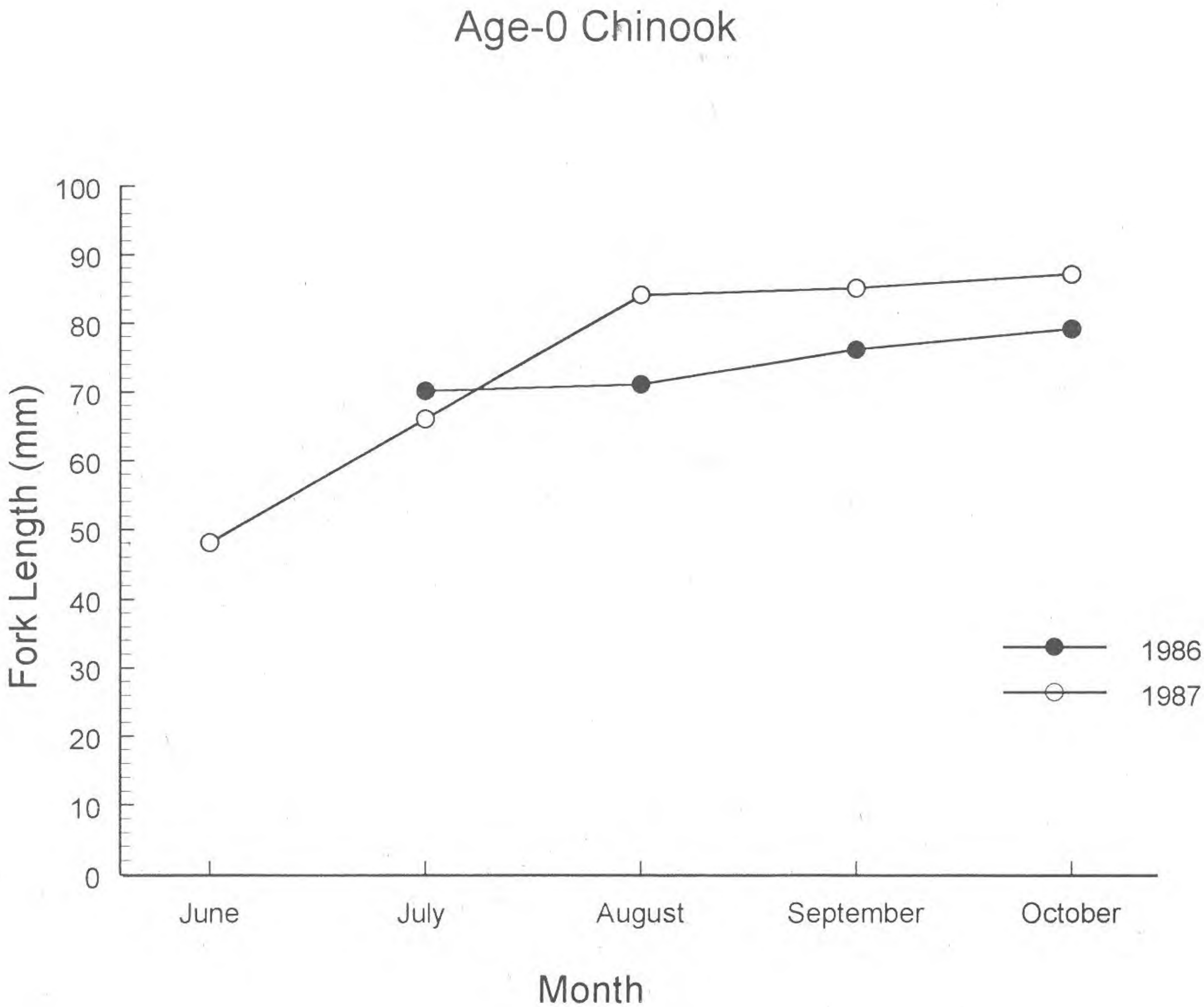


Figure 45. Mean fork lengths of juvenile chinook (mix of spring and summer/fall chinook) collected from six locations on the Wenatchee River (from Hillman and Chapman 1989).

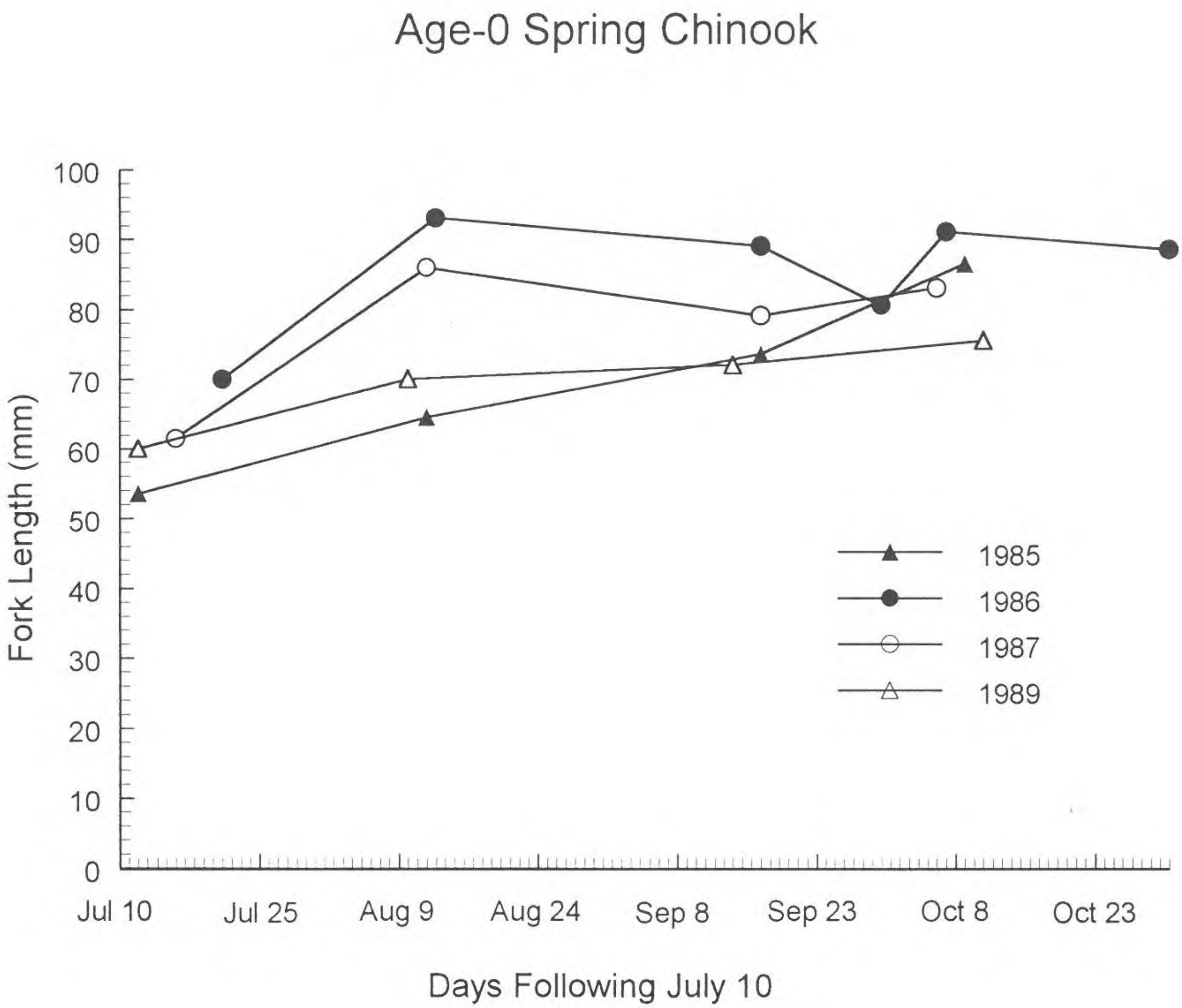


Figure 46. Mean fork lengths of juvenile spring chinook that emigrated from Icicle Creek (from Mullan et al. 1992b).

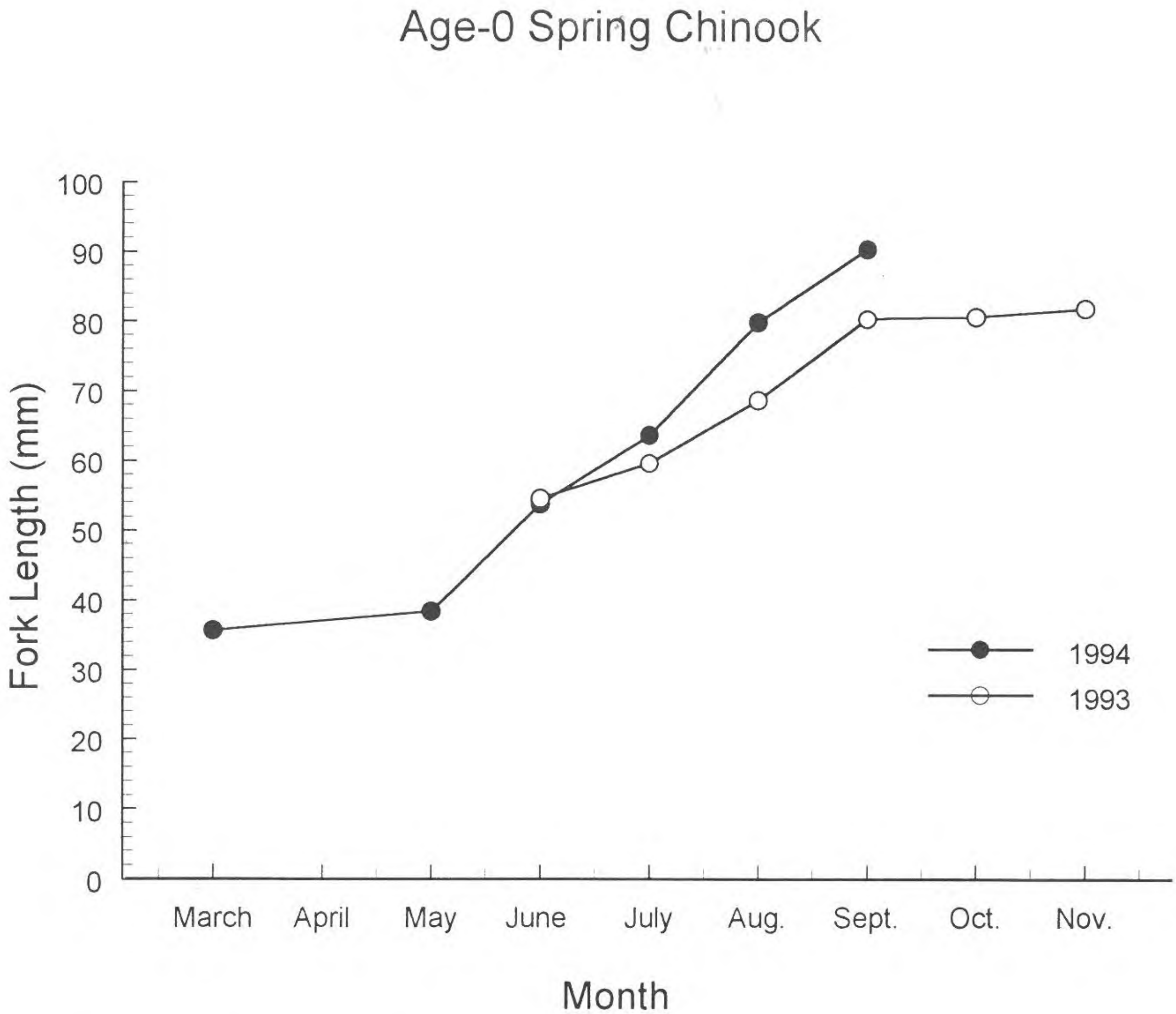


Figure 47. Mean fork lengths of spring chinook salmon that emigrated from the Chiwawa River (from Petersen et al. 1993; Petersen unpublished data).

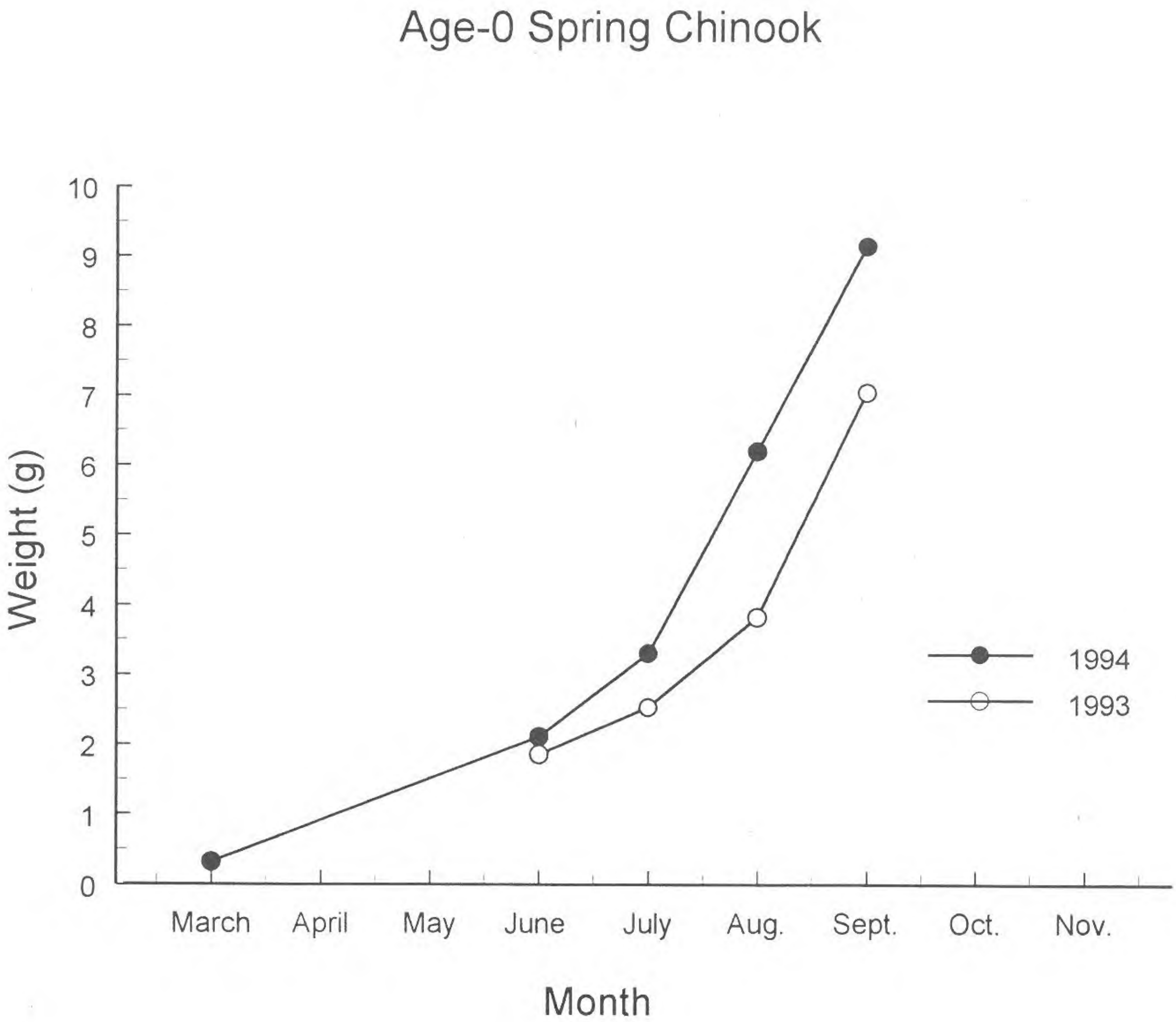


Figure 48. Mean weights of juvenile spring chinook that emigrated from the Chiwawa River (from Petersen et al. 1993; Petersen unpublished data).

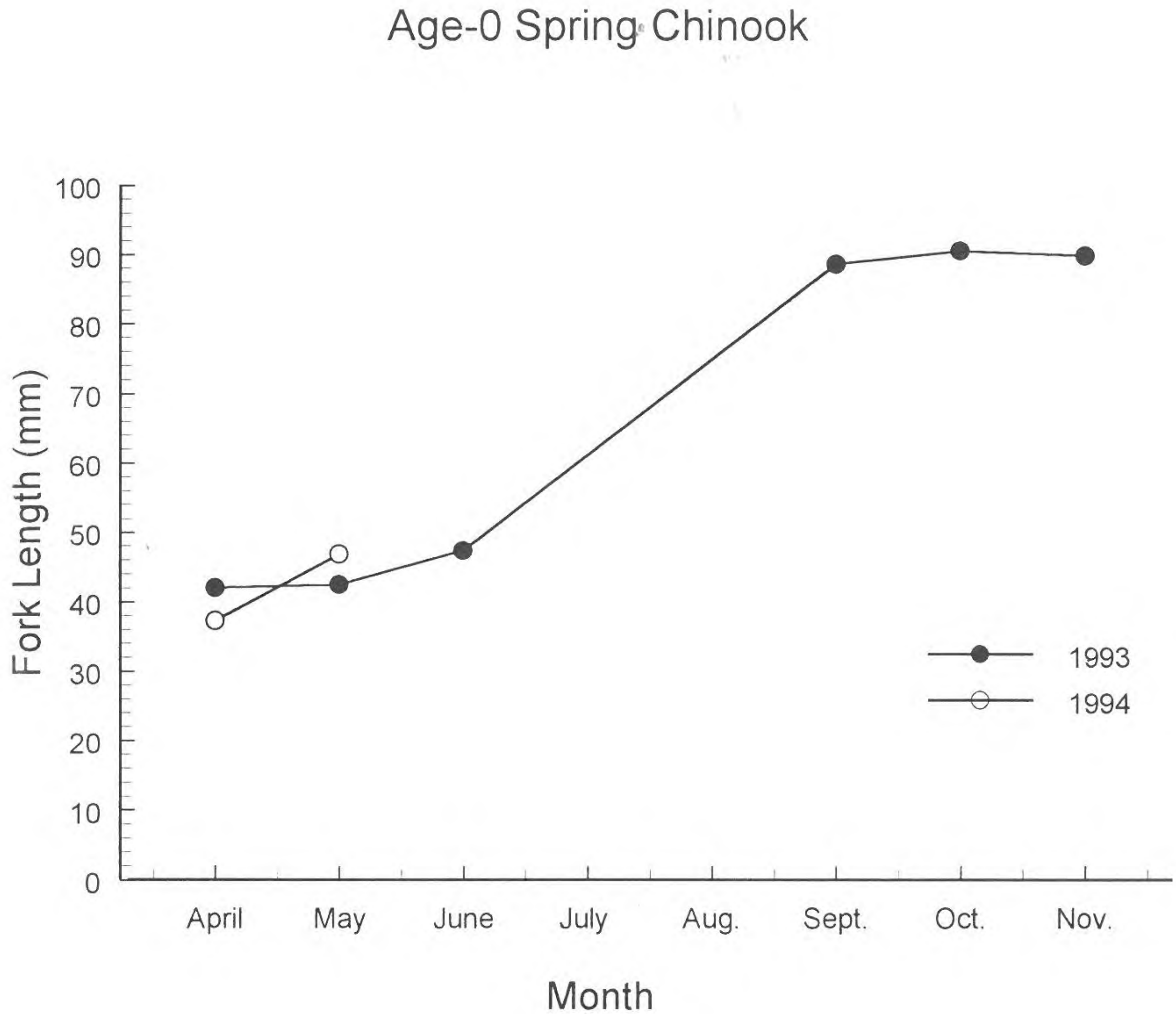


Figure 49. Mean fork lengths of juvenile spring chinook that emigrated from the Chewack River (J. Hubble, Yakima Indian Nation, unpublished data).

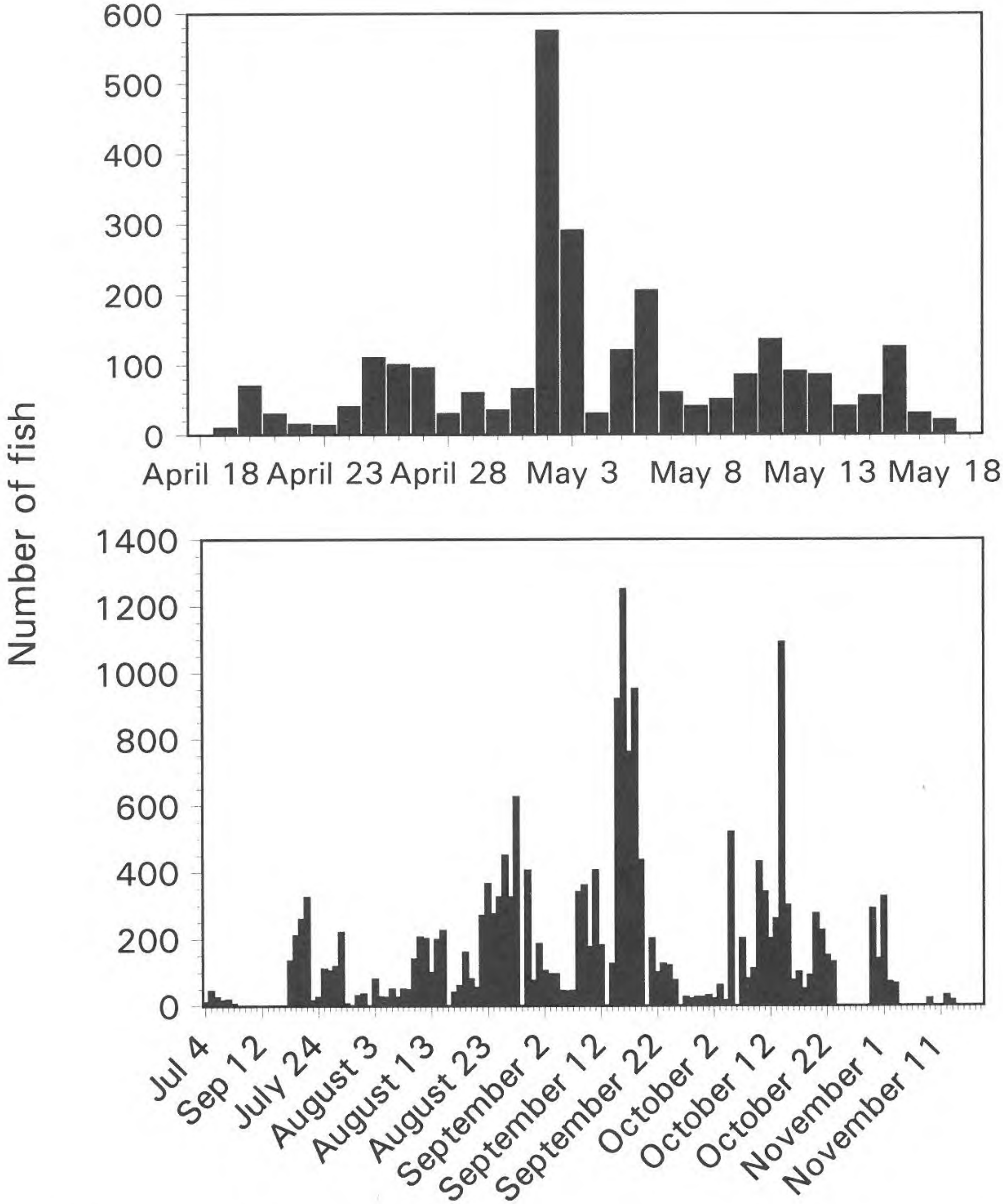


Figure 50. Timing of chinook migration past Tumwater Dam in 1955 in spring (mostly yearlings) and summer or fall months (all subyearlings; recreated from French and Wahle 1959).

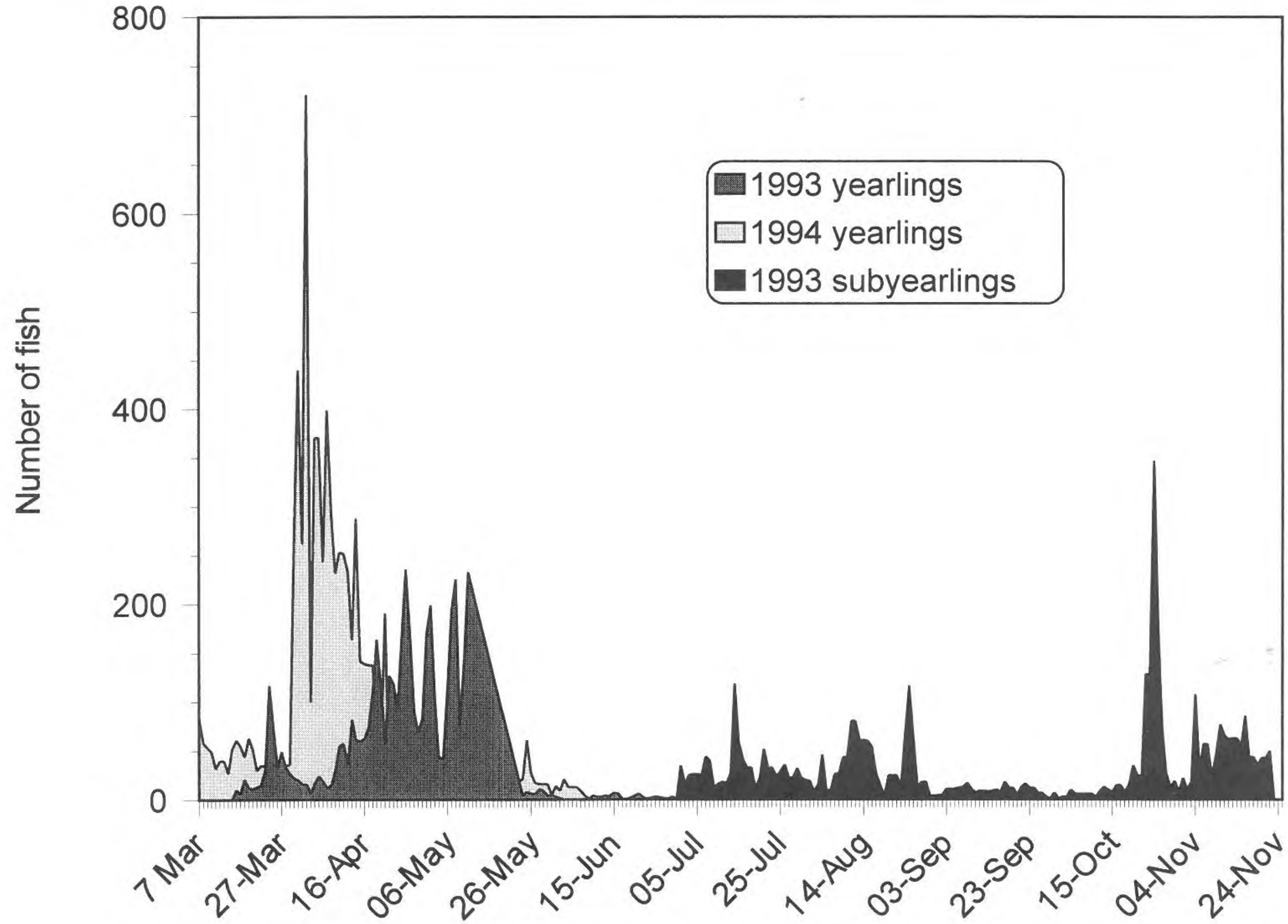


Figure 51. Timing of emigration of spring chinook salmon from the Chiwawa River (Petersen et al. 1994; Petersen, WDFW, personal communication).

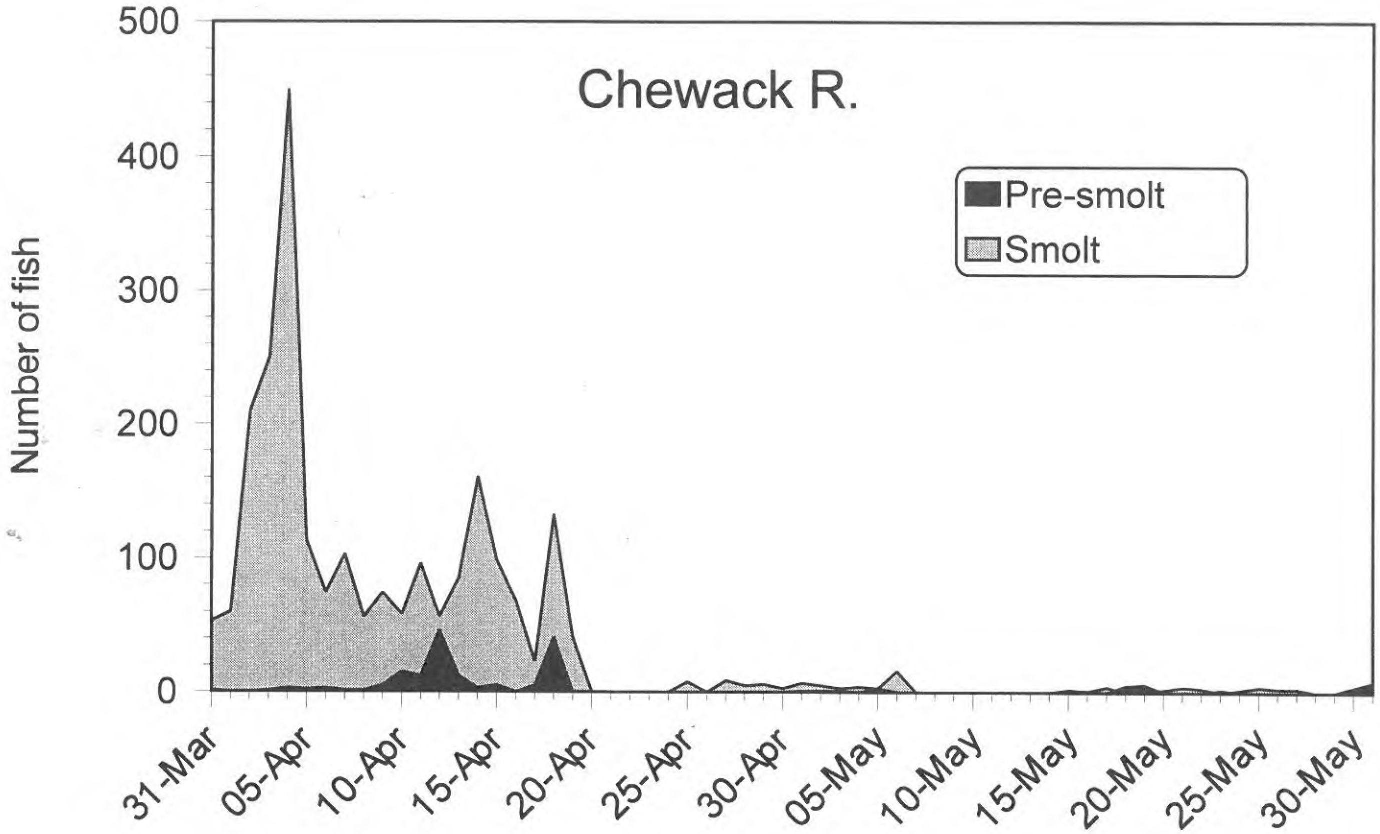


Figure 52. Timing of juvenile spring chinook emigrating from the Chewack River in 1994 (J. Hubble, YIN, personal communication).

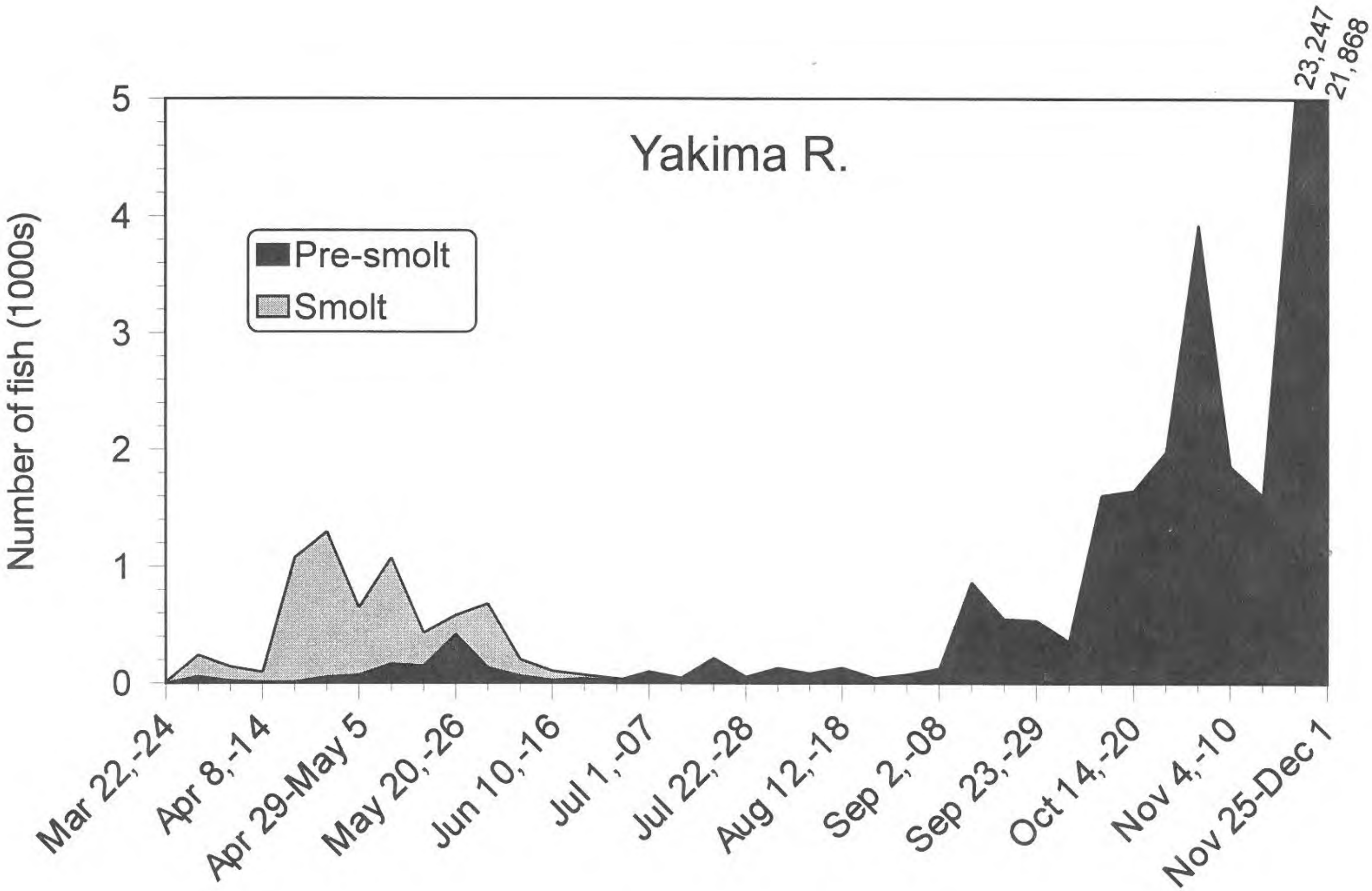


Figure 53. Timing of juvenile spring chinook emigration from the Yakima River basin, 1986 (Fast et al. 1986b, 1988).

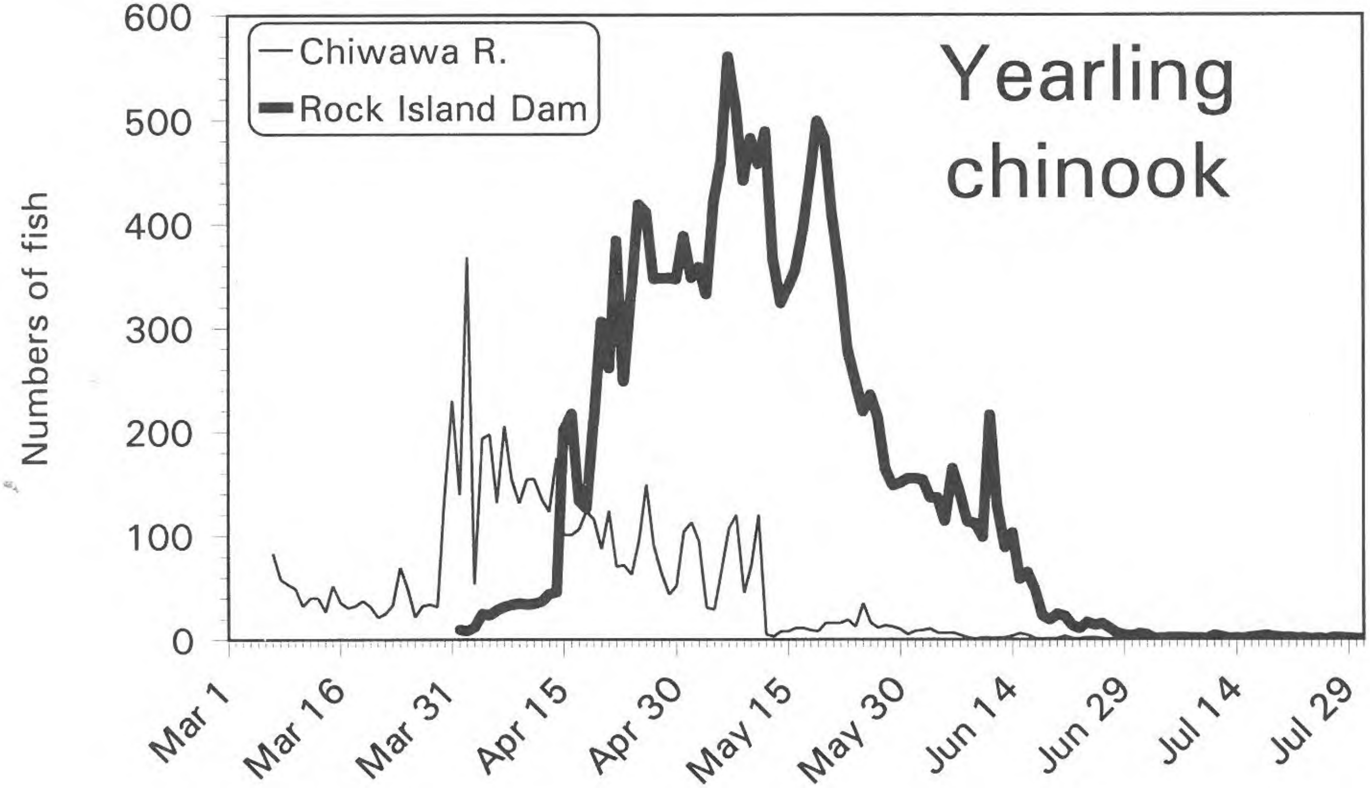


Figure 54. The average (1985-1994) time of passage of yearling chinook (hatchery and wild) salmon past Rock Island Dam, and the average (1993 and 1994) time of emigration of wild spring chinook yearlings from the Chiwawa River (K. Petersen, WDFW, personal communication).

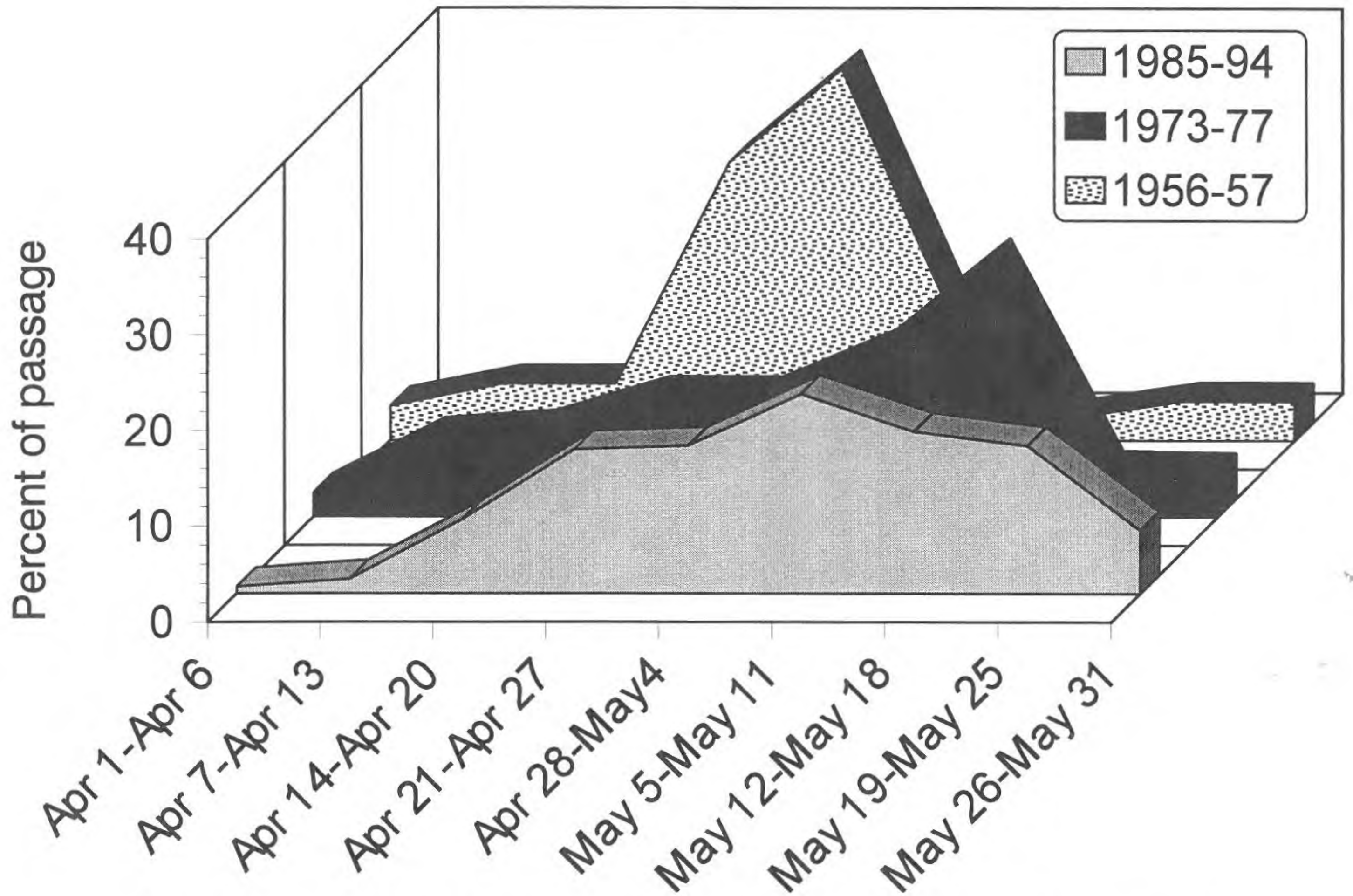


Figure 55. Run timing of chinook sampled at Rock Island Dam cooling water screens, 1956, 1957 (Edson 1958) and 1973-1977 (Chelan PUD, unpublished data), and the second powerhouse bypass trap, 1985-1994.

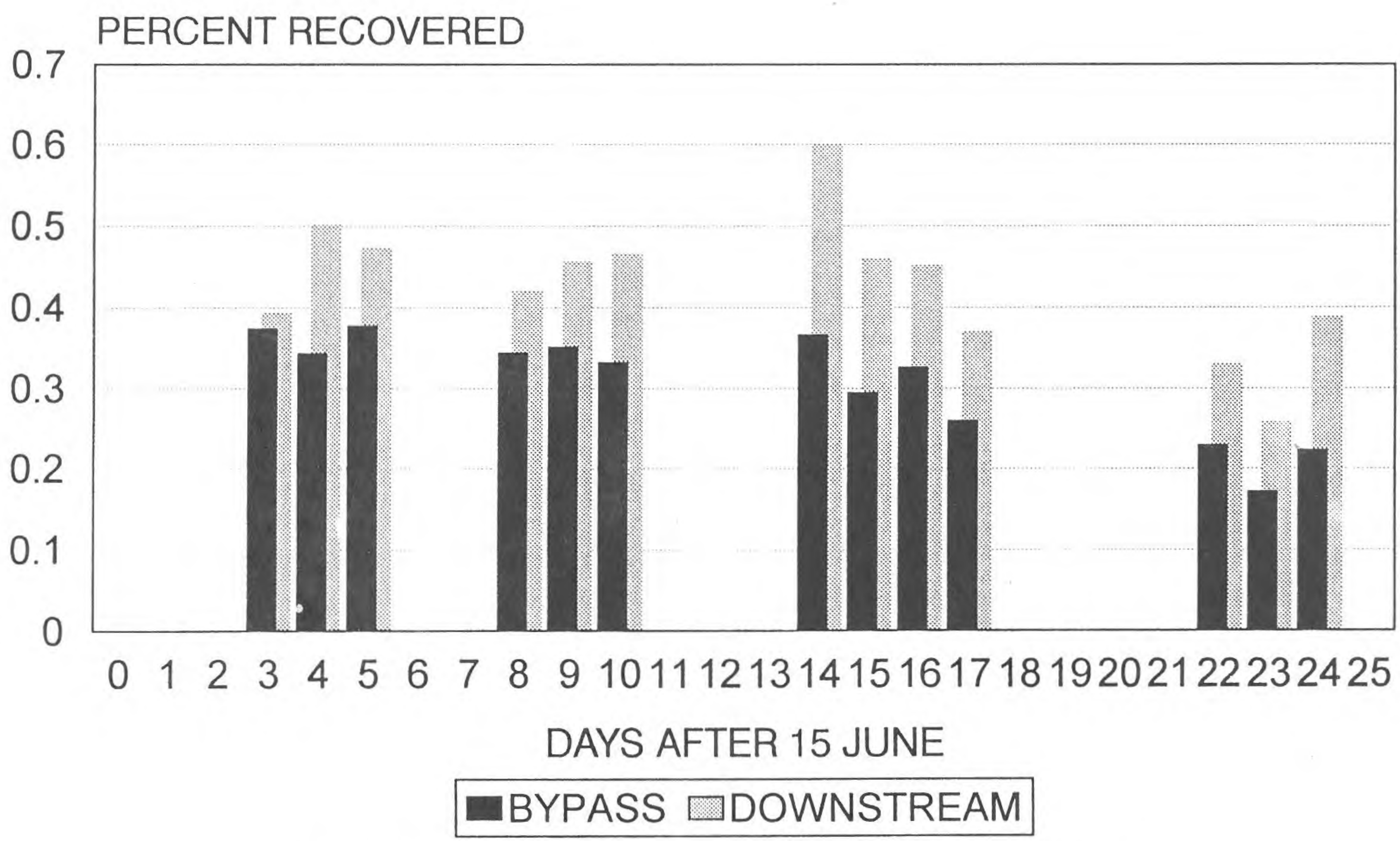
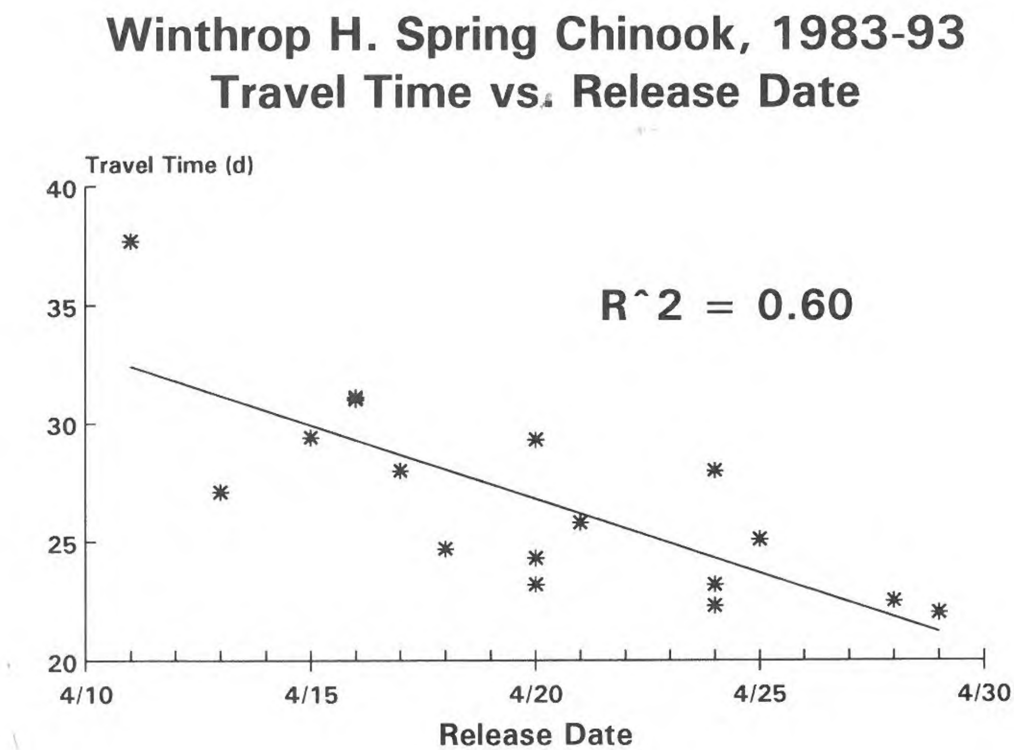


Figure 56. Percent of subyearling chinook recovered in sampling in the Columbia River estuary after release at the Bonneville Dam PH1 bypass and at a point mid-river 2.5 km downstream from Bonneville Dam.



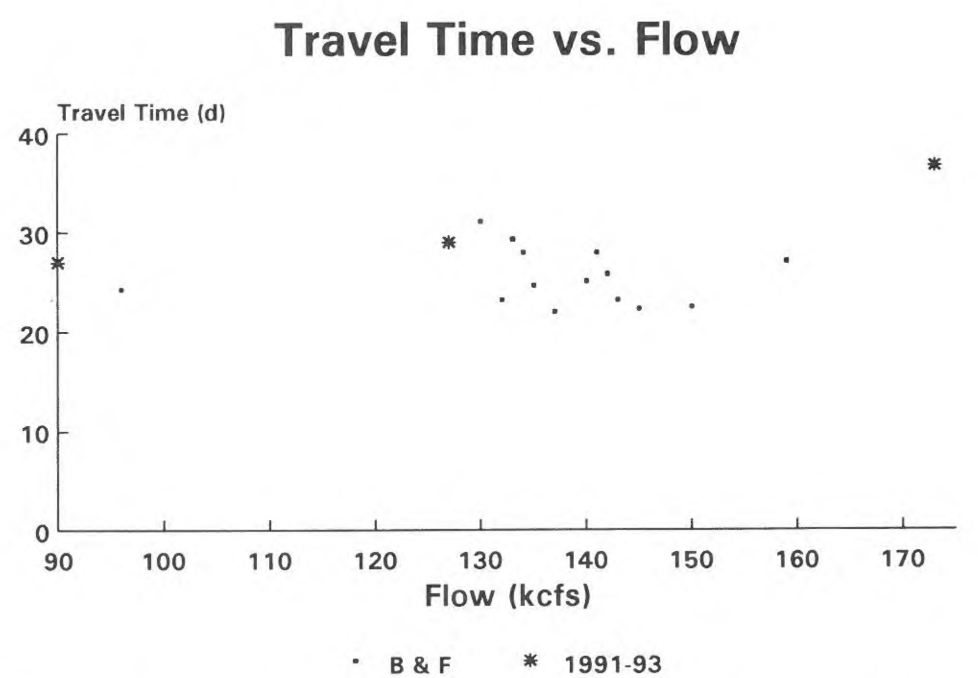
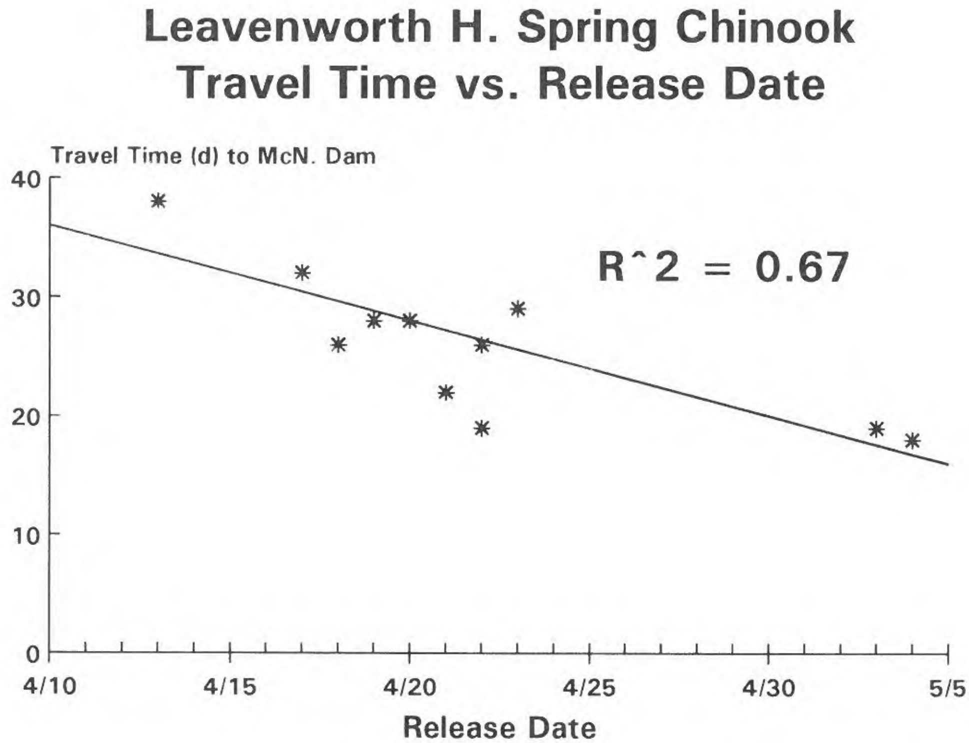


Figure 57. Travel time to McNary Dam of spring chinook released at Winthrop National Fish Hatchery, 1983-1993, in relation to release date and discharge, from reports of the Fish Passage Center.



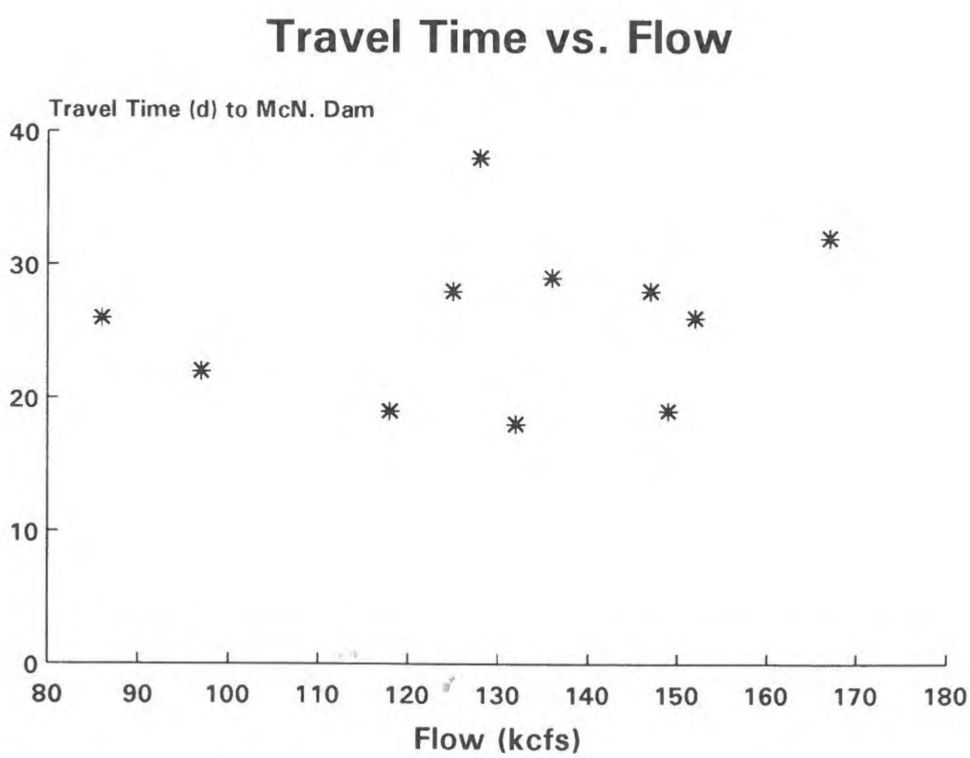
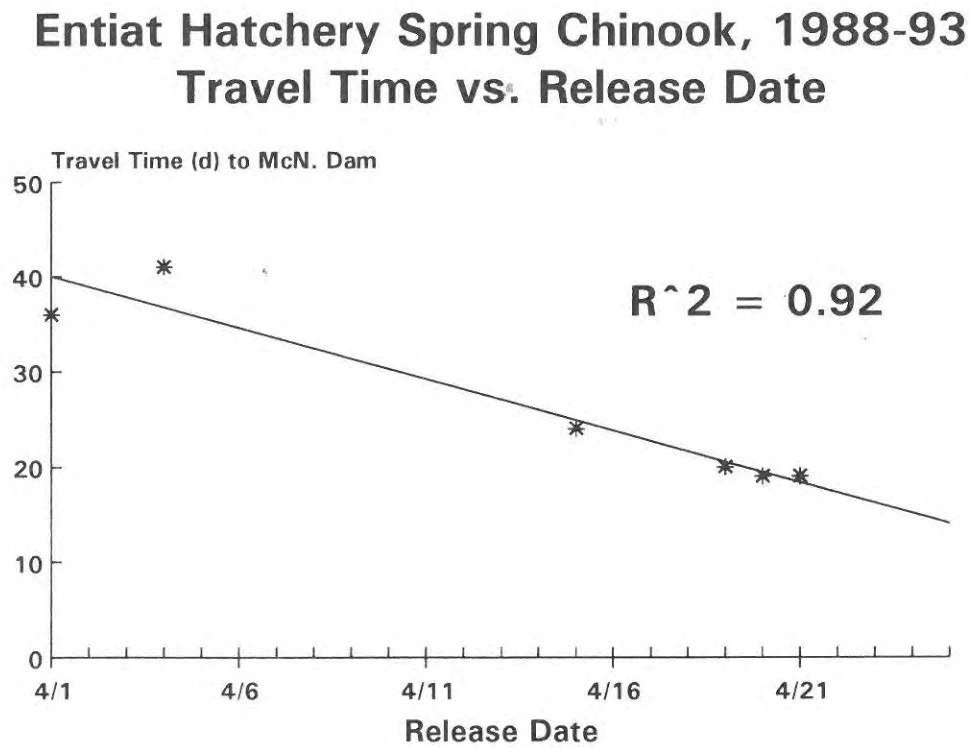


Figure 58. Travel time of to McNary Dam of spring chinook released at Leavenworth National Fish Hatchery, 1985-1992, in relation to release date and discharge, from reports of the Fish Passage Center.



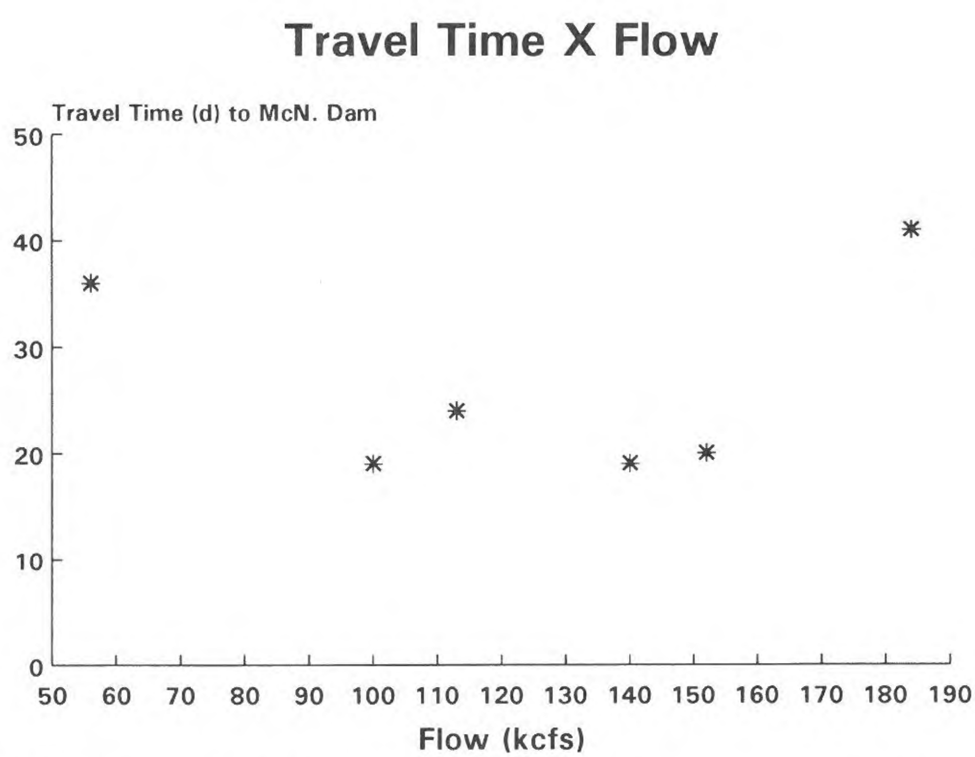
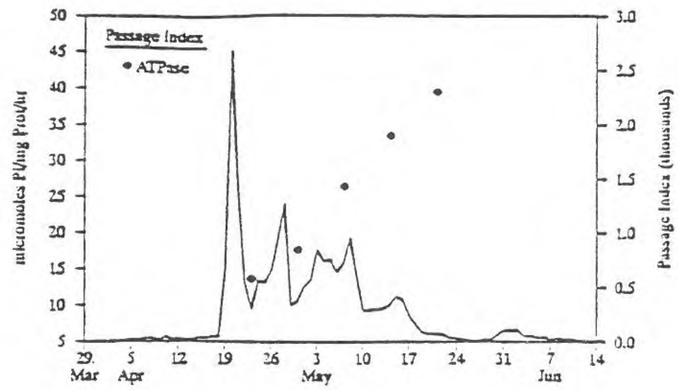
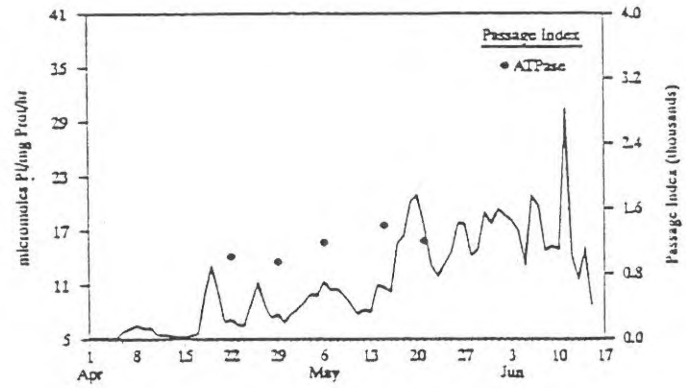


Figure 59. Travel time to McNary Dam of spring chinook released at Entiat National Fish Hatchery, 1988-1993, in relation to release date and discharge, from reports of the Fish Passage Center.

1990



1991



1992

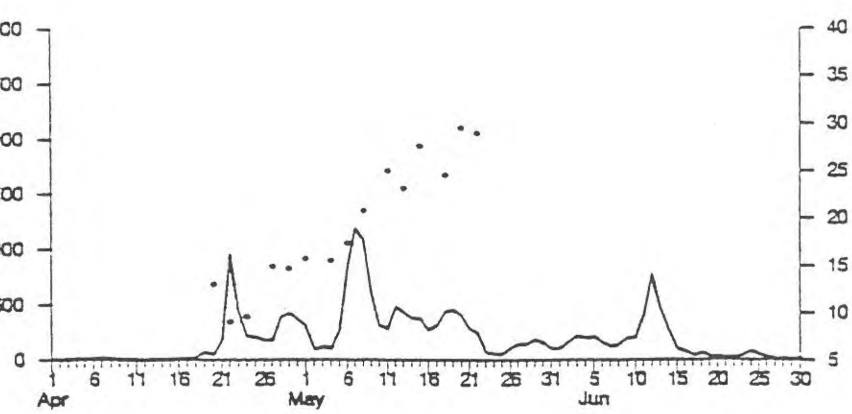


Figure 60. Passage indices and ATPase levels of yearling chinook sampled at Rock Island bypass trap, 1990-1992, from annual reports of the Fish Passage Center.

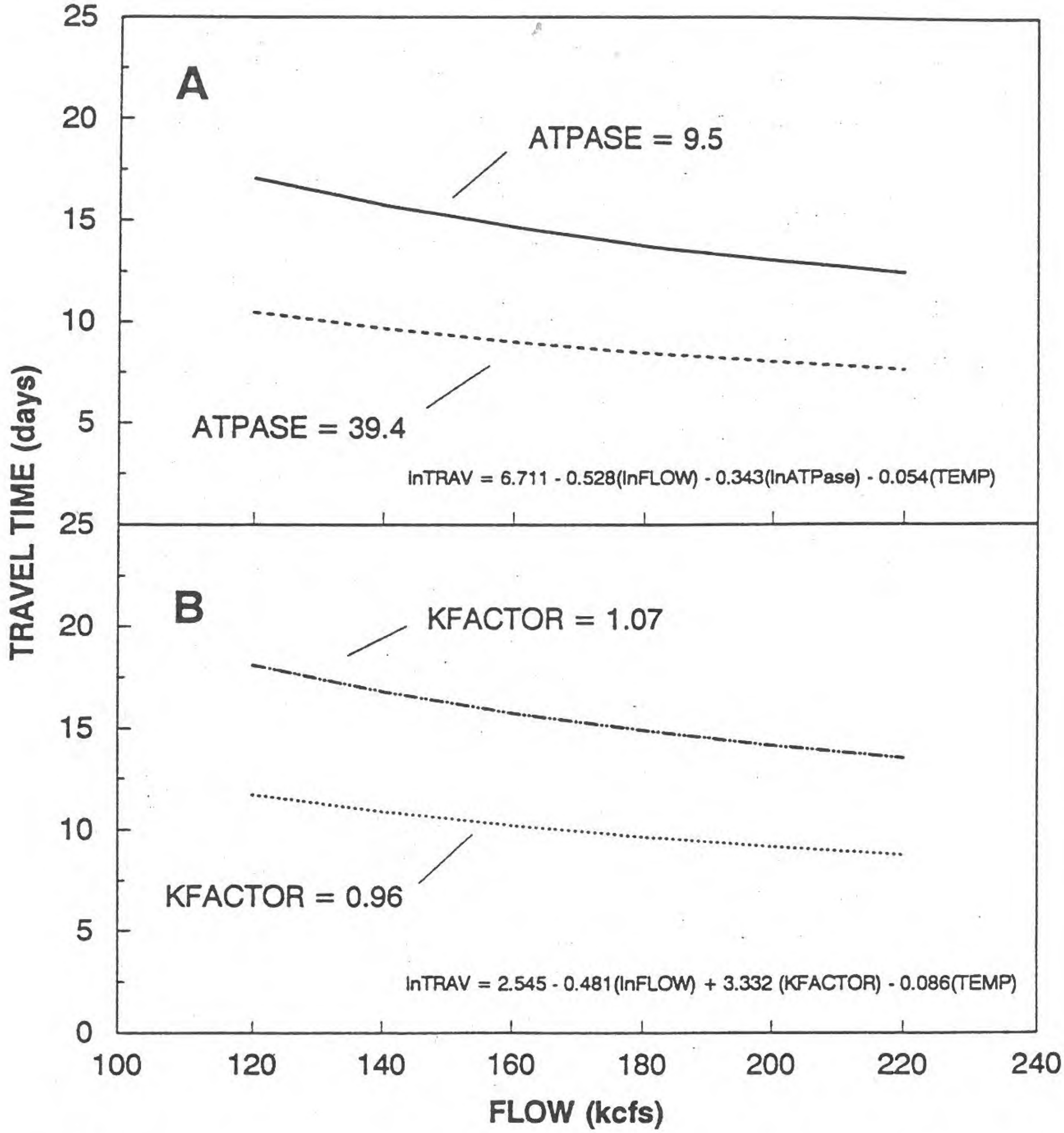


Figure 61. Predicted flow-travel time relations of juvenile spring chinook salmon migrating between Rock Island and McNary dams based on a multiple regression that includes gill-ATPase activity (ATPASE, graph A) or condition factor (KFACTOR; B). Levels of ATPASE and KFACTOR represent minima and maxima from data collected in 1989-1992. For these plots, the water temperature variate was held constant at its mean.

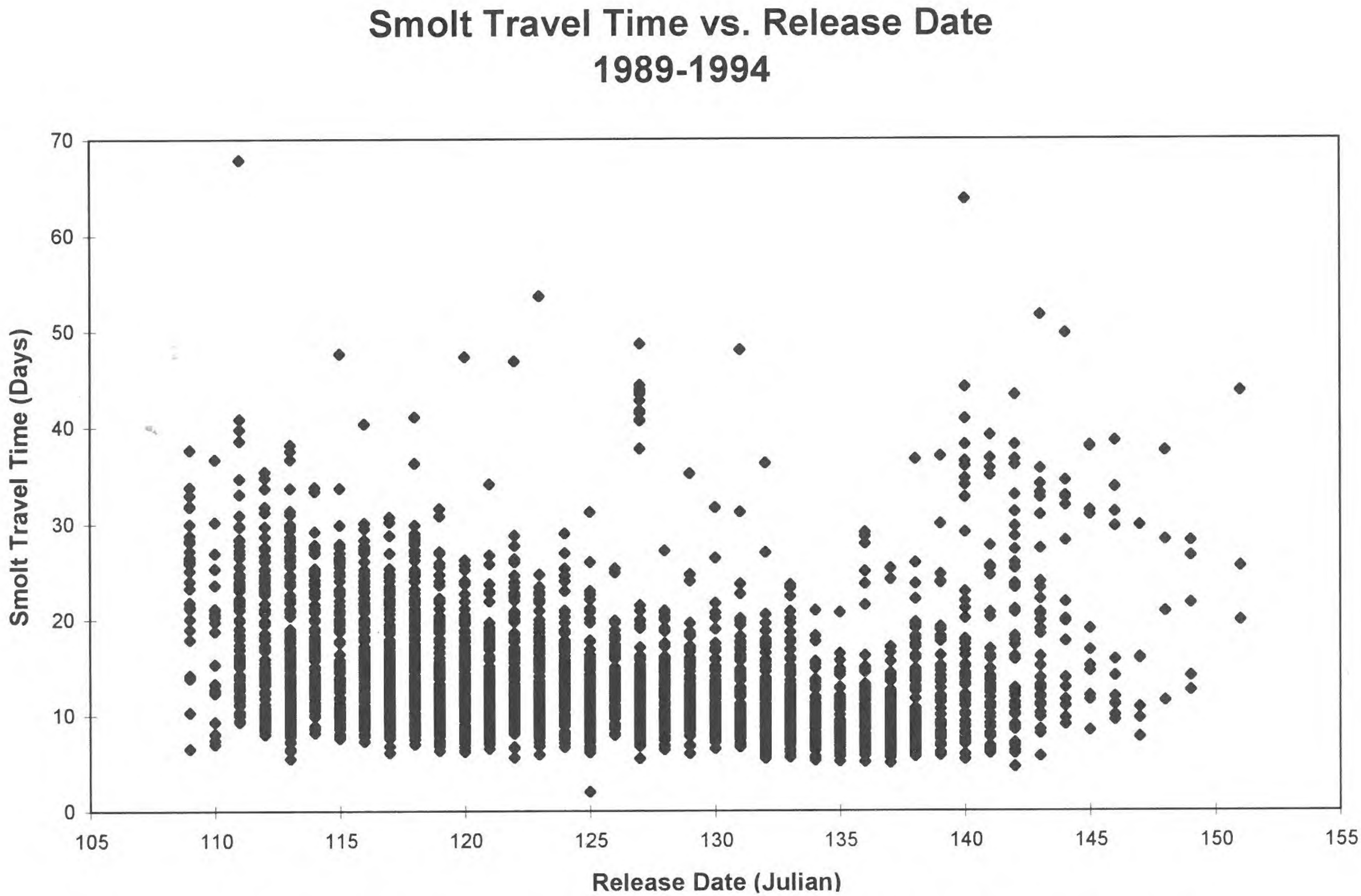


Figure 62. Smolt travel time from Rock Island Dam to McNary Dam in relation to release date, 1989-1994, from PIT-tag data obtained from PITAGIS databases.

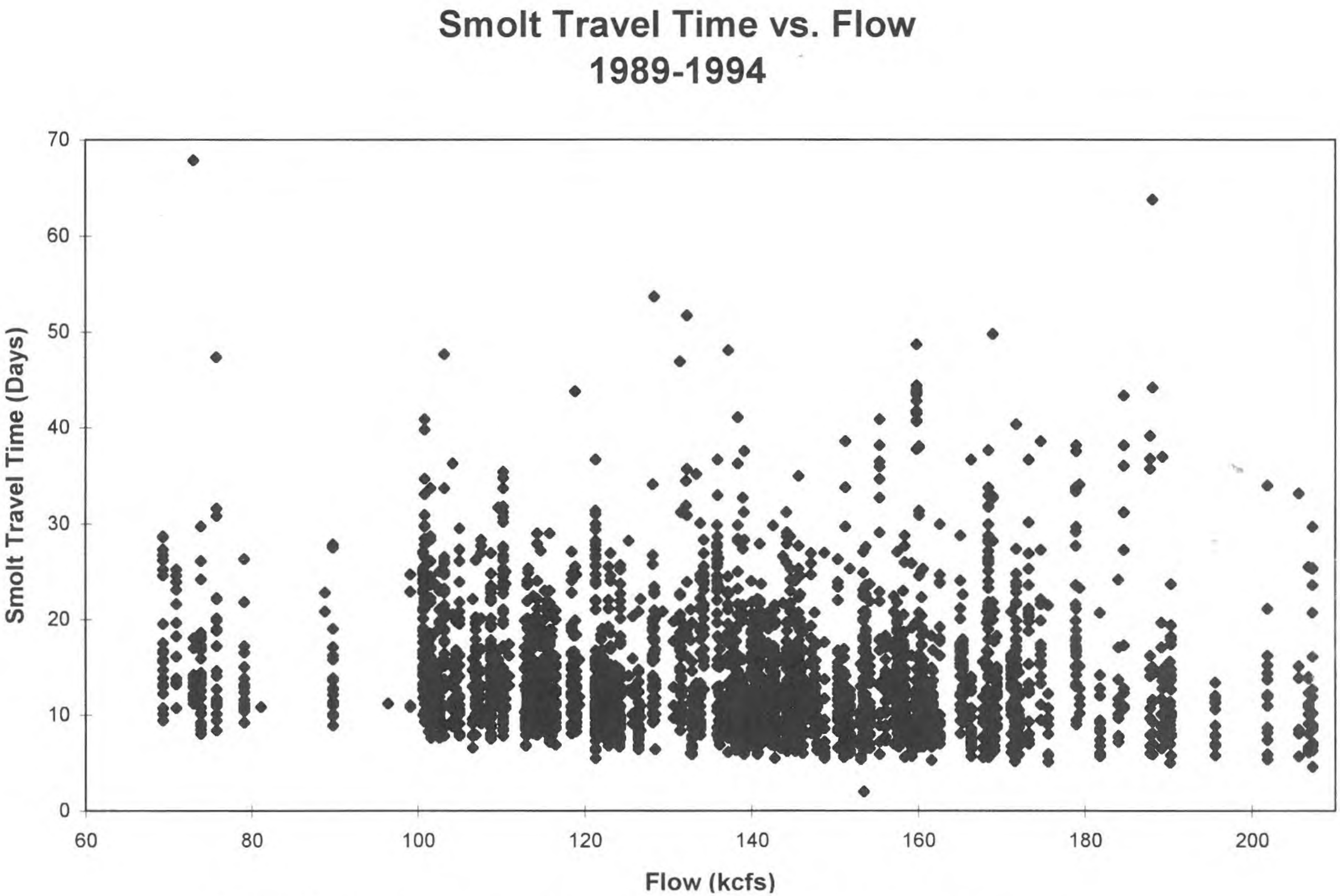


Figure 63. Smolt travel time from Rock Island Dam to McNary Dam in relation to Columbia River discharge, 1989-1994,from PIT-tag data obtained from PITAGIS databases.

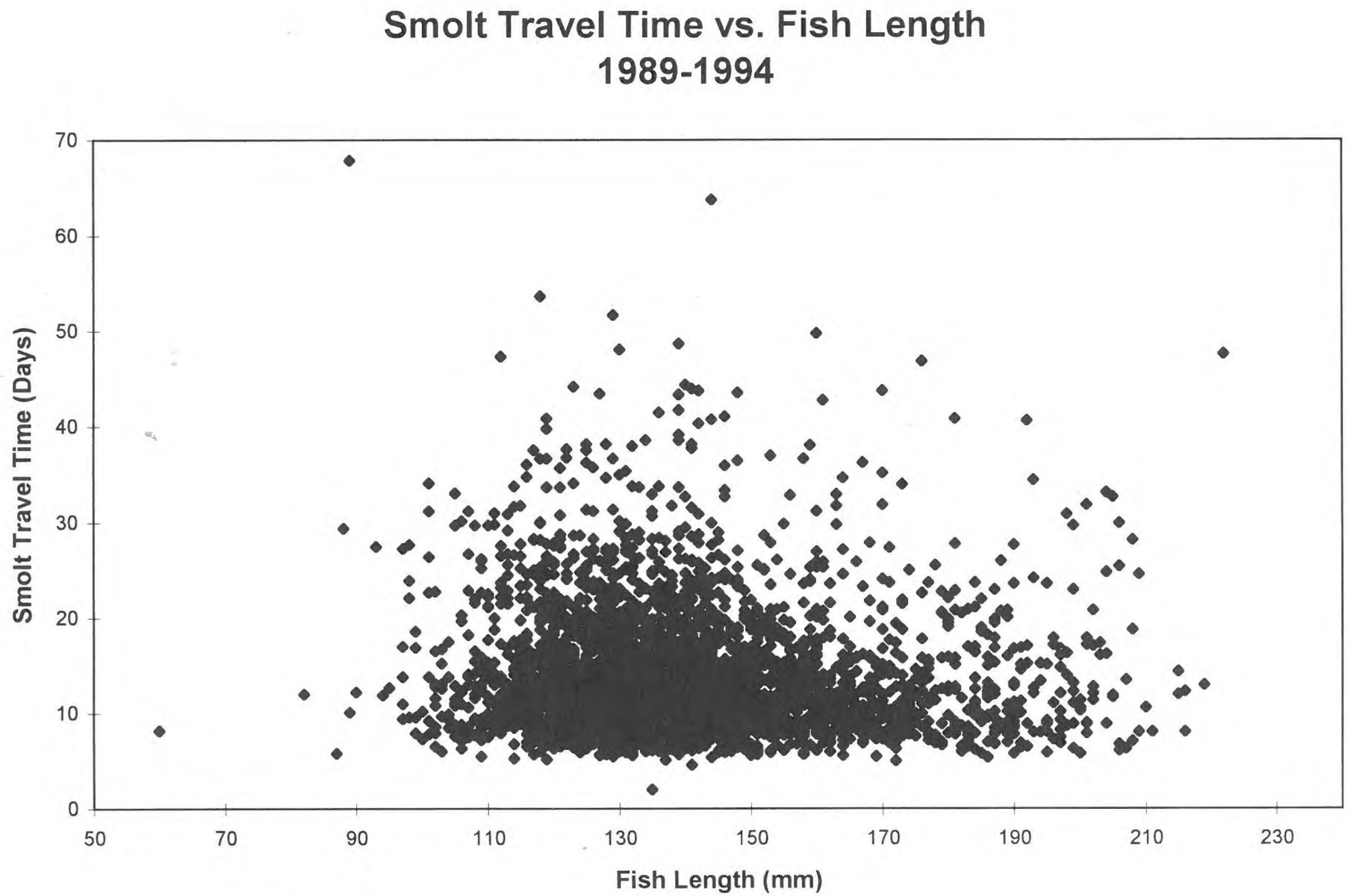


Figure 64. Smolt travel time from Rock Island Dam to McNary Dam in relation to fish length, 1989-1994, from PIT-tag data obtained from PITAGIS databases.

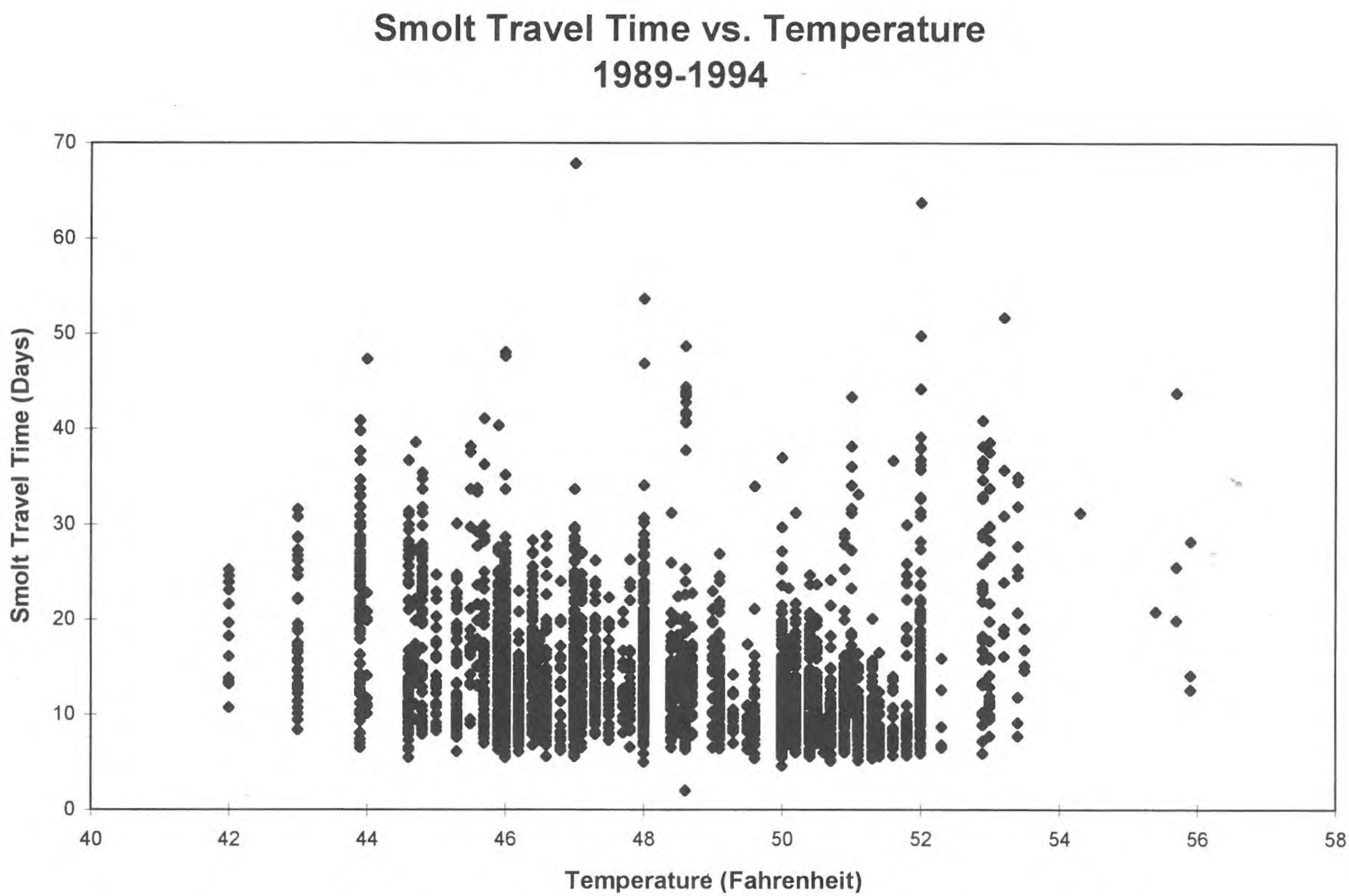


Figure 65. Smolt travel time from Rock Island Dam to McNary Dam in relation to river water temperature, 1989-1994, from PIT-tag data obtained from PITAGIS databases.

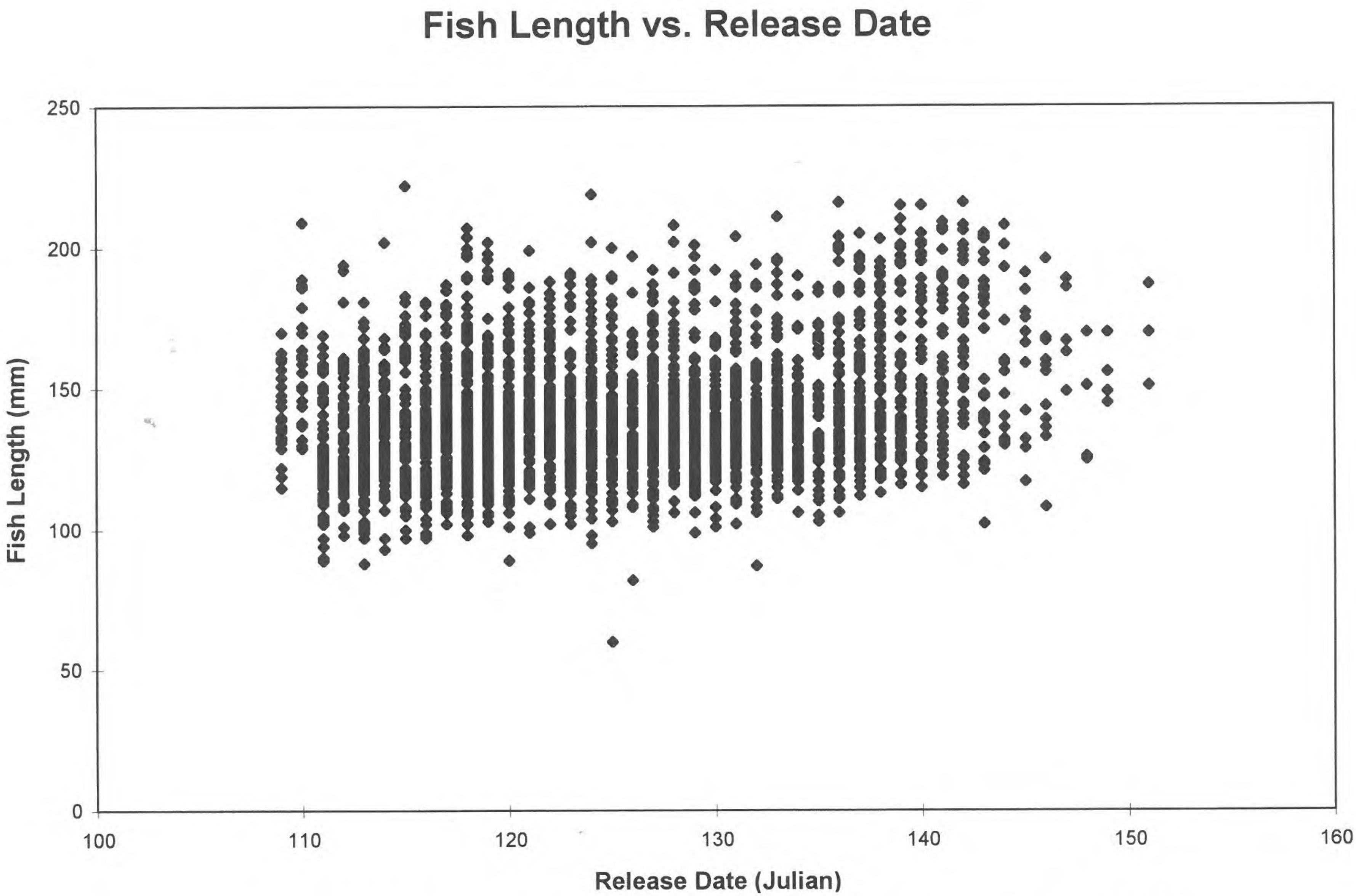


Figure 66. Fish length at Rock Island Dam in relation to release date, 1989-1994, from PIT-tag data obtained from PITAGIS databases.

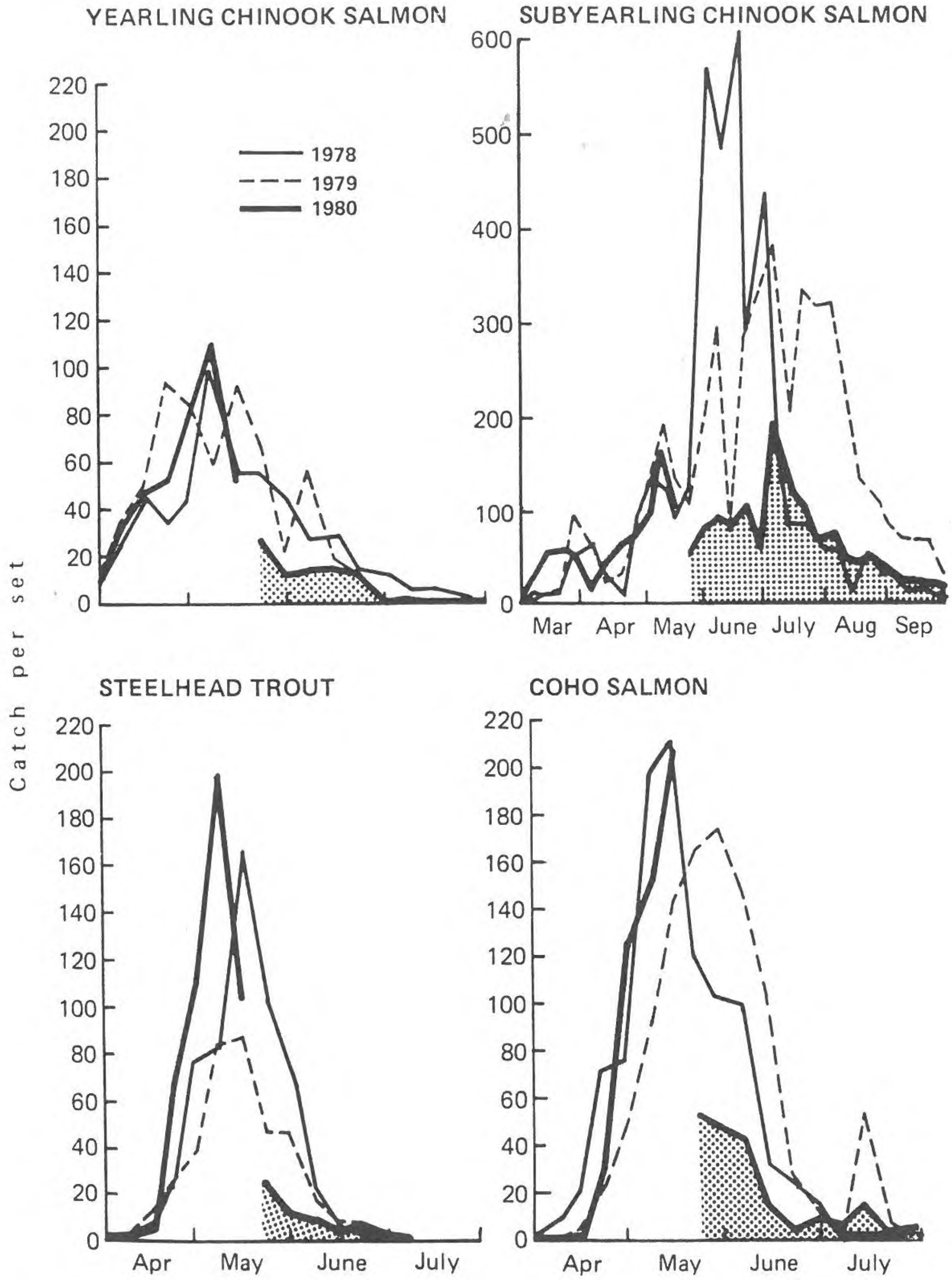


Figure 67. Weekly catch per set averages for yearling chinook and coho salmon and steelhead by purse seine, and subyearling chinook (beach seine) at Jones beach, 1978-1980. Shaded areas distinguish catches from highly turbid water after the eruption of Mount St. Helens on 18 May, 1980. (From Dawley et al. 1982).

Estimated Average Water Velocity
Range of Spring Conditions

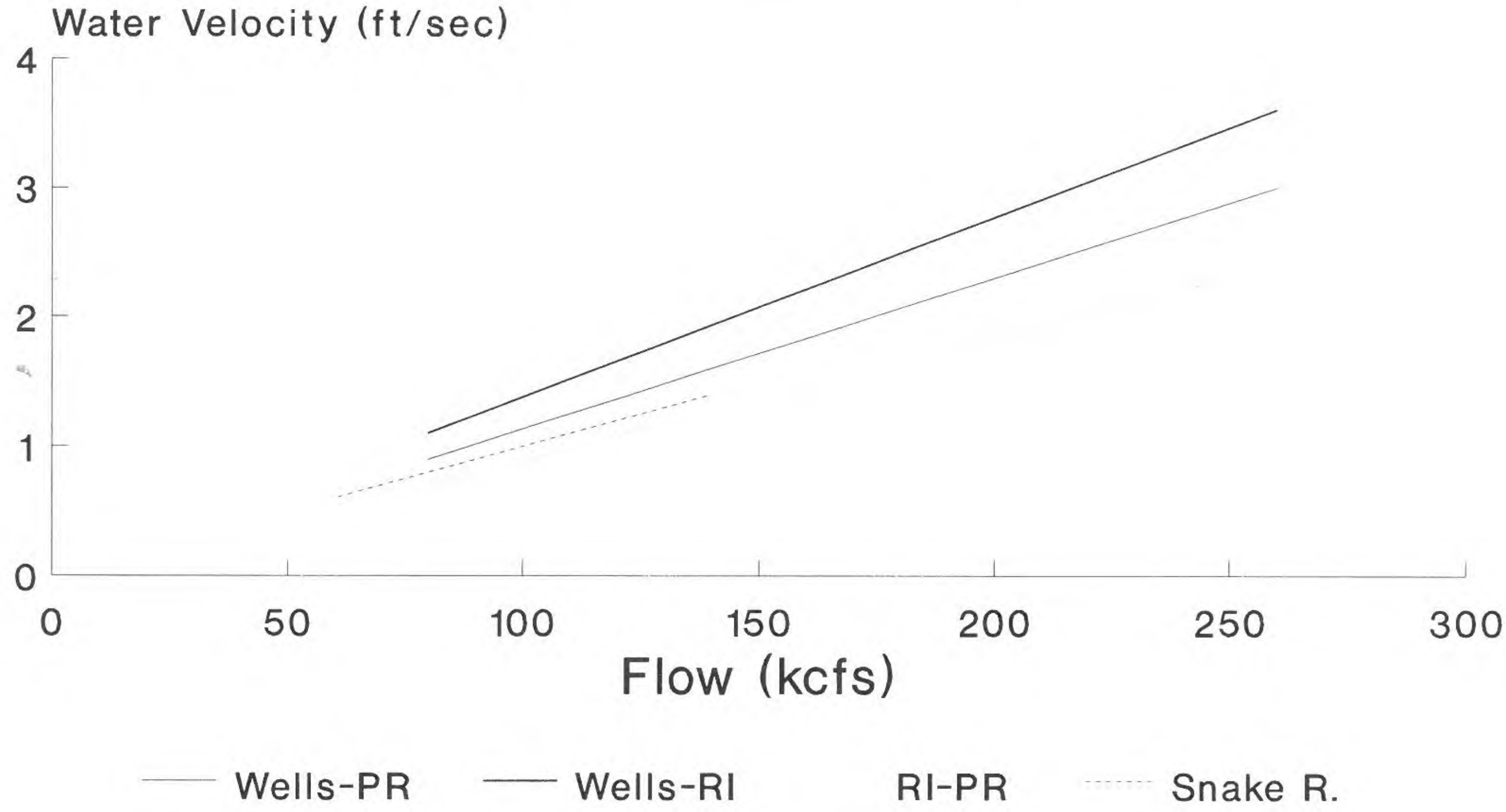


Figure 68. Estimated average water velocity, range of spring conditions, in the reaches from Wells to Priest Rapids, Wells to Rock Island, Rock Island to Priest Rapids, and in the Snake River, calculated on basis of volume replacement and reservoir dimensions as recorded in the CRiSP1.4 Manual.

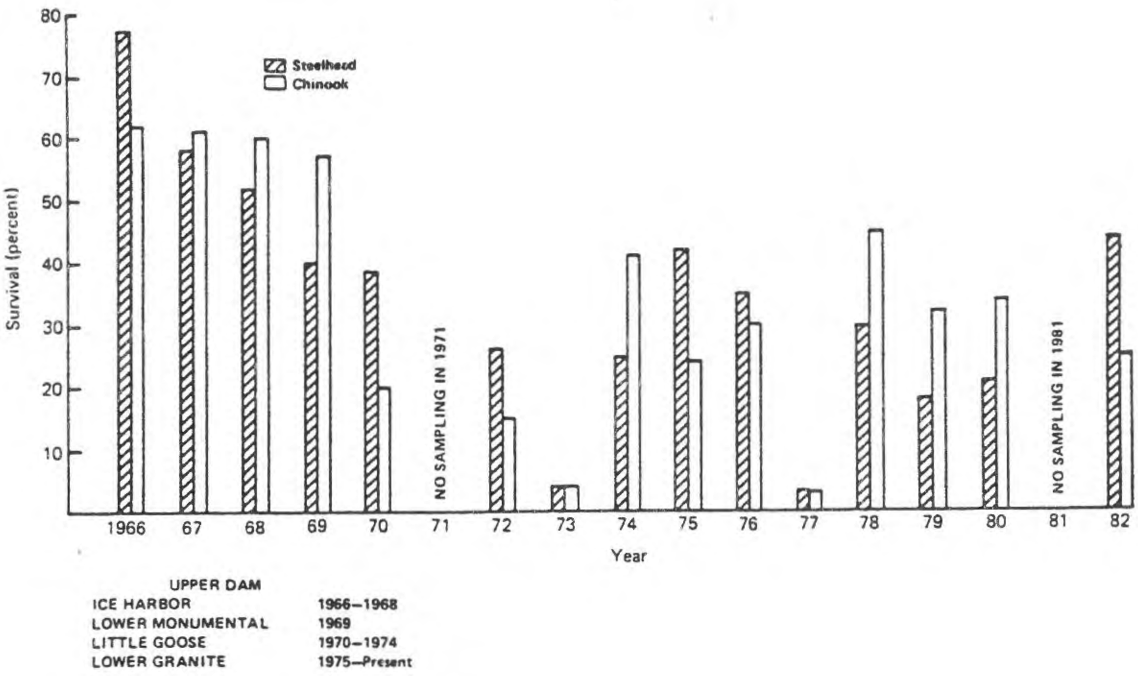


Figure 69. Estimated survival of yearling chinook salmon and steelhead smolts, 1966-1982, from Sims et al. (1983).

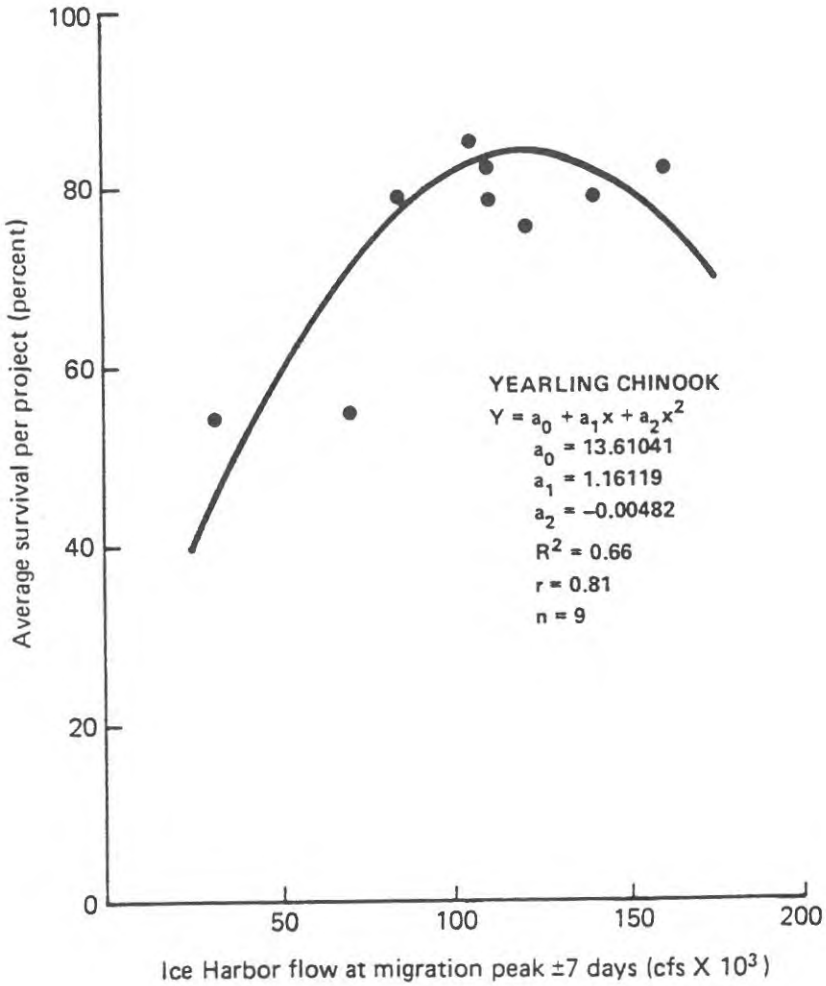
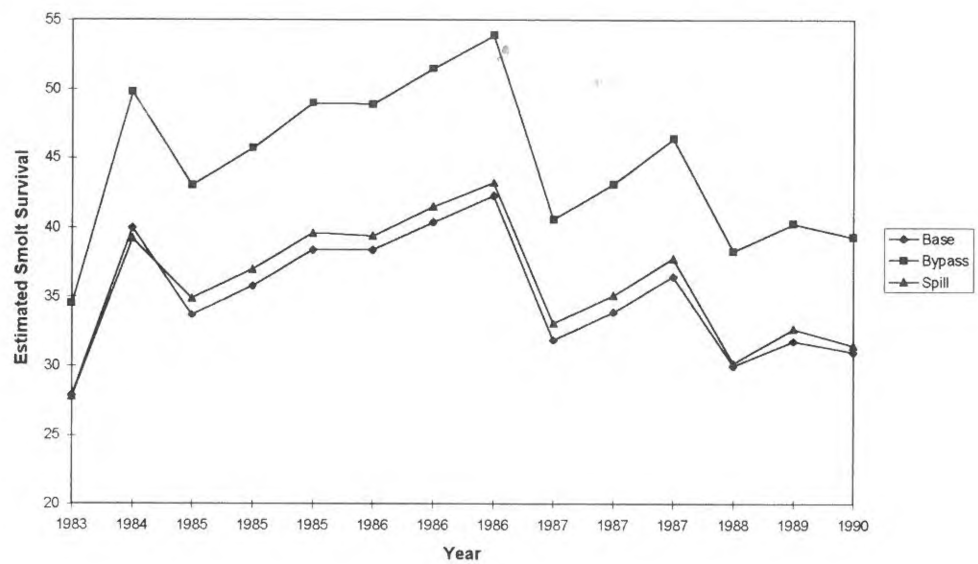


Figure 70. Estimated survival of yearling chinook in relation to river flow at Ice Harbor Dam, 1973-1982, from Sims et al. (1983).

Survival Estimates from Release to PRD Tailrace



Survival Estimates from Release to BON Tailrace

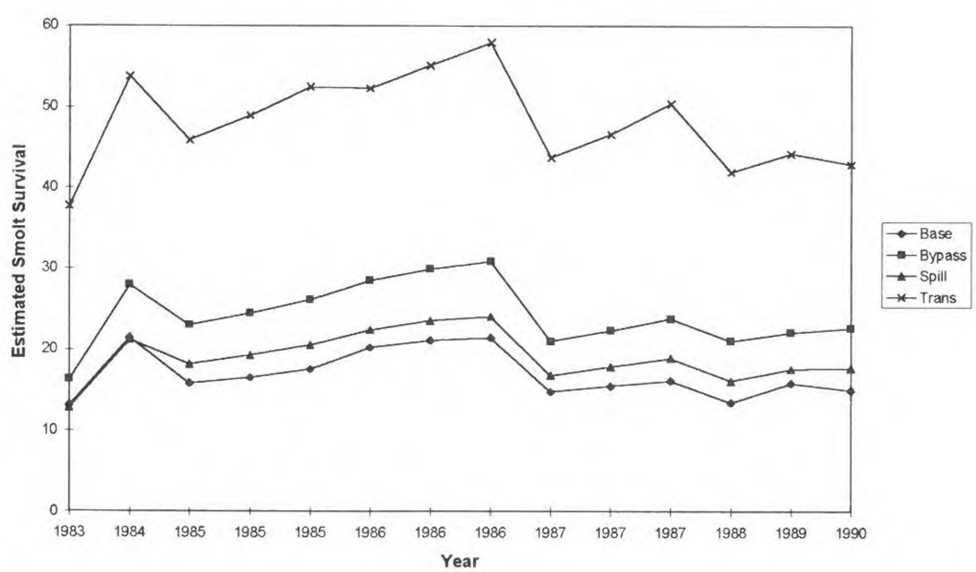


Figure 71. Estimated survival of Winthrop Hatchery spring chinook from point of release to Priest Rapids and Bonneville Dam tailraces, 1983-1993, based on CRiSP 1.5.

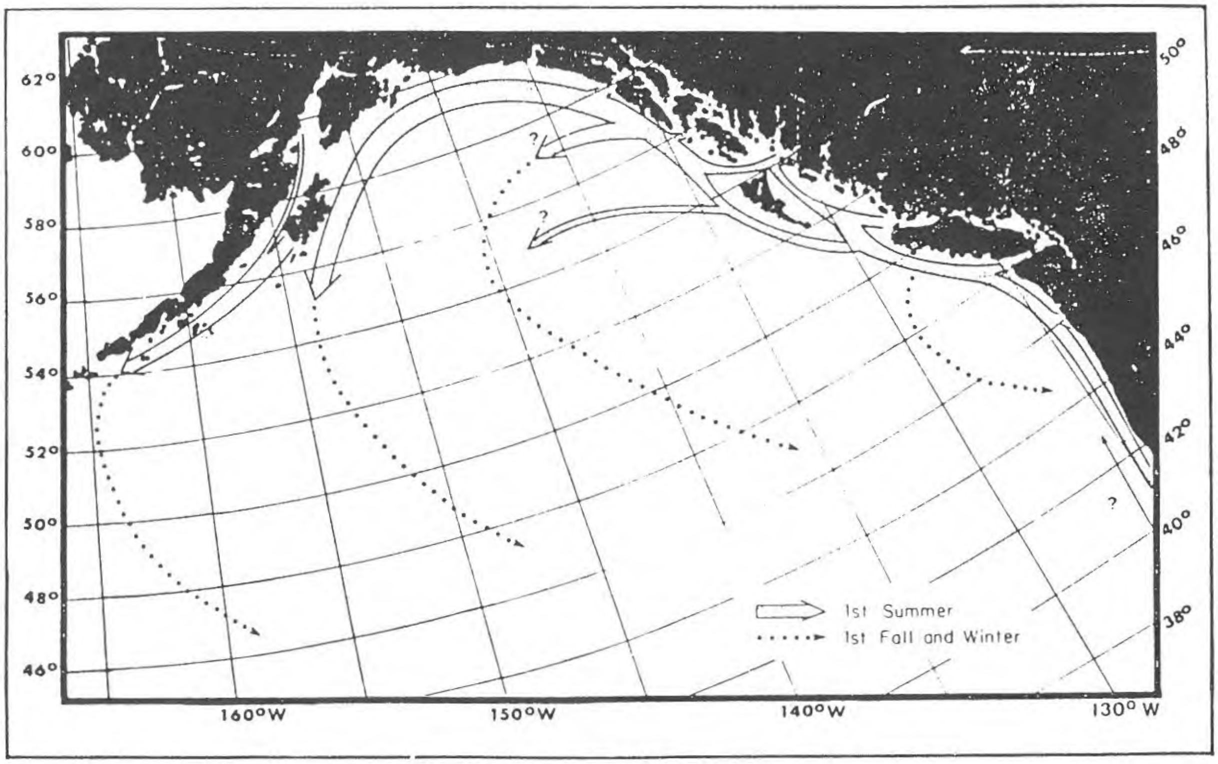


Figure 72. Diagram of ocean migration patterns of some major stocks of coho and chinook in the first summer at sea, with probable migrations during the first fall and winter, from Hartt and Dell (1986).

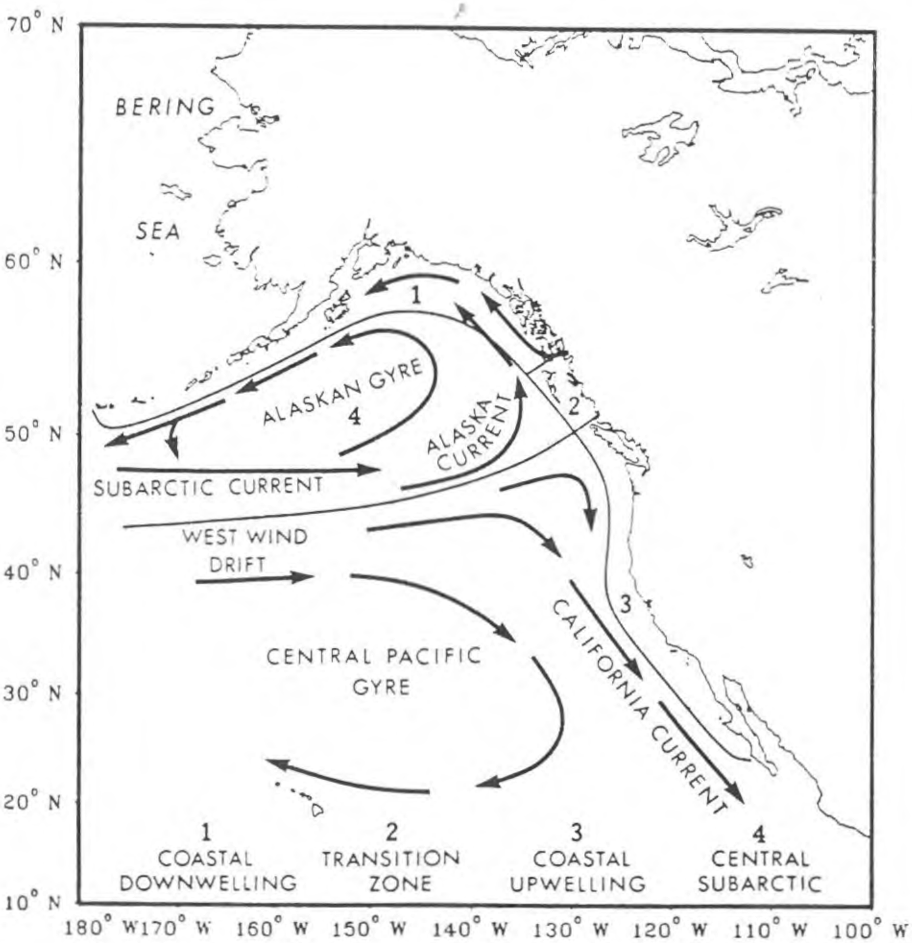


Figure 73. Approximate areas of oceanic domains and prevailing current directions in the northeast Pacific Ocean, from Ware and McFarlane (1989).

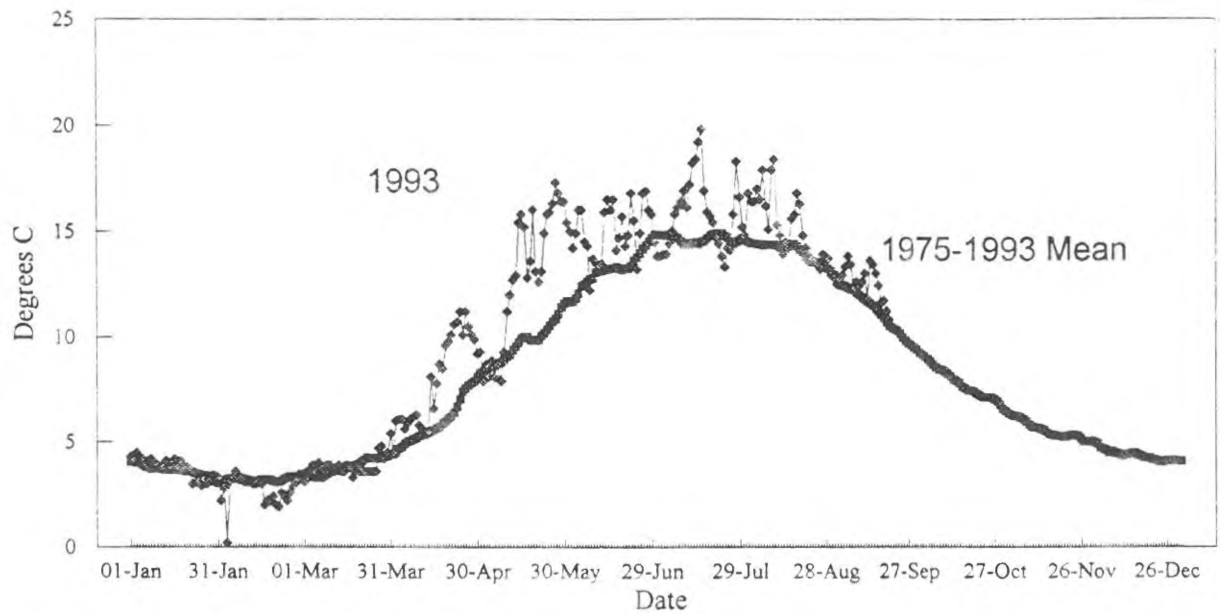


Figure 74. Daily sea surface temperatures in Auke Bay, Alaska, in 1993, compared to the mean temperatures 1975-1993, from Wing (1993).

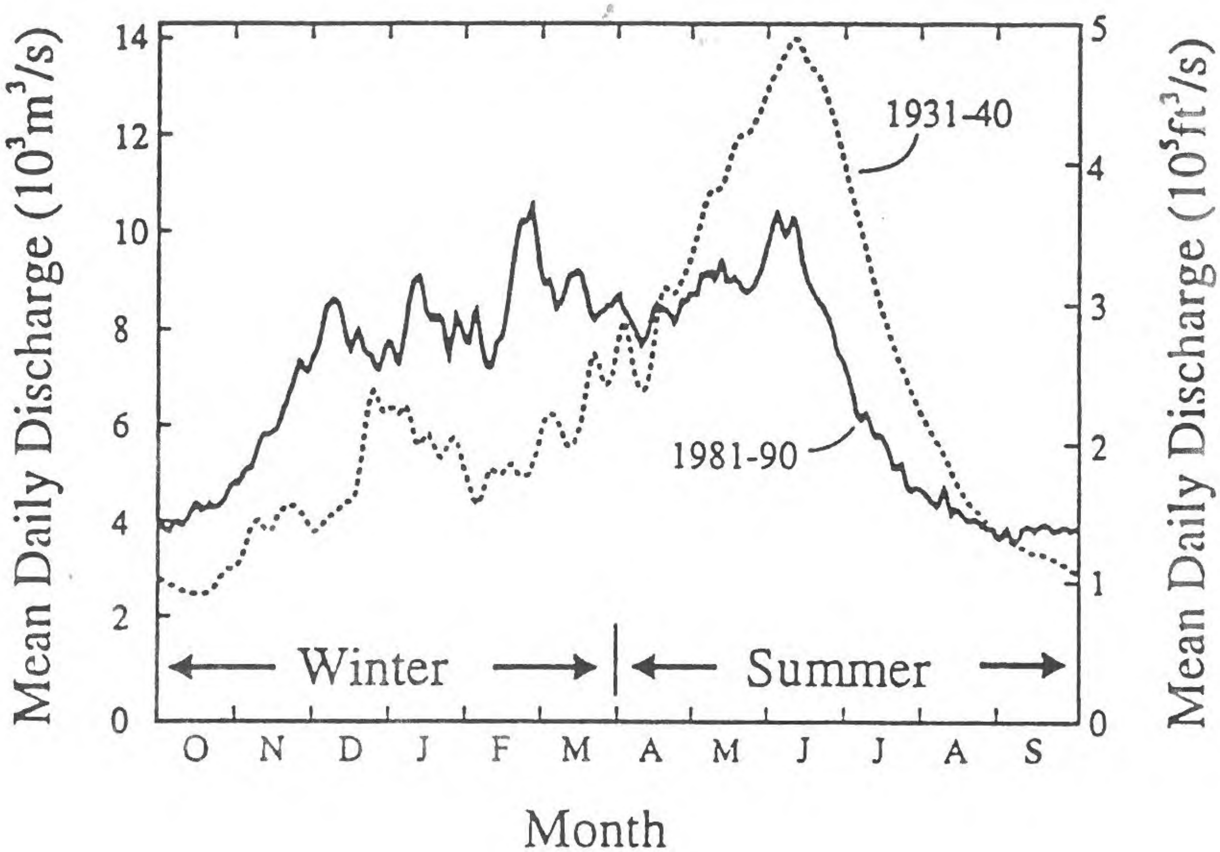


Figure 75. Mean daily discharge of the Columbia River 1931-1940 and 1981-1990, from Ebbesmeyer and Tangborn (1993).

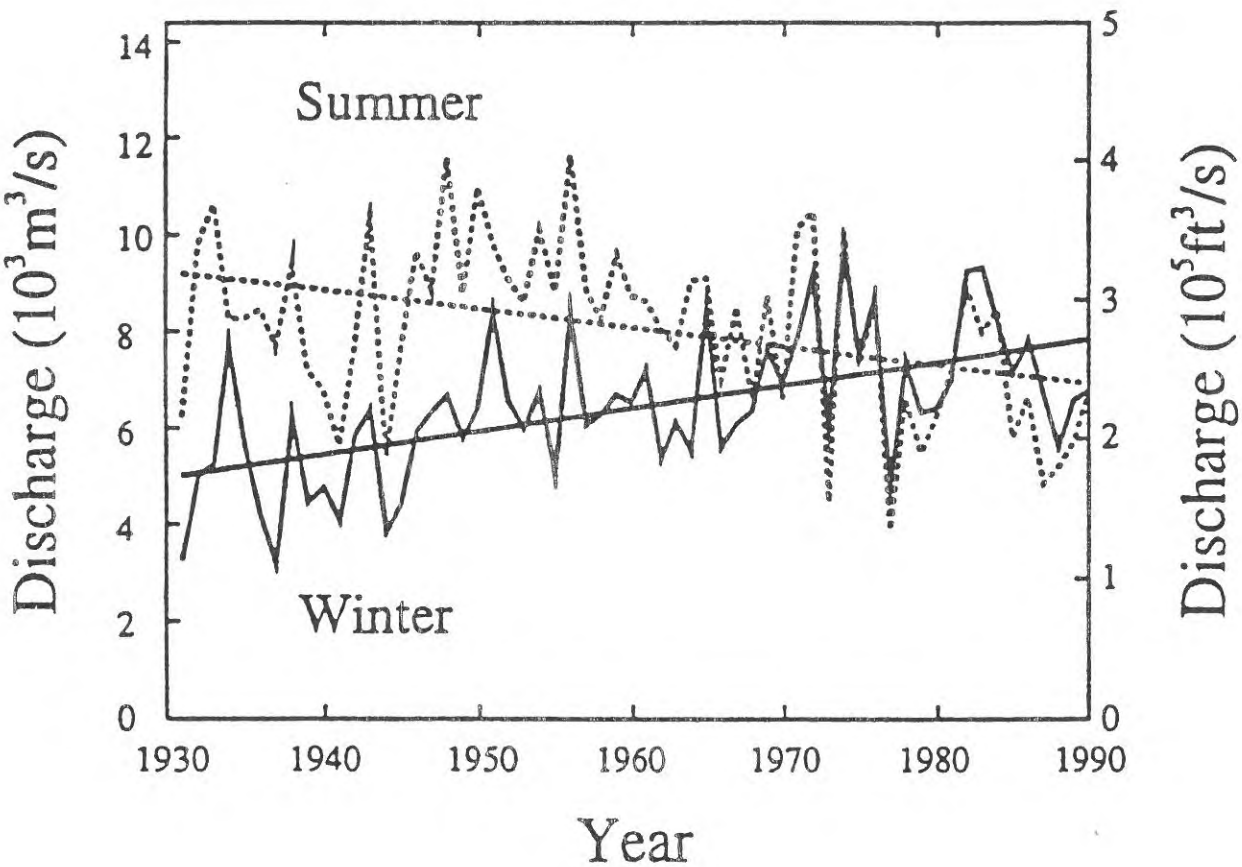


Figure 76. Summer and winter mean discharge of the Columbia River from 1932-1990, from Ebbesmeyer and Tangborn (1993).

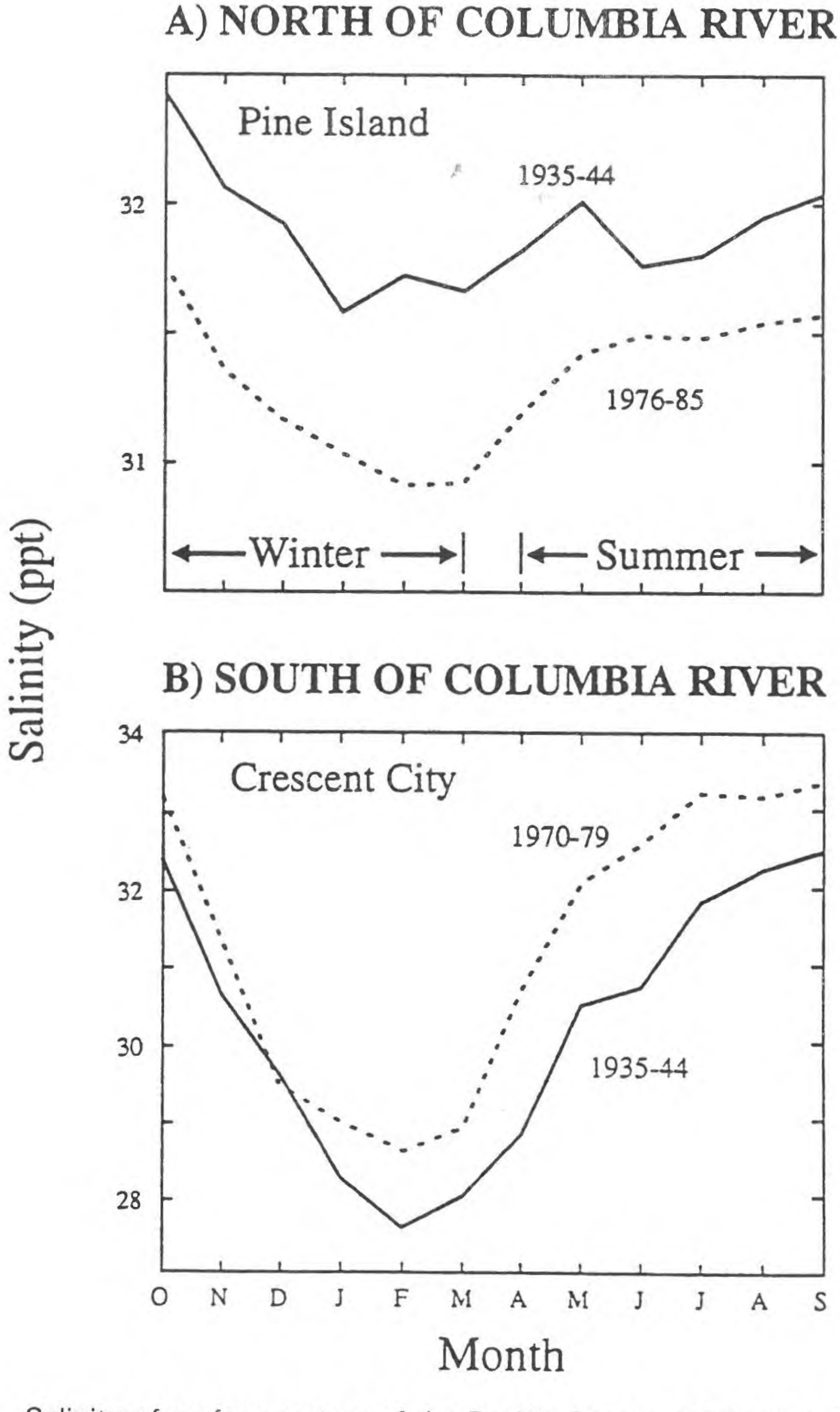


Figure 77. Salinity of surface waters of the Pacific Ocean at Crescent City, California, and Pine Island, British Columbia, 1935-1944 and 1970-1979 (Crescent City) and 1976-1985 (Pine Island), from Ebbesmeyer and Tangborn (1993).

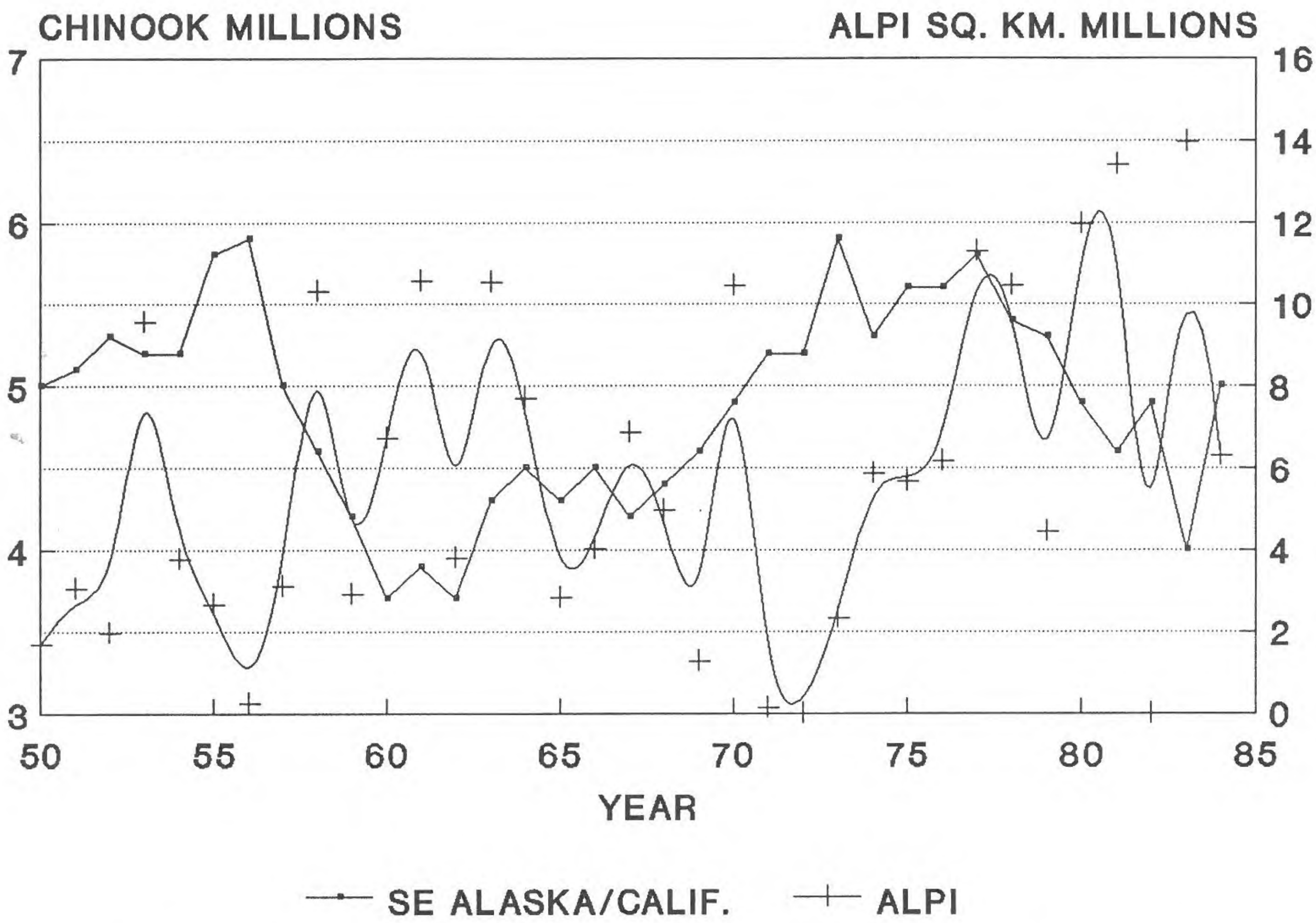


Figure 78. Chinook landings in millions from Southeast Alaska to California, from Rogers (1987), and the Aleutian Low Pressure Index (ALPI), from Beamish and Bouillon (1993). The ALPI consists of the surface area of the North Pacific covered by sea level atmospheric pressure of 100.5 kpascals or less. Smoothed curve represents the ALPI.

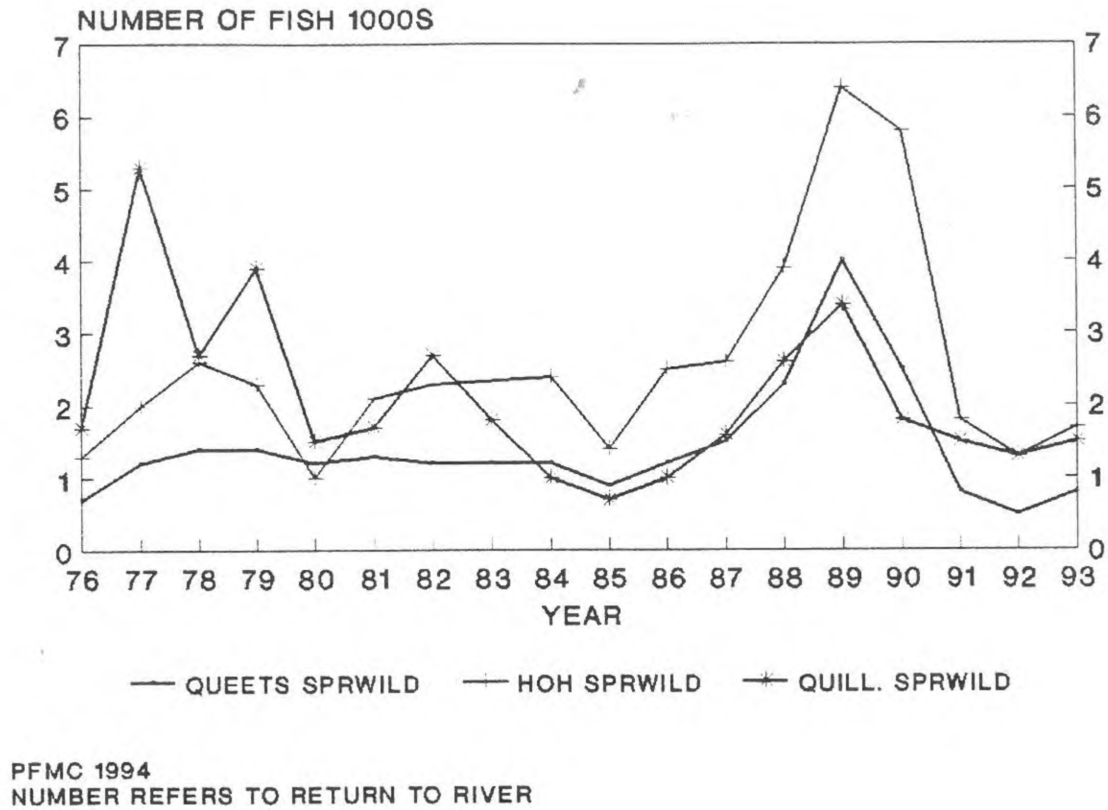
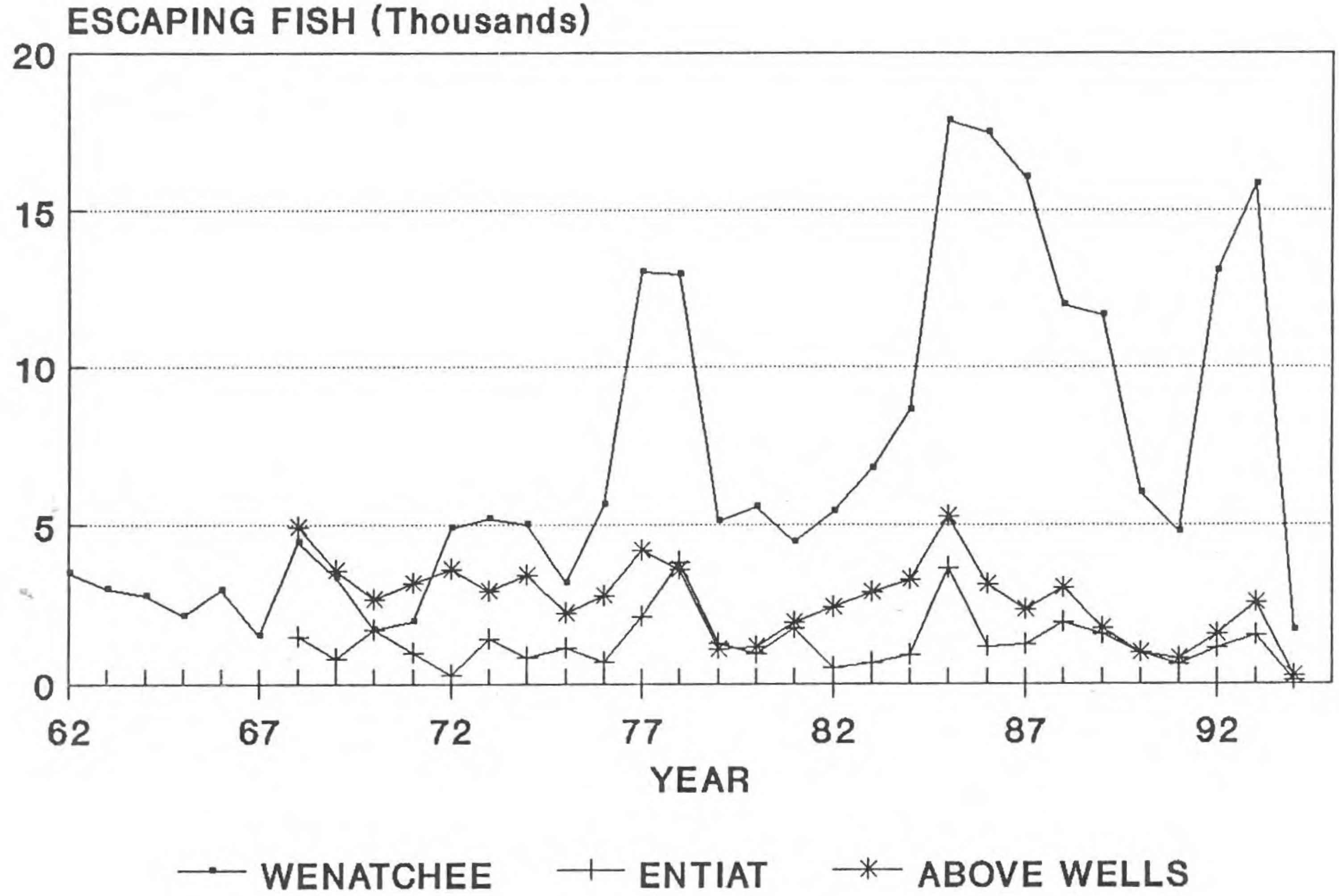


Figure 79. Queets, Hoh, Quillayute wild spring chinook terminal runs, from PFMC (1994).



68-72 WENATCHEE ESCAPEMENT DIFFERENCE BETWEEN PRIEST RAPIDS AND ROCKY REACH

Figure 80. Escapement to the Wenatchee, Entiat, and above Wells areas, based on dam count differences.

SPRING/SUMMER CHINOOK AT ICE HARBOR
AND SPRING CHINOOK AT PRIEST RAPIDS

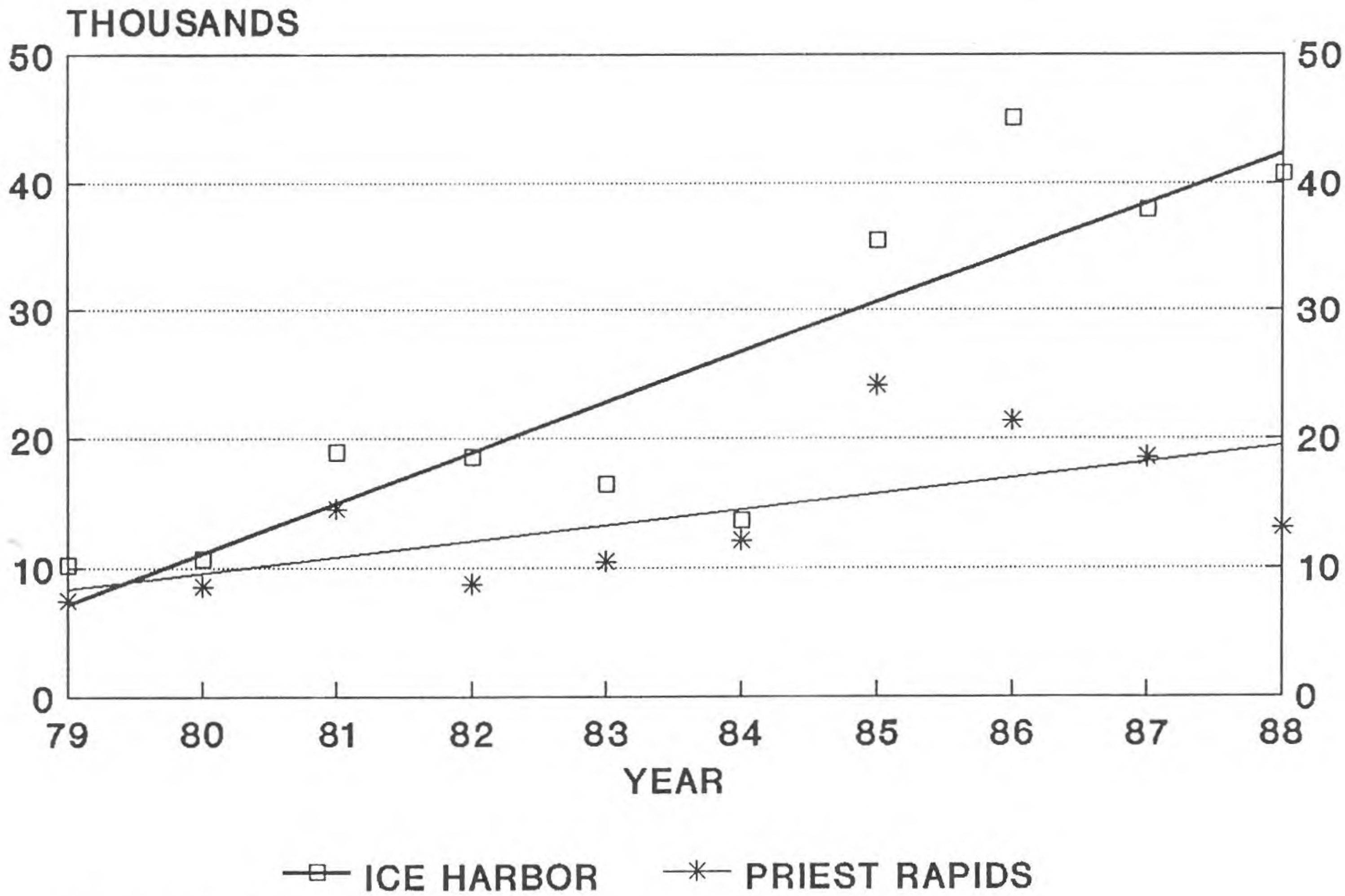


Figure 81. Escapements of spring chinook at Priest Rapids Dam, and spring/summer chinook at Ice Harbor Dam, 1979-1988, from WDFW/ODFW (1994).

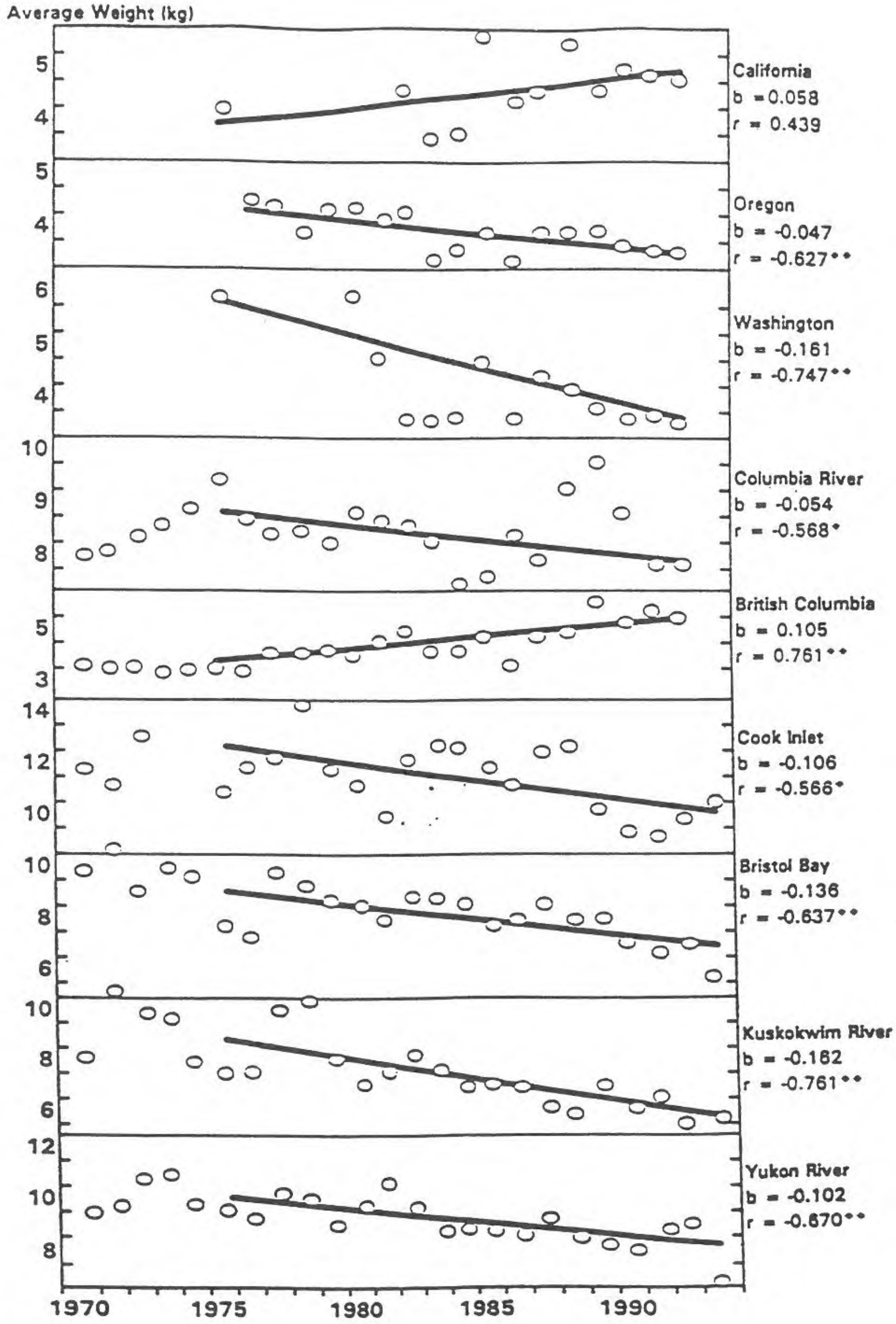


Figure 82. Average body weight of chinook salmon in harvest, 1970-1993, from Bigler and Helle (1994).

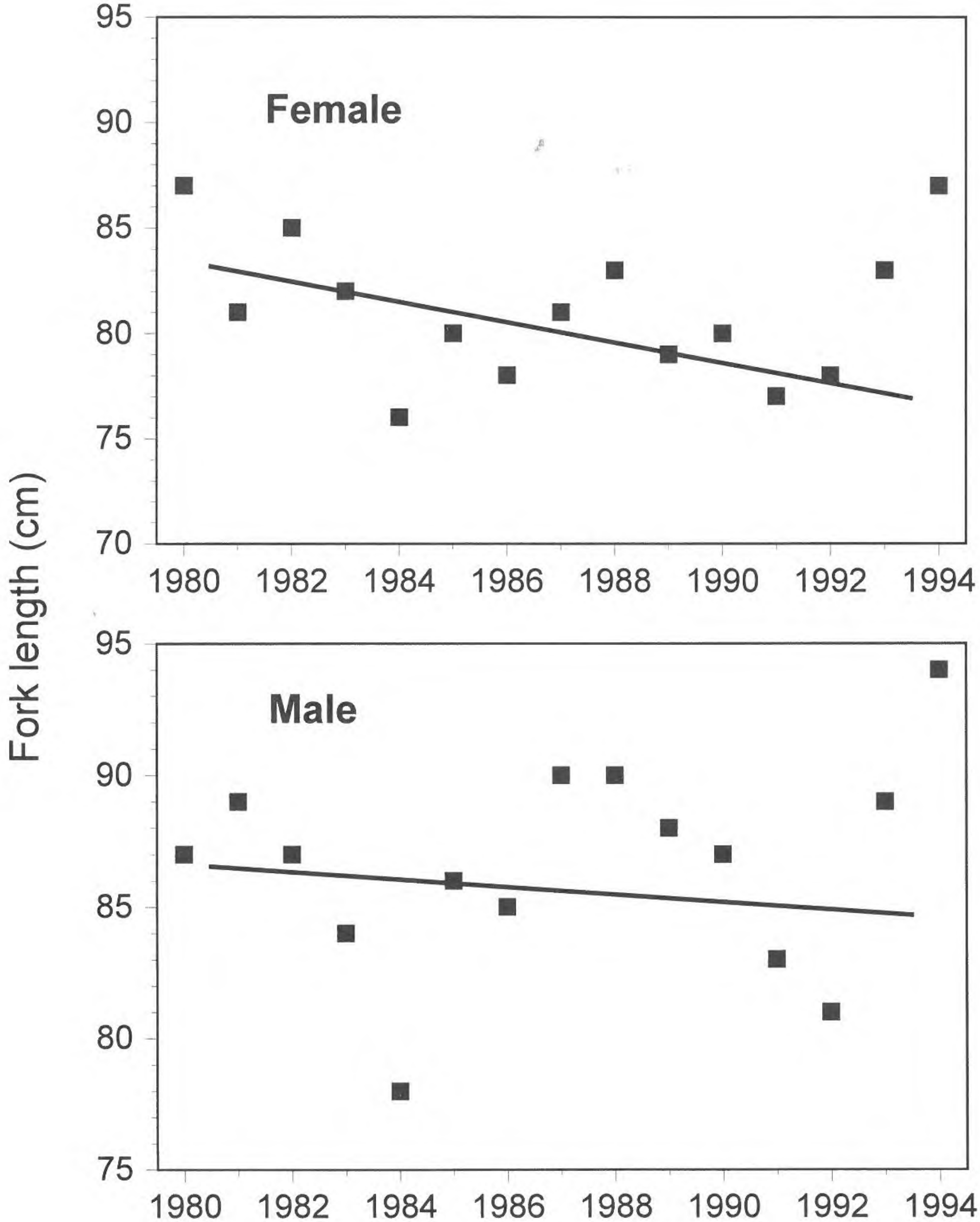


Figure 83. Average length of Leavenworth NFH spawners between 1980 and 1994, from records obtained from USFWS, B. Kelly, personal communication.

Years 1993 and 1994 are not included in the trend.

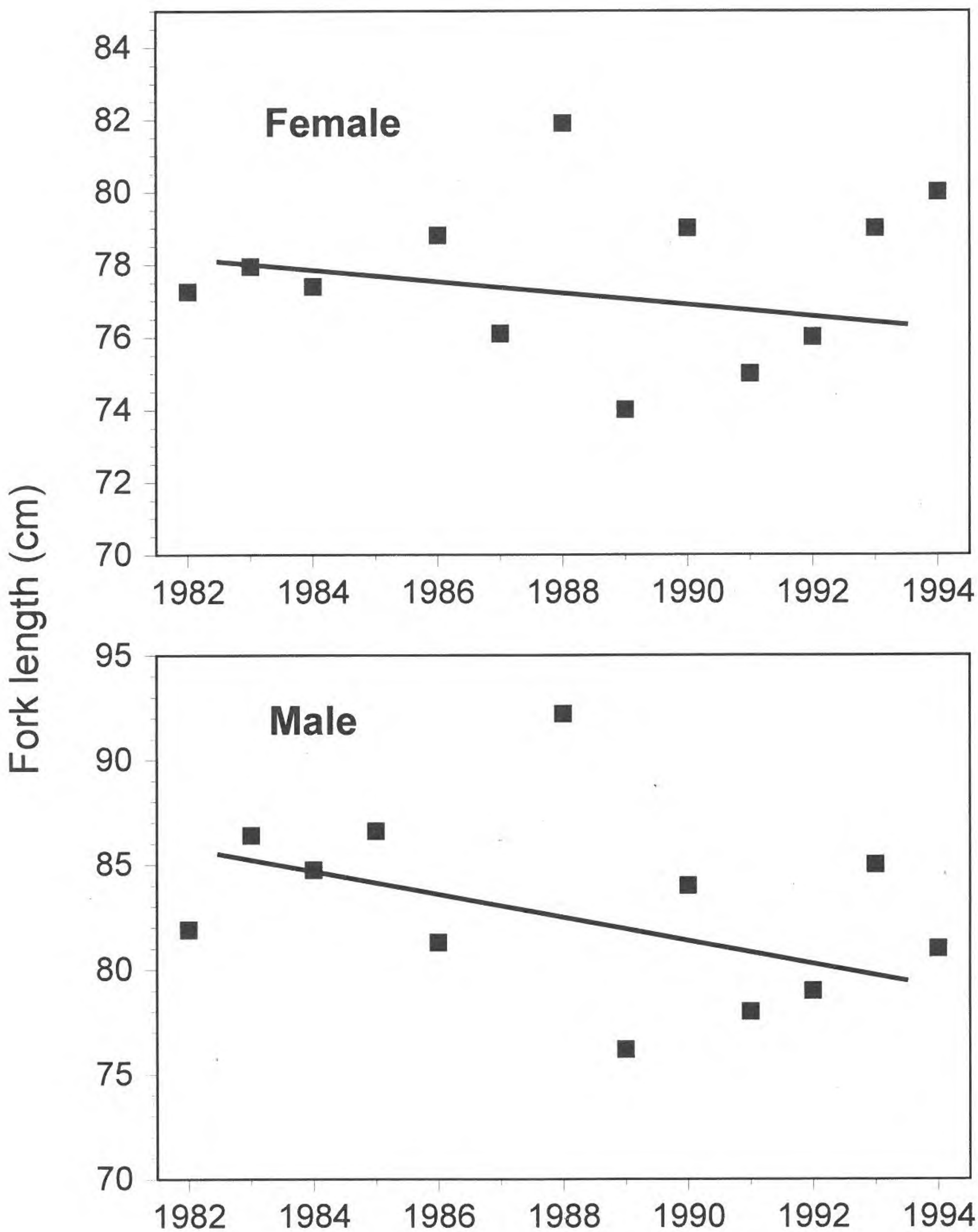


Figure 84. Average length of Entiat NFH spawners between 1982 and 1994, from records obtained from the USFWS, B. Kelly, personal communication.

No data for 1985; 1993 and 1994 are not included in the trend.

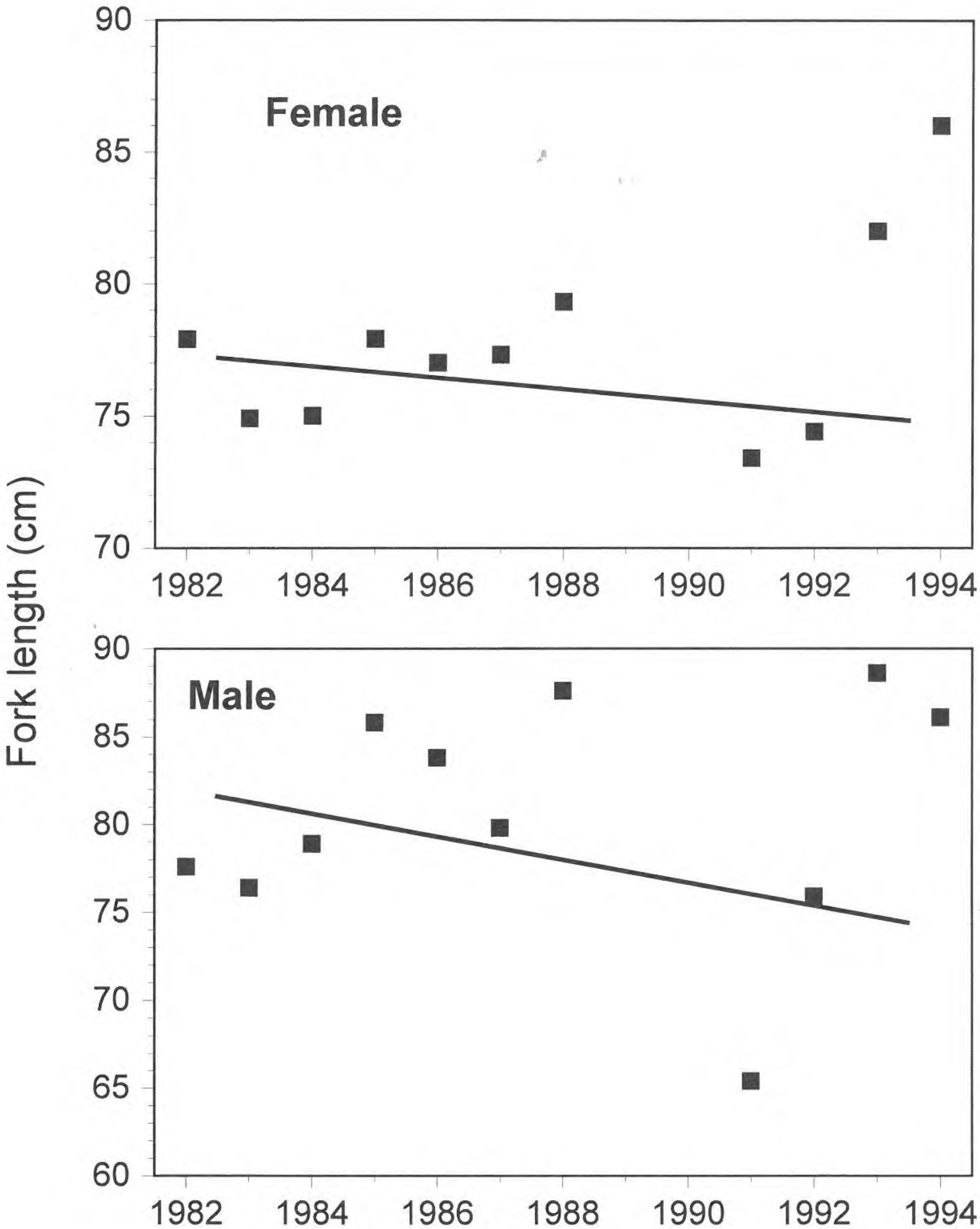


Figure 85. Average length of Winthrop NFH spawners between 1982 and 1994, from records obtained from the USFWS, B. Kelly, personal communication.

No data for 1989 and 1990; 1993 and 1994 are not included in the trend.

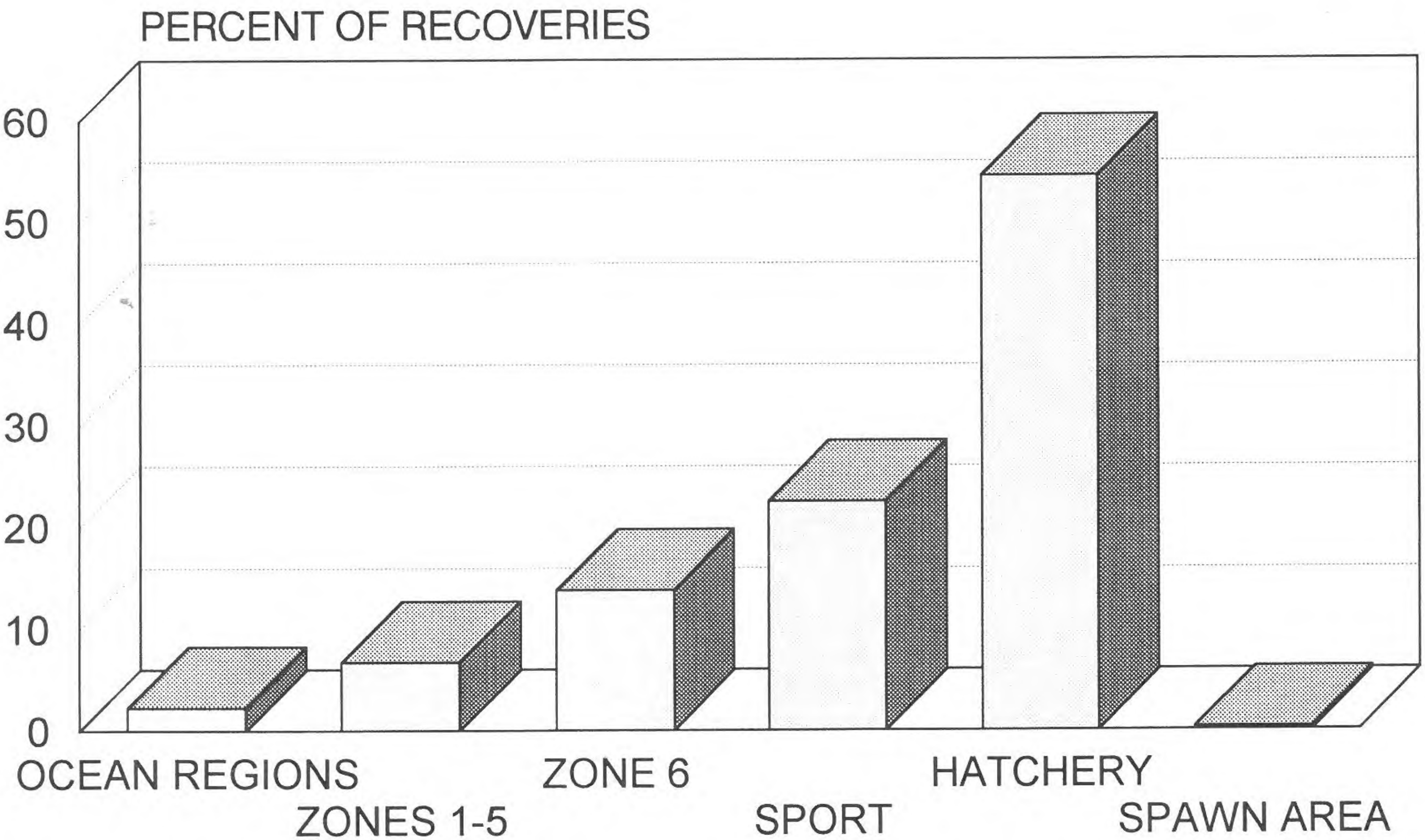


Figure 86. Percentage of coded-wire tag recoveries in various fisheries or sites for spring chinook from the mid-Columbia region, from PSMFC data base.

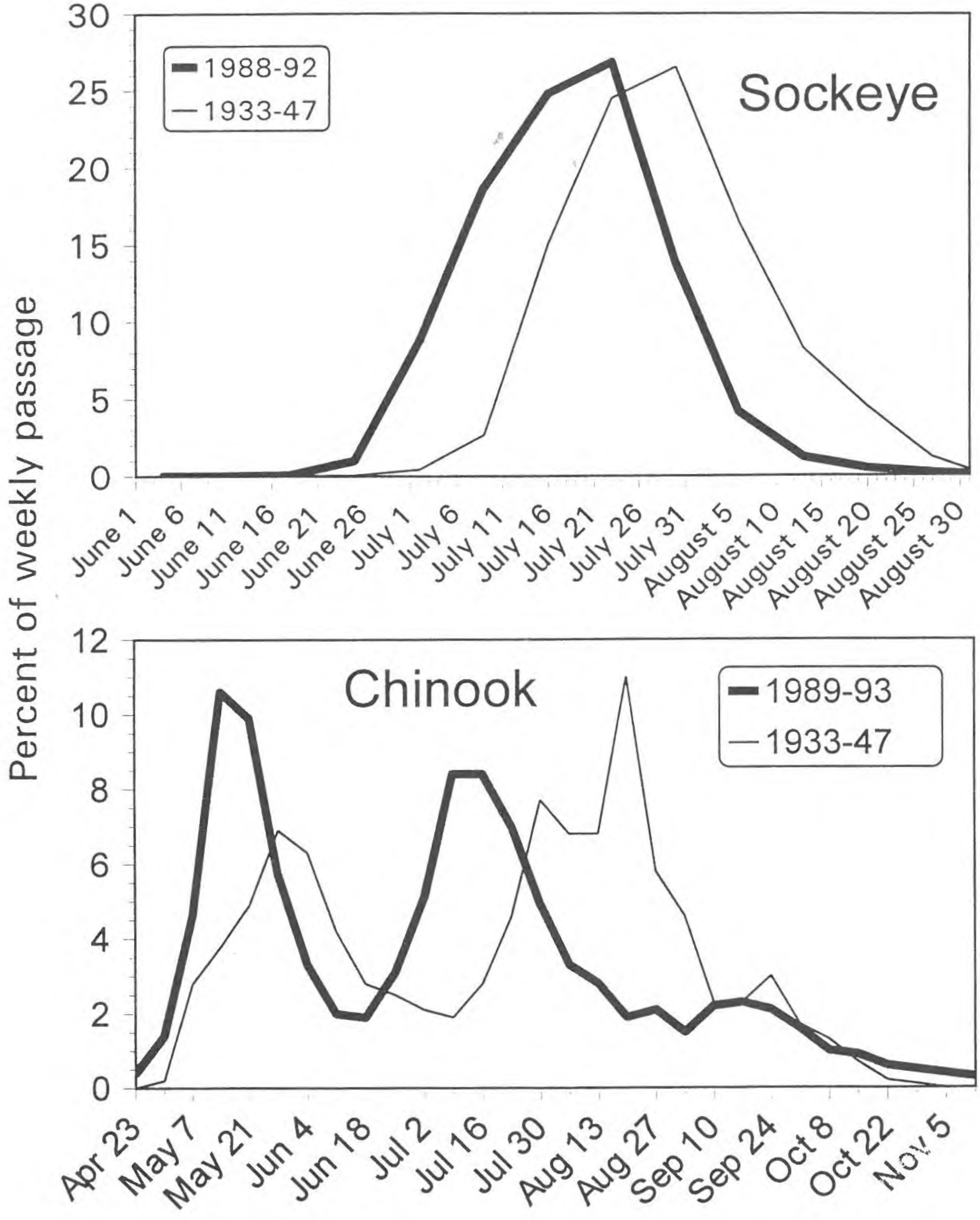


Figure 87. Run timing of adult chinook salmon passing Rock Island Dam 1933-1947 and 1989-1993, from Fish and Hanavan (1948) and Chelan PUD unpublished data.

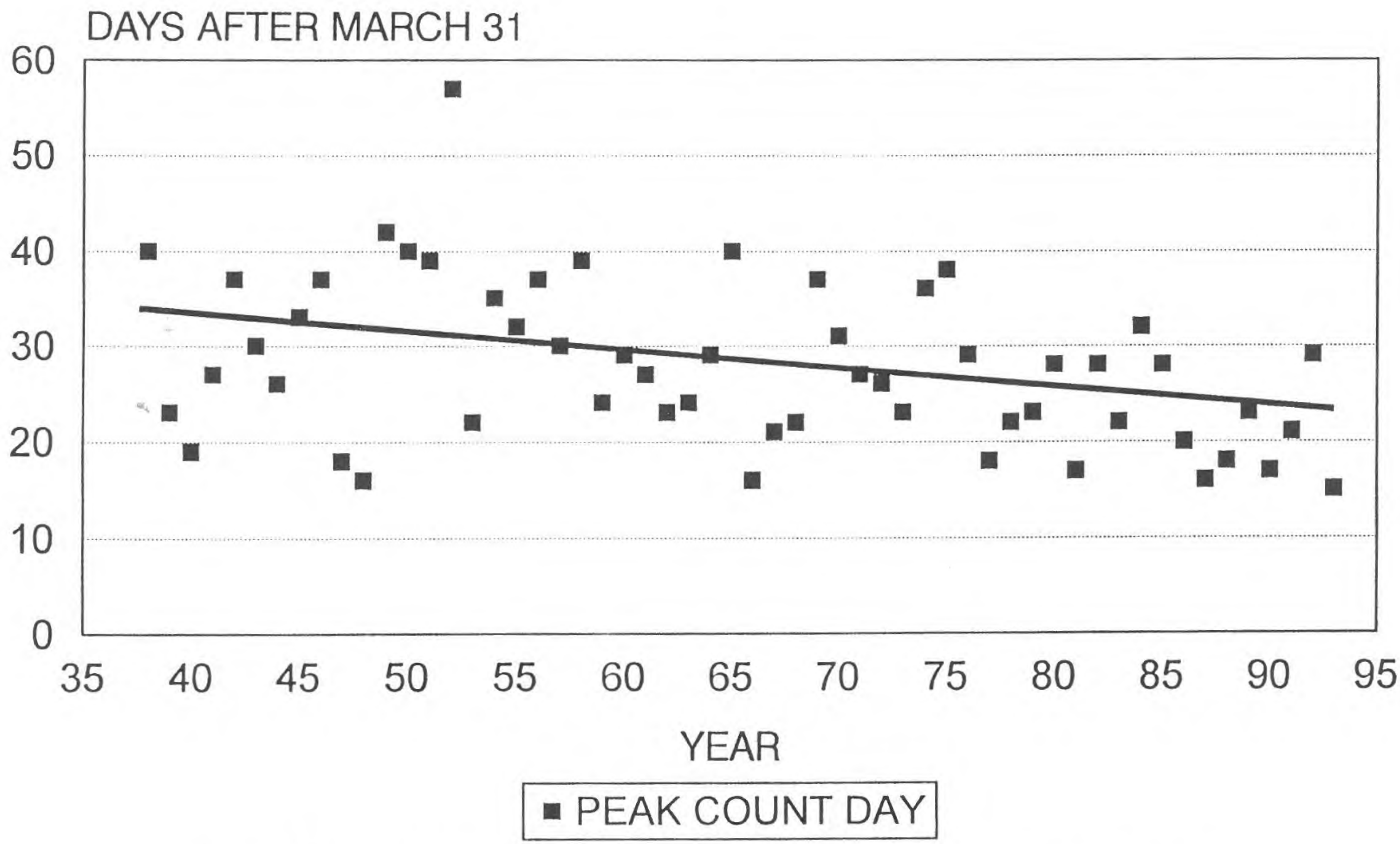


Figure 88. Day on which peak spring chinook count at Bonneville Dam occurred, 1938-1993, from Annual Fish Passage Reports of the U.S. Army Corps of Engineers.

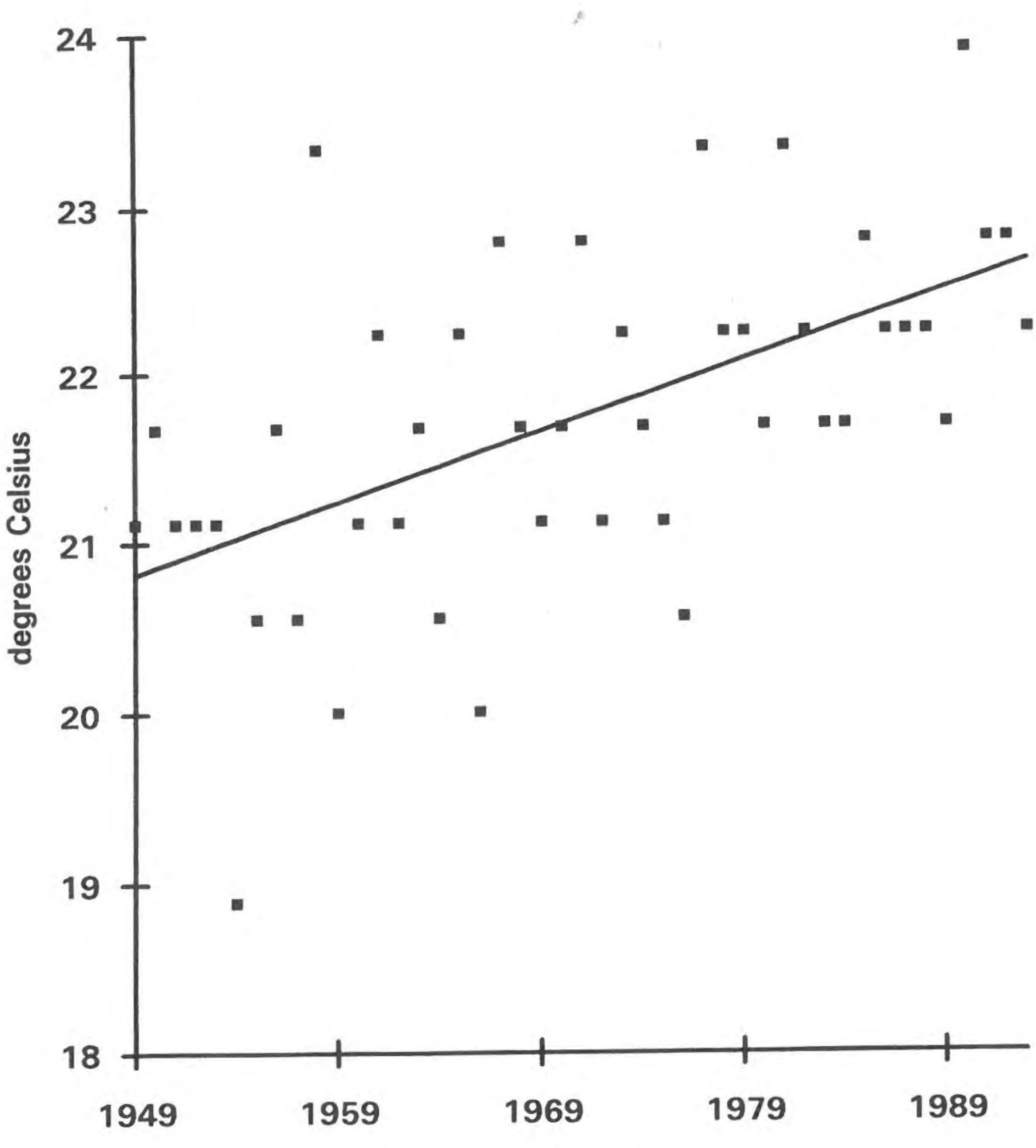


Figure 89. Annual maximum water temperature at Bonneville Dam, 1949-1993. From T. Quinn, University of Washington, personal communication.

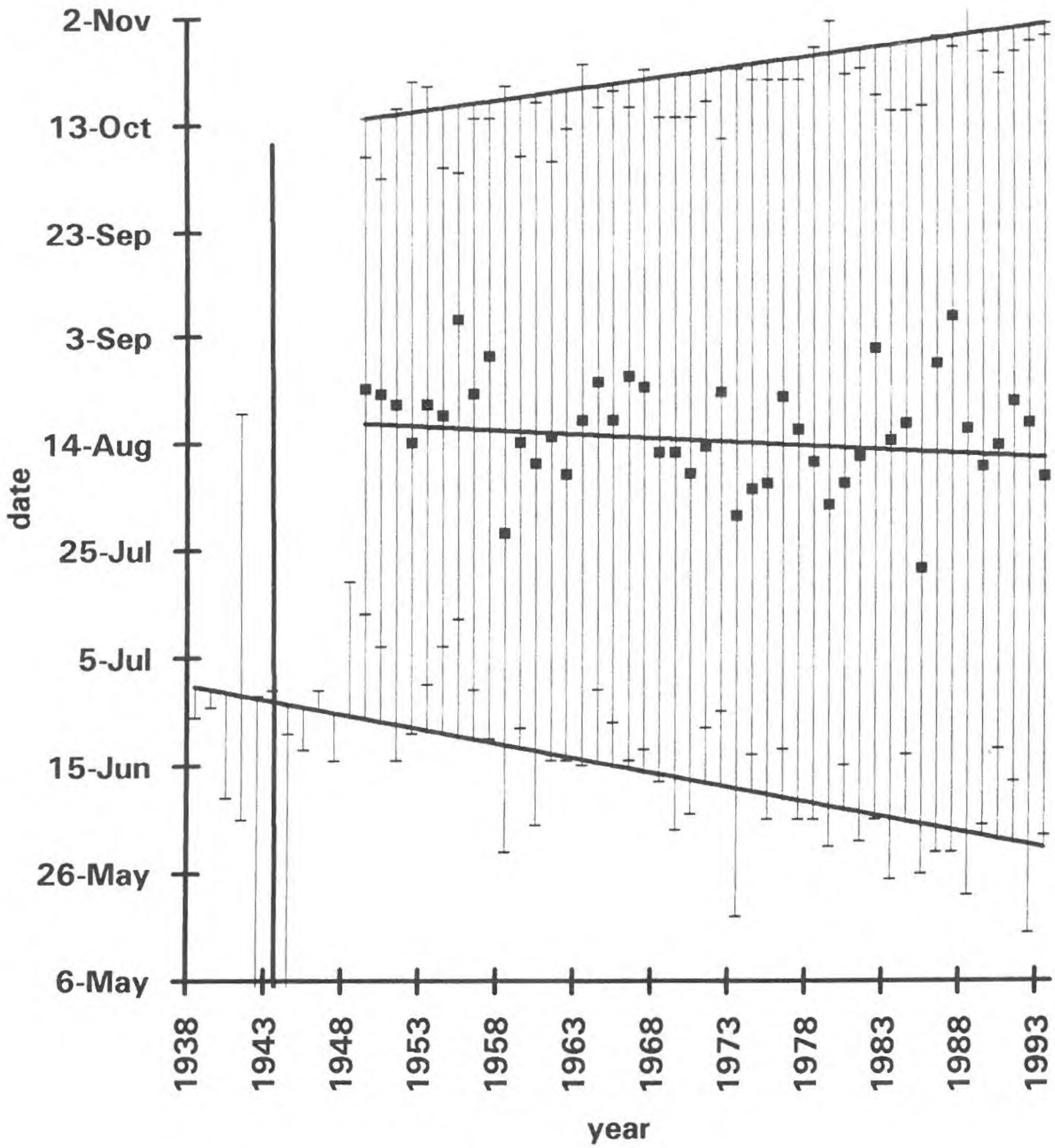


Figure 90. Date of annual maximum temperature and first and last day of temperature greater than 15.5° C at Bonneville Dam, 1938-1994. From T. Quinn, University of Washington, personal communication.

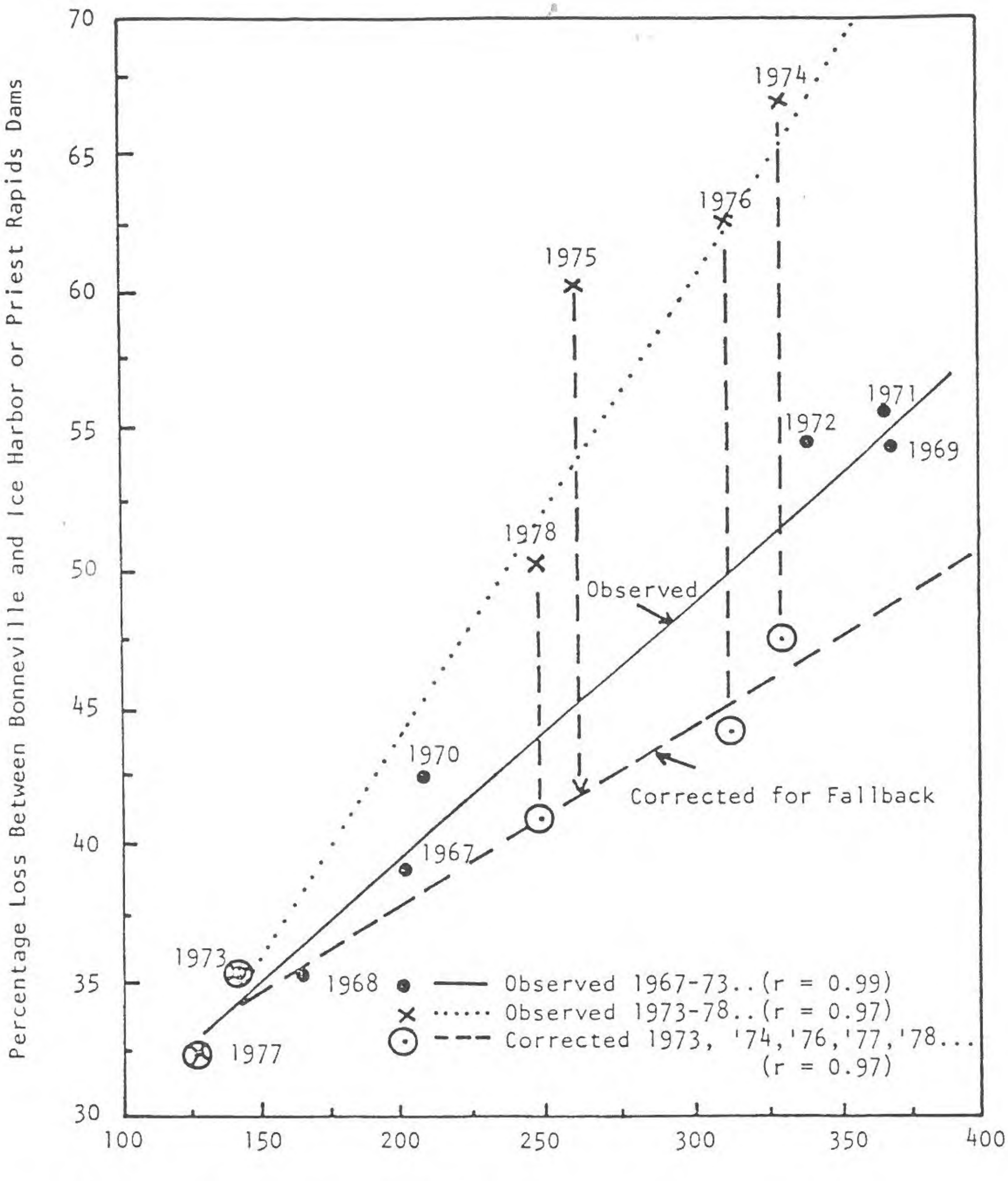


Figure 91. Estimated losses of adult spring and summer chinook between Bonneville and Ice Harbor or Priest Rapids dams minus Indian catch, related to river discharge in April and May, 1967-1978. Circled points were corrected for fallback. Points for 1973 and 1977 are both observed and corrected because no fallback was thought to have occurred in those years of very low flow. Figure from Young et al. (1978a).

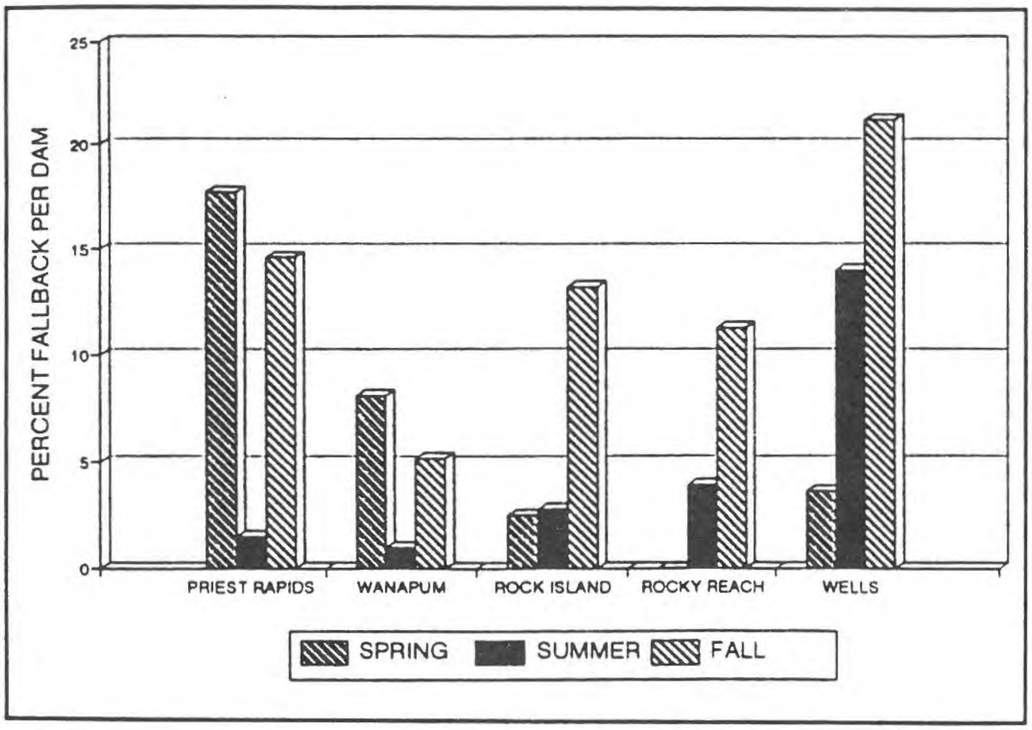


Figure 92. Fallback of radio-tagged spring, summer, and fall chinook salmon at mid-Columbia region dams, from Stuehrenberg et al. (1994).

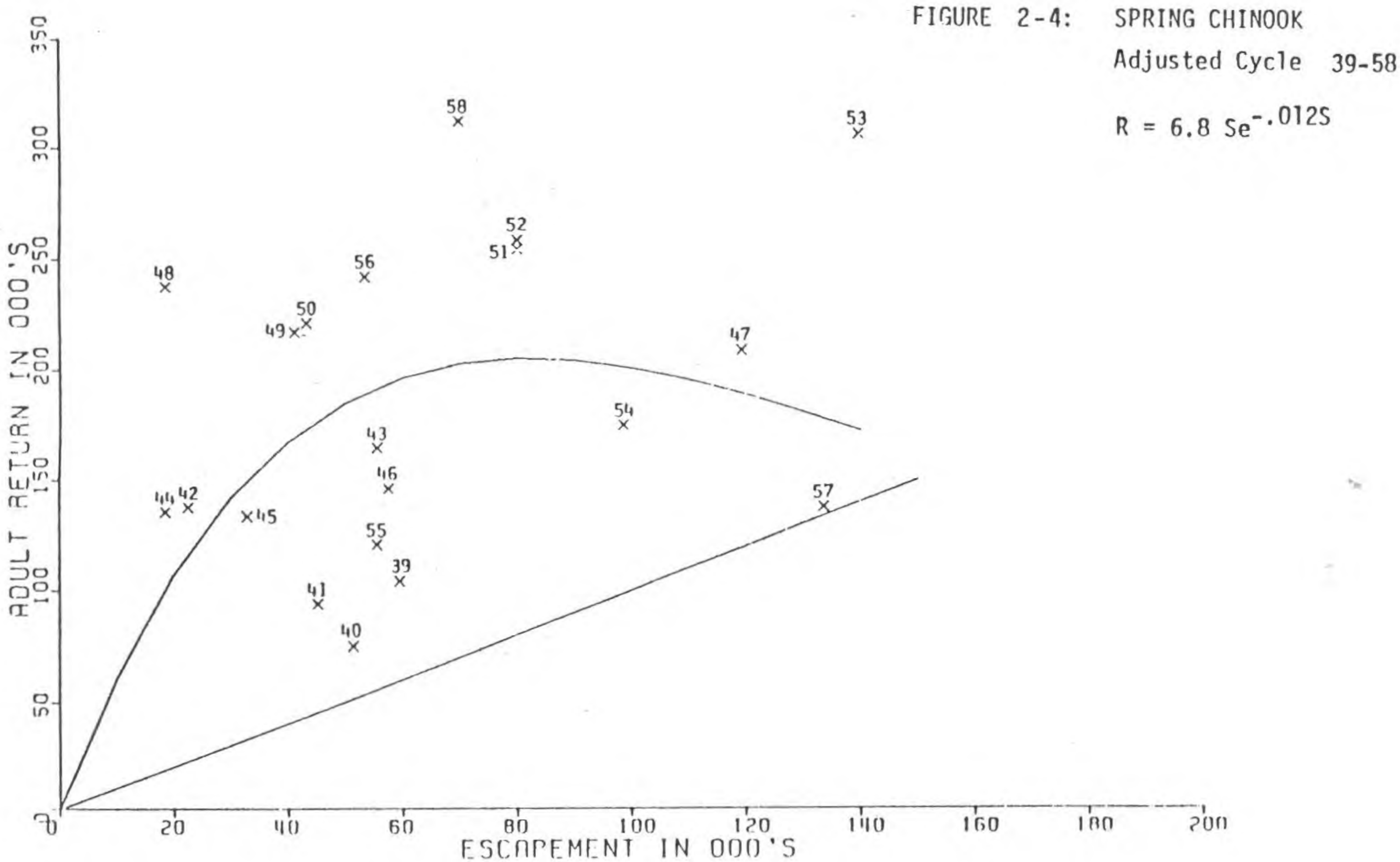


Figure 93. Stock-recruit relationship for aggregated upriver spring chinook in the Columbia River, brood years 1939-1958, from Chapman et al. (1981).

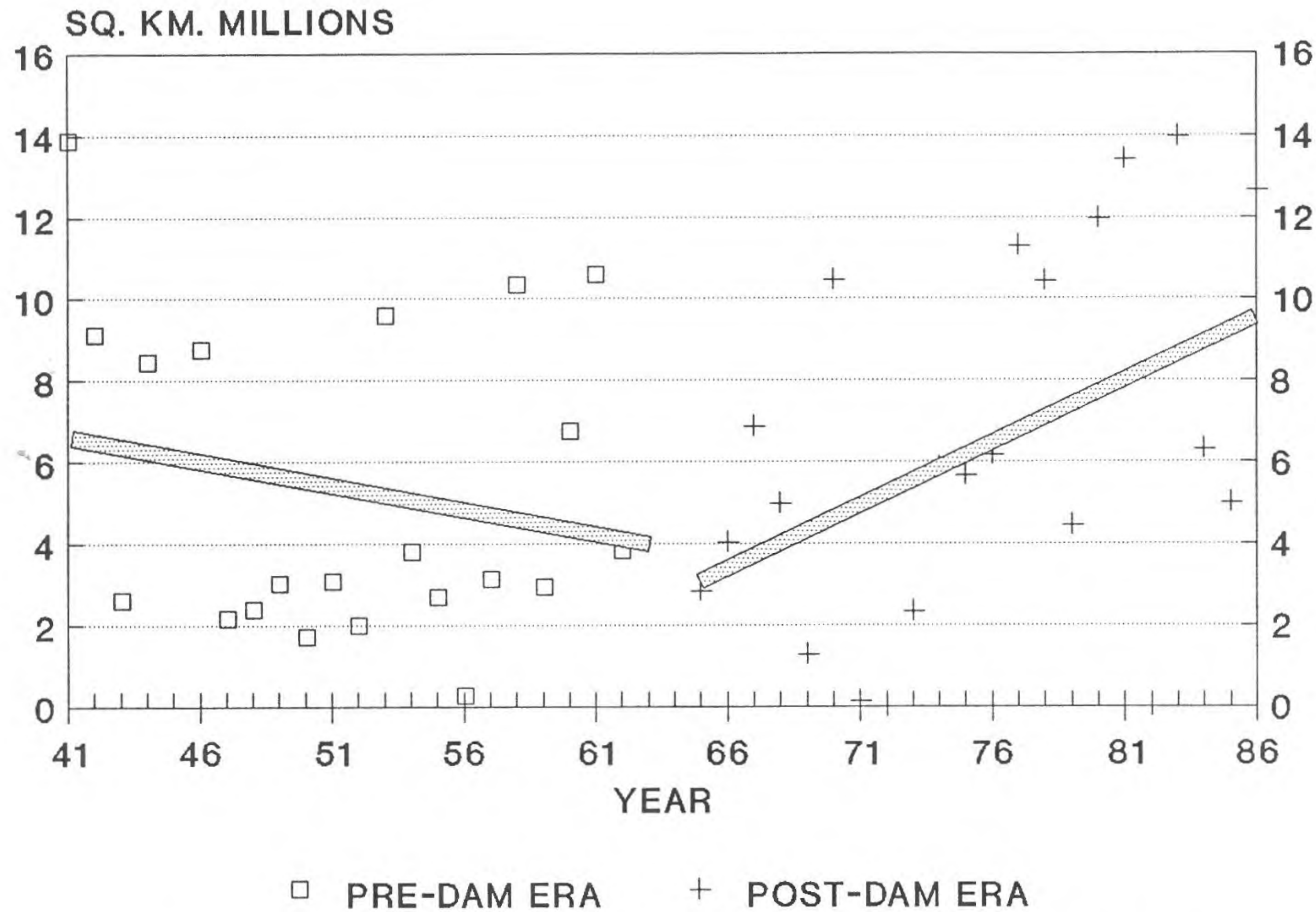


Figure 94. Aleutian Low Pressure Index, from Beamish and Bouillon (1993) for the era before (1942-1961) and after (1965-1986) most mainstem dams were completed. The ALPI is the surface area of the North Pacific covered by sea-level atmospheric pressure of 100.5 kilopascals or less.

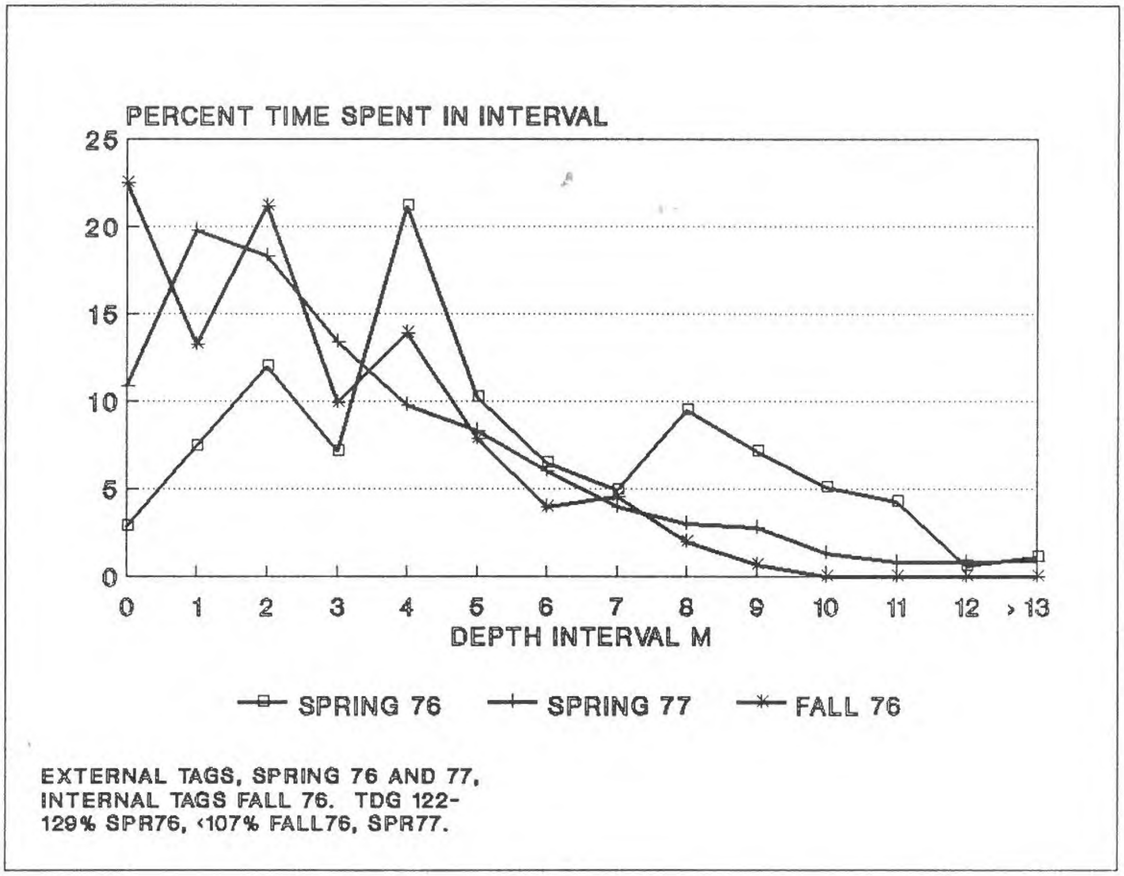


Figure 95. Percent of time that radio-tagged adult chinook salmon spent in various depth intervals, from Gray and Haynes (1977).

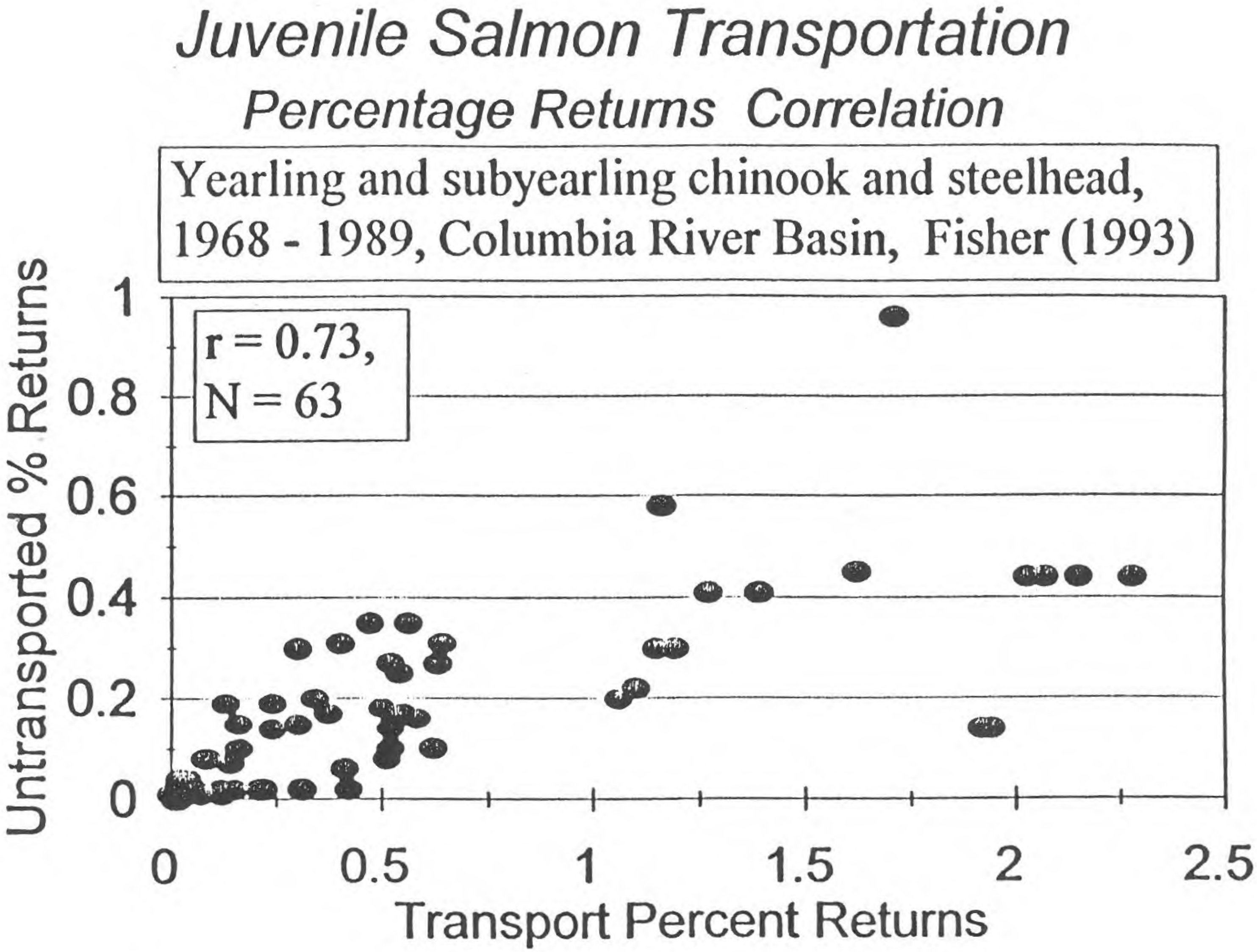


Figure 96. Correlations between observed percentage returns of adult salmon and steelhead untransported and transported, 1968-1989, from Fisher (1993) and Mundy et al. (1994).

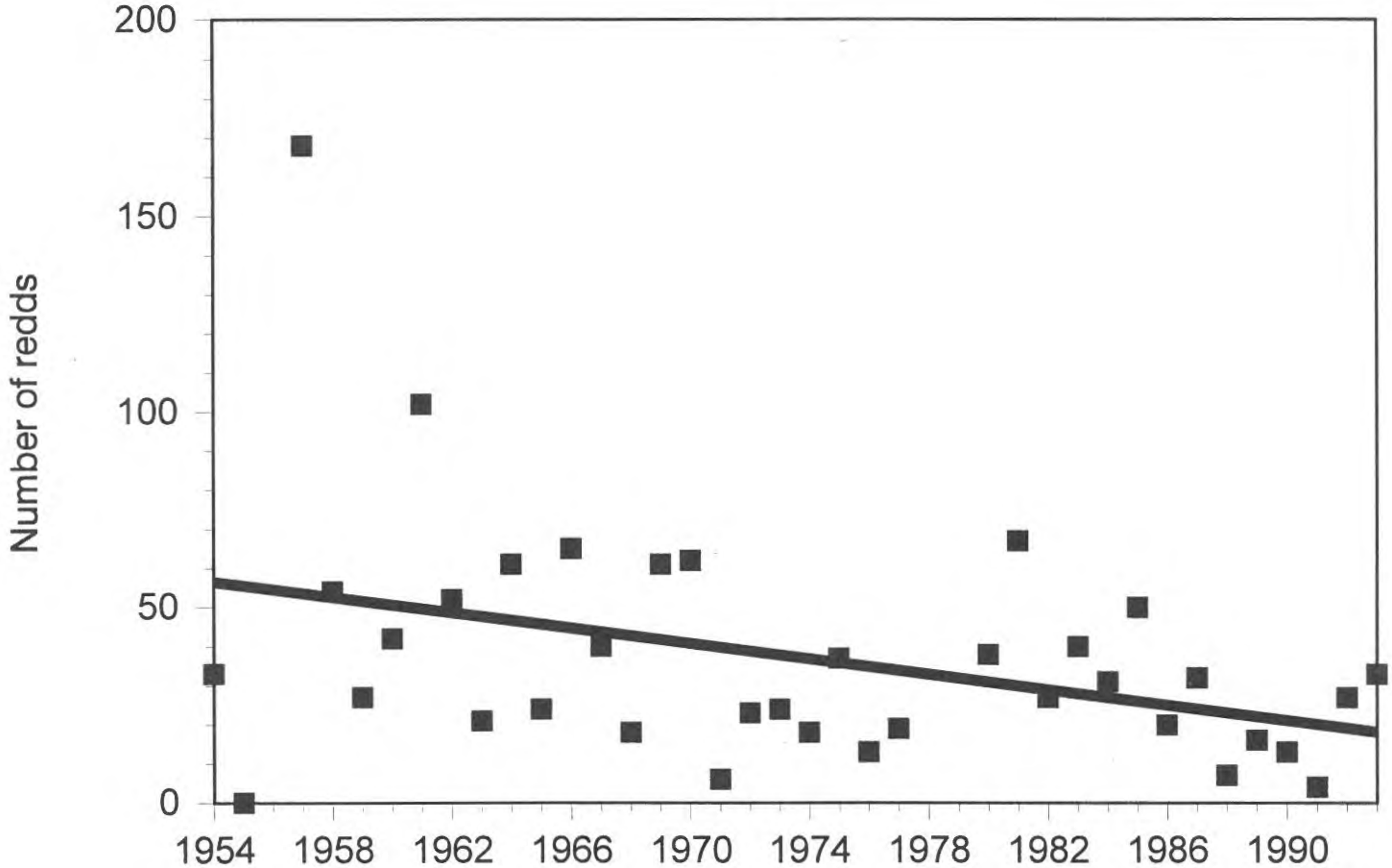


Figure 97. Number of redds observed in the Tucannon River in the historical index area (Cow Camp Creek Bridge to Camp Wooten Bridge), 1954-1993 (Mendel et al. 1993; Bumgarner et al. 1994).

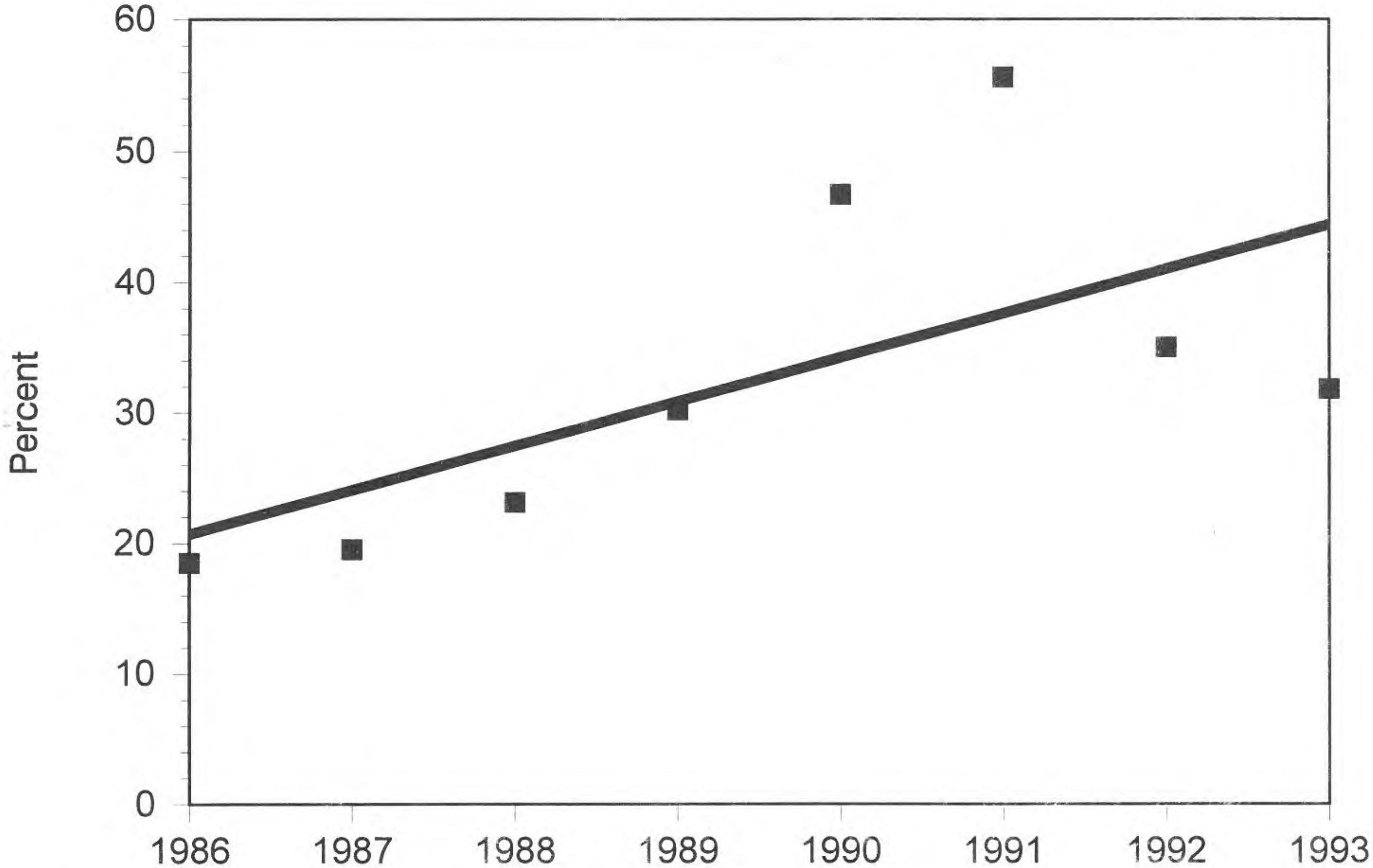


Figure 98. Percent of spring chinook redds in the Tucannon River that were observed downstream from the hatchery weir, 1986-1993 (Bumgarner et al. 1994).

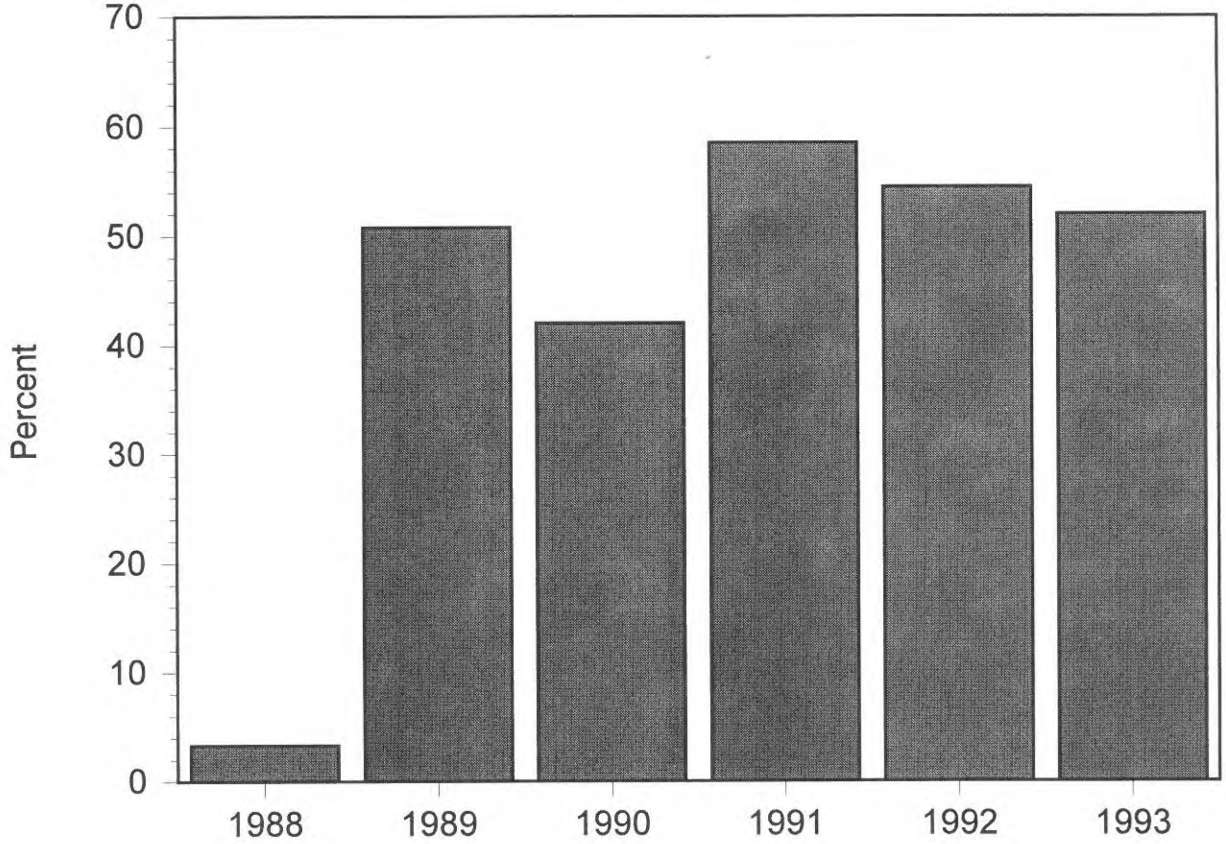


Figure 99. Approximate percentage of hatchery fish in run returning to the Tucannon River (from Bumgarner et al. 1994).

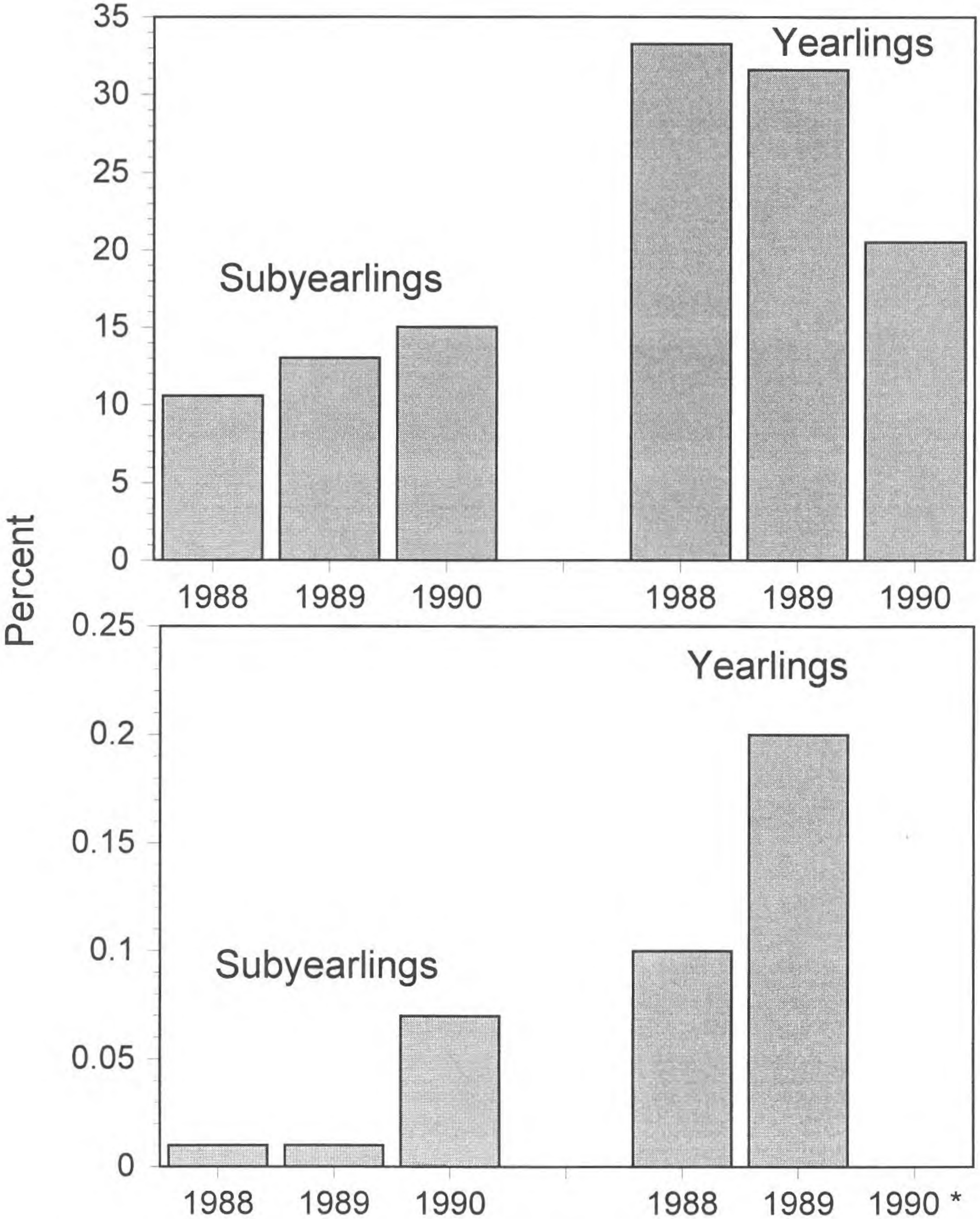


Figure 100. Percentage of juveniles captured at McNary Dam (top) and the percentage of adults returning (bottom) from releases of accelerated smolts from 1988-1990 (Sullivan 1991; and Sullivan, personal communication).

* Yearling group not tagged - no adult data available.

Table 1. Spring chinook redd counts, 1987-1993, in and out of index areas in the Methow River basin (from Scribner et al. 1993).

Year	Redds above Index area (%)	Redds within Index area (%)	Redds downstream of Index area (%)	Total redds
1987	124 (10.4)	288 (42.8)	261 (38.8)	673[1]
1988	165 (22.5)	294 (40.1)	274 (37.4)	733[2]
1989	69 (13.3)	262 (50.7)	186 (36.0)	517[3]
1990	73 (14.6)	252 (50.5)	174 (34.9)	499[4]
1991	47 (18.8)	117 (46.8)	86 (34.4)	250
1992	96 (13.0)	315 (42.7)	327 (44.3)	738[5]
1993	122 (19.8)	287 (46.5)	208 (37.7)	617

[1]An additional 7 redds were in Lake and Gold creeks for a basin total of 680.

[2]An additional 13 redds were in Lake and Gold creeks for a basin total of 746.

[3]An additional 3 redds were in Gold Creek for a basin total of 520.

[4]An additional 3 redds were in Gold Creek for a basin total of 502.

[5]An additional 3 redds were in Lake Creek for a basin total of 741.

Table 2. Run estimates for Wenatchee River spring chinook, based on dam counts and on redd expansion (from LaVoy 1995).

Year	Rock Island Dam Count	Rocky Reach Dam Count	Wenatch. turnoff	Lvnworth NFH run[1]	Wild by subtract.	Redd Count	Redd Expand[2]
1975	6153	3302	2851	827	2024	519	2675
1976	8412	3354	5059	1138	3921	396	2041
1977	18582	6211	12371	3891	8480	472	2683
1978	19228	7317	11911	2784	9127	622	3702
1979	6548	2186	4362	2177	2185	156	804
1980	7133	2023	5110	3200	1910	223	1149
1981	7776	3593	4183	2634	1549	263	1356
1982	7892	2827	5065	2998	2067	300	1546
1983	9884	3458	6426	3412	3014	542	2793
1984	12185	4063	8122	4195	3927	386	1989
1985	25848	8700	17148	8038	9110	747	3850
1986	21001	4183	16818	9189	7629	441	2273
1987	18883	3480	15403	7573	7830	545	1878
1988	16212	4823	11389	6265	5124	491	1692
1989	10690	3168	7522	5134	2388	493	1698
1990	7721	1909	5812	4373	1439	446	981
1991	5781	1323	4458	3934	524	251	552
1992	15634	2714	12920	11117	1803	491	1080
1993	19943	4128	15815	12312	3503	536	1203
1994	2041	349	1692	1118	574	125	275

[1]Includes sport and tribal harvest of hatchery fish in Icicle and Wenatchee. For 1977-78, Wenatchee harvest split equally between hatchery and wild.

[2]Highest redd count in Nason, Little Wenatchee, White, Chiwawa, upper Wenatchee index area for 1966-1989; total redds in non-Icicle areas 1990-1994. Expansion factors include 2.2 fish per redd (LaVoy 1994), 1.566 index redds/total redds, and 1.496 single/cumulative redd count from Peven and Truscott (1995).

Table 3. Run estimates for Entiat River spring chinook, based on dam counts and on redd expansion (from LaVoy 1995).

Year	Rocky Reach Dam Count	Wells Dam Count	Entiat R. turnoff	Entiat NFH run	Wild by subtract.	Redd Count	Redd Expand[1]
1975	3302	2152	1150	0	1150	156	706
1976	3354	1510	1844	0	1844	47	213
1977	5842	3976	1866	0	1866	171	774
1978	7264	3532	3732	0	3732	326	1475
1979	2015	971	1044	0	1044	[75]	339
1980	1801	941	860	305	555	107	484
1981	3458	1837	1621	247	1374	95	430
1982	2728	2270	458	247	211	107	484
1983	3355	2726	629	672	-43	107	484
1984	3832	3066	766	808	-42	85	385
1985	8518	5151	3367	912	2455	115	520
1986	4097	2896	1201	979	222	105	475
1987	3391	2272	1119	913	206	64	290
1988	4651	3024	1627	689	938	67	303
1989	3082	1633	1449	669	780	37	167
1990	1876	967	909	583	326	83	376
1991	1227	687	540	437	103	32	145
1992	2682	1542	1140	520	620	42	190
1993	4122	2601	1521	730	791	100	453
1994	349	258	91	80	11	24	109

[1]Single redd count in index area Fox Creek to Dill Creek.

Table 4. Run estimates for Methow River spring chinook (from LaVoy 1995).

Year	Wells Dam Count	Methow turnoff	Winthrop NFH run	Wild by subtract.	Redd Count	Wild run by redd Expand[1]
1975	2152	2152	0	2152	375	2699
1976	2759	2759	0	2759	121	871
1977	4211	4211	0	4211	360	2591
1978	3615	3615	38	3577	532	3829
1979	1103	1103	102	1001	109	785
1980	1182	1182	155	1027	91	655
1981	1935	1935	399	1536	97	698
1982	2401	2401	601	1800	116	835
1983	2896	2869	755	2114	179	1288
1984	3280	3280	900	2380	193	1389
1985	5267	5267	1201	4066	256	1843
1986	2961	2961	836	2125	186	1339
1987	2346	2346	594	1752	673	1481
1988	3126	3126	1327	1799	733	1613
1989	1720	1720	195	1525	517	1137
1990	981	981	121	860	482	1060
1991	785	785	92	639	250	550
1992	1573	1573	332	1241	738	1624
1993	2628	2628	744	1884	647	1357
1994	258	258	46	212	133	293

[1]Index redd counts 1975-1986 (Peven 1992), total 1987-1994 (Meekin 1993; Scribner et al. 1993; Hubble 1995). Expansions include 2.2 fish/redd (LaVoy 1994, 2.187 index / total redds from 1987-1993 average and 1.496 single / cumulative redd count.

Table 5. Spring chinook estimated run sizes and 5% interdam loss expansion, as a fraction of actual Rock Island Dam count (adapted from LaVoy 1995).

Year	Lvnworth NFH run size	Entiat NFH run size	Winthrop NFH run size	Wenatch. wild from redd exp.	Entiat wild from redd exp.	Methow wild from redd exp.	Total	Total after 5% loss exp.[1]	Rock Island count	Total / Rock Isl. count
1975	827	0	0	2675	706	2699	6907	7236	6153	1.176
1976	1138	0	0	2041	213	871	4263	4368	8413	0.519
1977	3891	0	0	2683	774	2591	9939	10259	18582	0.552
1978	2784	0	38	3702	1475	3829	11828	12324	19228	0.641
1979	2177	0	102	804	339	785	4207	4320	6548	0.66
1980	3200	305	155	1149	484	655	5949	6078	7133	0.852
1981	2634	247	399	1356	430	698	5764	5918	7776	0.761
1982	2998	247	601	1546	484	835	6711	6905	7892	0.875
1983	3412	672	755	2793	484	1288	9405	9687	9884	0.98
1984	4195	808	900	1989	385	1389	9666	9976	12185	0.819
1985	8038	912	1201	3850	520	1843	16364	16768	25848	0.649
1986	9189	979	836	2273	475	1339	15091	15402	21001	0.733
1987	7573	913	594	1878	290	1481	12728	13015	18883	0.689
1988	6265	689	1327	1692	303	1613	11888	12258	16212	0.756
1989	5134	669	195	1698	167	1137	9//1	9189	10690	0.86
1990	4373	583	121	981	376	1060	7494	7672	7721	0.994
1991	3934	437	92	552	145	550	5710	5810	5781	1.005
1992	11117	520	332	1080	190	1624	14863	15112	15634	0.967

Table 5. Concluded.

Year	Lvnworth NFH run size	Entiat NFH run size	Winthrop NFH run size	Wenatch. wild from redd exp.	Entiat wild from redd exp.	Methow wild from redd exp.	Total	Total after 5% loss exp.[1]	Rock Island count	Total / Rock Isl. count
1992	11117	520	332	1080	190	1624	14863	15112	15634	0.967
1993	12312	730	744	1179	453	1357	16775	17065	19943	0.856
1994	1118	80	46	275	109	293	1921	1967	2041	0.964
Mean	4815	440	422	1811	440	1397	9325	9568	12377	0.815

[1]Entiat and Methow run sizes expanded for 5% loss passing Rockey Reach and Wells dams.

Table 6. Spring chinook released and later examined as carcasses in Nason Creek, 1939-1943 (from Fish and Hanavan 1948).

Year	Number Released	Number Recovered	Percent Recovered	Spawned	Percent Spawned	Recovered Unspawned	Percent Unspawned
1939	3,957	423	11	327	77	96	23
1940	3,165	574	18	387	67	187	33
1941	1,251	417	33	156	37	261	63
1942	1,014	255	25	129	51	126	49
1943[1]	1,191	243	20	209	86	34	14

Table 7. Numbers of spring chinook potentially available for artificial culture (difference between Rock Island Dam counts and numbers of fish delivered to Nason Creek natural spawning area, the only area in which spring chinook were confined), number of adult fish shown as received, and artificially spawned (females) (from Fish and Hanavan 1948).

Year	Rock Island Dam Counts	Fish delivered to Nason Creek	Potential adults	Adult fish "received"	Adults unaccounted for
1939	4,256	3,957	299	-	299
1940	4,328	3,165	1,163	922	241
1941	1,610	1,251	359	-	359
1942	1,359	1,014	345	45	300
1943	7,374	1,191	6,183	5,560	623

[1]Flood in May destroyed rack, which was rebuilt by late July. Fish and Hanavan (1948) thought that most of the spring chinook delivered to the stream spawned there, as they were progeny of the transplanted 1939 run. some fish may have spawned elewhere

Table 8. Counts of spring chinook at Rock Island Dam using different separation dates, or the nadir in the counts between spring and summer chinook.[1]

Return year	ACE cut-off (6/ 17)	PUD cut-off (6/23)	Nadir	COE v nadir	PUD v nadir
1975	6,153	6,532	6,298	-145	-234
1976	8,413	9,065	9,417	-1,004	352
1977	18,582	19,382	17,602	980	-1,780
1978	19,228	20,406	18,316	912	-2,090
1979	6,548	7,520	6,066	482	-1,454
1980	7,133	7,664	6,646	487	-1,018
1981	7,776	8,130	8,130	-354	0
1982	7,892	8,337	8,573	-681	236
1983	9,884	10,277	10,372	-488	95
1984	12,185	12,774	12,246	-61	-528
1985	25,848	26,758	25,349	499	-1,409
1986	21,001	21,759	20,343	658	-1,416
1987	18,883	19,604	18,764	119	-840
1988	16,212	16,925	16,017	195	-908
1989	10,630	11,986	10,261	369	-1,725
1990	7,721	7,963	7,671	50	-292
1991	5,781	6,192	5,962	-181	-230
1992	15,634	16,126	15,223	411	-903
1993	19,943	20,801	21,064	-1,121	263
1994	2,041	2,371	1,951	90	-420
Average	12,374.4	13,028.6	12,313.5		
% diff. from nadir	0.48	5.5			

[1] The Army Corps of Engineers (ACE) uses June 17 and Chelan Public Utility District (PUD) uses June 23 as cut-off dates.

Table 9. Summary of adult age estimates from spring chinook sampled in the tributaries of the mid-Columbia basin, 1986-1993, from this study.

		Age (#s)				Age (%)		
Stream	Sex	1.1	1.2	1.3	Total	1.1	1.2	1.3
Chiwawa R	Male	3	46	48	97	3.09	47.42	49.48
Little Wen. R.	Male	2	9	7	18	11.11	50.00	38.89
Nason Cr.	Male	11	55	37	103	10.68	53.40	35.92
White R.	Male		75	34	109	0.00	68.81	31.19
Methow R.	Male		1	4	5	0.00	20.00	80.00
Twisp R.	Male		7	4	11	0.00	63.64	36.36
Chewack R.	Male	3	26	5	34	8.82	76.47	14.71
Total	**Male**	**19**	**219**	**139**	**377**	**5.04**	**58.09**	**36.87**
Chiwawa R	Female		116	74	190	0.00	61.05	38.95
Little Wen. R.	Female		1	1	2	0.00	50.00	50.00
Nason Cr.	Female		103	63	166	0.00	62.05	37.95
White R.	Female		55	43	98	0.00	56.12	43.88
Methow R.	Female		6	9	15	0.00	40.00	60.00
Twisp R.	Female		8	10	18	0.00	44.44	55.56
Chewack R.	Female		17	18	35	0.00	48.57	51.43
Total	**Female**	**0**	**306**	**218**	**524**	**0.00**	**58.40**	**41.60**

Age estimates of hatchery produced fish from the Rock Island Fish Hatchery Complex (sampled in the Wenatchee River basin) are included from the 1993 sample year.

Table 10. Summary of adult spring chinook ages and lengths, from carcasses sampled in mid-Columbia region tributaries, 1986-1993, from this study.

Stream	Sex	Age	Length (cm) Avg.	Min.	Max.	N.
Chiwawa R.	Female	1.2	63	51	77	116
		1.3	72	54	80	74
Lit. Wenatchee R.	Female	1.2	62			1
		1.3	69			1
Nason Cr.	Female	1.2	62	52	73	103
		1.3	72	63	80	63
White R.	Female	1.2	64	42	78	55
		1.3	72	57	79	43
Methow R.	Female	1.2	67	63	69	6
		1.3	75	72	78	9
Twisp R.	Female	1.2	64	57	74	8
		1.3	72	59	88	10
Chewack R.	Female	1.2	59	54	64	17
		1.3	71	61	88	18
Chiwawa R.	Male	1.1	45	37	57	3
		1.2	61	54	76	46
		1.3	77	57	88	48
Lit. Wenatchee R.	Male	1.1	49	43	55	2
		1.2	61	54	70	9
		1.3	72	68	78	7
Nason Cr.	Male	1.1	48	34	59	11
		1.2	62	51	79	55
		1.3	76	65	86	37
White R.	Male	1.1				
		1.2	64	44	74	75
		1.3	75	65	83	34
Methow R.	Male	1.1				0
		1.2	67			1
		1.3	79	74	89	4
Twisp R.	Male	1.1				0
		1.2	64	55	75	7
		1.3	79	71	84	4
Chewack R.	Male	1.1	51	49	52	3
		1.2	59	48	73	26
		1.3	77	68	84	5

Table 11. Summary of fecundity of Methow River basin spring chinook collected for the supplementation program in the Methow River (from H. Bartlett, WDFW, personal communication).

Stream	Year(s)	Average	Min.	Max.	St. dev.	N
Twisp	1992-94	5,136	3,263	6,851	902	35
Chewack	1992-93	5,210	2,938	8,056	970	68
Methow	1993-94	4,958	2,632	7,453	1,172	23
Overall		5,143	2,632	8,056	988	126

Table 12. Summary of the average fecundity and length (POH) per age group of spring chinook salmon collected for the supplementation program in the Methow River (from H. Bartlett, WDFW, personal communication).

	Age					
	1.2			1.3		
Stream	Fecundity	Length (cm)	N	Fecundity	Length (cm)	N
Twisp	4,293	62	9	5,562	72	19
Chewack	4,247	60	11	5,442	70	43
Methow	4,315	62	1	5,041	72	7
Overall	4,270	61	21	5,434	71	69

Table 13. Summary of releases of chinook salmon (in thousands) from the Wenatchee and Methow hatcheries, 1899-1932 (from Craig and Suomela 1941).

	Wenatchee				Methow			
Year	Eggs taken	Eggs received	Donor stock	Fry planted	Eggs taken	Eggs received	Donor stock	Fry planted
1899				7,810				
1900				6,025				153
1901								
1902				7,935				2,969
1903				600				100
1904-1907				No releases				
1908					10			
1909					8			
1910					31			
1911					68			
1912					5			
1913								
1914		2,076	52% from Willamette	1,038				
1915	105	1,350	Willamette, McKenzie					
1916		1,872	Chinook Hatchery	1,464	2			3
1917			1500	1,384		1,500		3,136
1918-1925				No releases				
1926		600	Little White			400		400
1927		1,750		593		700	Quilcene	593
1928		1,650		1,703		500		230
1929		1,500		1,633		500		761
1930				1,445				99
1931						500	Little White	
1932		2,000	(lost-frozen at Chiwkm.)					

Species not specified for fry plants between 1899-1903.
Fry plant in Methow in 1931 "planted in lakes."

Table 14. Summary of the estimated return by brood year and smolt-to-adult survival of spring chinook released from the Leavenworth NFH.

	Smolts		Adult returns							
				Age at return (yrs)				Total	Smolt-to-adult	Corrected smolt-adult
Hatchery	Release year	Number released[1]	Year	1.1	1.2	1.3	1.4[2]	per brood	survival (%)[3]	survival[4]
Leavenworth	1978	1,879,000						**2,446**	0.13	0.21
	1979	1,154,036	1979	**65**				3,270	0.28	0.45
	1980	2,229,325	1980	128	**885**			3,287	0.15	0.24
	1981	2,381,147	1981	37	1,101	**1,496**		2,069	0.09	0.14
	1982	1,878,286	1982	87	870	2,041		5,082	0.27	0.43
	1983	1,906,488	1983	47	985	2,380		8,382	0.44	0.70
	1984	2,316,480	1984	285	2,913	997		11,121	0.48	0.77
	1985	2,242,800	1985	246	5,670	2,122	0	6,914	0.31	0.49
	1986	2,073,778	1986	222	6,540	2,427	0	4,016	0.19	0.31
	1987	2,417,768	1987	205	3,033	4,335	0	5,880	0.24	0.39
	1988	2,207,294	1988	41	2,579	3,645	0	3,787	0.17	0.27
	1989	2,239,677	1989	87	3,801	1,232	14	6,229	0.28	0.44
	1990	2,304,237	1990	60	2,275	2,038	0	14,293	0.62	0.99
			1991	115	2,399	1,420	0			
			1992		7,220	3,758	5			
			1993			6,956	12			
			1994				2			
Average		2,094,640						5,906	0.28	0.45

[1] We report only fish released as smolts in the spring (fry and parr, and fall and winter releases not considered).

[2] For years where no numbers are entered, 6 year-old fish are included with 5 year-olds.

[3] If fry and parr releases were considered, the "smolt"-to-adult survival would decrease.

[4] Adult returns corrected for 5% interdam loss, incidental in-river catch of 8% (Mullan et al. 1992), and ocean harvest of 5% (this report).

Sources: Pettit (1995) and B. Kelly, USFWS, personal communication, for adult returns. Appendix for smolt releases.

Table 15. BKD incidence at mid-Columbia Hatcheries.

Location	Year	# sampled	# positive	# severe
Entiat	1988	60	3	0
	1989	60	14	10
	1990	120	54	30
	1991	60	13	6
	1992	60 (60)[1]	0 (2)	(0 (0)
	1993	(30)	(11)	(0)
	1994	(30)	(21)	(12)
Leavenworth	1988	60	20	3
	1989	60	7	0
	1990	60	11	0
	1991	60	2	0
	1992	60 (60)	2 (9)	1 (2)
	1993	(55)	(24)	(0)
	1994	(38)	(22)	(0)
Winthrop	1988	120	9	1
	1989	60	36	28
	1990	60	22	12
	1991	180	39	33
	1992[2]	60 (60)	0 (10)	0 (0)
	1993	(60)	(36)	(13)
	1994	(60)	(36)	(20)

[1]#'s in ()'s are ELISA-BKD results. All others are FAT results.

[2]300k inventory loss to predation over winter.

Table 16. Summary of the estimated return by brood year and smolt-to-adult survival of spring chinook released from the Entiat NFH.

	Smolts		Adult returns							
				Age at return (yrs)					Smolt-to-	Corrected
Hatchery	Release year	Number released [1]	Year	1.1	1.2	1.3	1.4 [2]	Total per brood	adult survival (%) [3]	smolt-adult survival [4]
Entiat	1981	623,373						**436**	0.07	0.12
	1982	997,841	1982	**4**				746	0.07	0.13
	1983	955,970	1983	0	**251**			1,160	0.12	0.20
	1984	645,458	1984	55	572	**181**		808	0.13	0.21
	1985	894,631	1985	0	738	174		1,090	0.12	0.20
	1986	835,090	1986	14	588	367		219	0.03	0.04
	1987	925,000	1987	0	593	220		916	0.10	0.17
	1988	838,940	1988	27	179	483		449	0.05	0.09
	1989	791,263	1989	17	612	40	0	487	0.06	0.10
	1990	639,306	1990	0	306	277	0	680	0.11	0.18
			1991	3	308	126	0			
			1992		331	179	0			
			1993			346	0			
			1994				0			
Average		814,687						699	0.09	0.14

1 We report only fish released as smolts in the spring (fry and parr, and fall and winter releases not considered).

2 For years where no numbers are entered, 6 year-old fish are included with 5 year-olds.

3 If fry and parr releases were considered, the "smolt"-to-adult survival would decrease.

4 Adult returns corrected for 5% interdam loss, incidental in-river catch of 8% (Mullan et al. 1992), and ocean harvest of 5% (this report).

Sources: Pettit (1995) and B. Kelly, USFWS, personal communication, for adult returns. Appendix for smolt releases.

Table 17. Summary of the estimated return by brood year and smolt-to-adult survival of spring chinook released from the Winthrop NFH.

	Smolts		Adult returns						Smolt-to-	Corrected
				Age at return (yrs)						
Hatchery	Release year	Number released [1]	Year	1.1	1.2	1.3	1.4 [2]	Total per brood	adult survival (%) [3]	smolt-adult survival [4]
Winthrop	1981	966,300						**401**	0.04	0.07
	1982	712,700	1982	**49**				1,172	0.16	0.29
	1983	782,988	1983	24	**233**			1,032	0.13	0.23
	1984	621,881	1984	18	763	**119**		877	0.14	0.25
	1985	1,167,625	1985	20	796	385		1,027	0.09	0.15
	1986	1,062,794	1986	9	609	218		734	0.07	0.12
	1987	1,069,693	1987	31	315	248		168	0.02	0.03
	1988	1,090,200	1988	13	611	703		92	0.01	0.01
	1989	865,734	1989	5	98	92	0	116	0.01	0.02
	1990	1,424,866	1990	0	64	57	0	278	0.05	0.03
			1991	18	51	23	0			
			1992		260	65	0			
			1993			489	0			
			1994				0			
Average		976,478						590	0.07	0.12

1 We report only fish released as smolts in the spring (fry and parr, and fall and winter releases not considered).

2 For years where no numbers are entered, 6 year-old fish are included with 5 year-olds.

3 If fry and parr releases were considered, the "smolt"-to-adult survival would decrease.

4 Adult returns corrected for 5% interdam loss, incidental in-river catch of 8% (Mullan et al. 1992), and ocean harvest of 5% (this report).

Sources: Pettit (1995) and B. Kelly, USFWS, personal communication, for adult returns. Appendix for smolt releases.

Table 18. Summary of smolt releases in the mid-Columbia River.

Year	Chinook Spring	Chinook Sum/fall	Steelhead	Sockeye	Coho	Total
1936			41,165			41,165
1937			39,629			39,629
1938			3,000			3,000
1942	50,400		600		5,470	56,470
1943					11,050	11,050
1945		60,900	6,342	116,748	128,799	312,789
1946				64,939	1,896	66,835
1947		73,600		79,812		153,412
1948				122,000		122,000
1949				2,390	6,203	8,593
1950	112,100			28,647	229,969	370,716
1951				59,413		59,413
1952				13,163	286,469	299,632
1953		254,600		32,962	137,607	425,169
1954		212,000		36,142	94,514	342,656
1955		212,000		100,000		312,000
1956		250,500			4,715	255,215
1957		273,900		272,829		546,729
1958	77,688	137,500		1,111,066		1,326,254
1959					186,575	186,575
1960		143,800	31,434		638,039	813,273
1961	57,349	152,300	88,208			297,857
1962	34,808	316,500	92,560			443,868
1963		229,800	122,078			351,878
1964			224,650		824,045	1,048,695
1965			322,314		473,882	796,196
1966			285,108	17,000	656,000	958,108
1967	251,000		205,766		1,947,146	2,403,912
1968	86,000		192,664		1,775,844	2,054,508
1969			366,775	1,400	1,395,707	1,763,882
1970		359,000	408,041		908,000	1,675,041
1971	64,000		369,361		1,457,000	1,890,361
1972	290,000		550,307		1,102,000	1,942,307
1973	585,920	873,000	365,930		734,000	2,558,850
1974	480,000	155,000	529,201		801,000	1,965,201
1975	695,401	762,000	377,007		659,000	2,493,408
1976	2,384,673	641,000	455,534		500,000	3,981,207
1977	2,644,000	311,209	427,421		500,000	3,882,630
1978	2,685,067	910,080	298,957		500,000	4,394,104
1979	2,187,718	314,389	541,435		500,000	3,543,542
1980	4,094,423	42,727	624,520		356,645	5,118,315
1981	3,970,820	10,533	867,544		979,975	5,828,872
1982	4,040,063	1,014,814	768,064		428,690	6,251,631
1983	4,008,646	381,880	880,517		515,605	5,786,648

Table 18. Concluded.

Year	Chinook Spring	Chinook Sum/fall	Steelhead	Sockeye	Coho	Total
1984	3,583,819	334,129	789,208		517,000	5,224,156
1985	4,305,056	421,937	705,476		516,890	5,949,359
1986	3,971,662	724,721	847,413		554,563	6,098,359
1987	4,412,461	646,000	960,079		473,121	6,491,661
1988	4,192,927	832,870	1,190,868		417,100	6,633,765
1989	3,896,674	2,096,722	1,011,568		385,200	7,390,164
1990	4,302,835	1,077,587	1,074,658		473,000	6,928,080
1991	4,174,797	3,884,112	1,181,430	260,400	435,200	9,935,939
1992	3,307,919	2,400,490	1,046,110	372,102	548,000	7,674,621
1993	3,147,155	3,545,784	944,063	167,523	524,000	8,328,525
1994	2,620,724	3,177,734	882,697	340,557		7,021,712

Sources: Chapman 1994a, 1994b; Rocky Reach Annex hatchery records (coho); J. Moore, K. Petersen, WDFW and B. Kelly, USFWS, personal communication.

Table 19. Numbers of fish collected, dates of collections, life stage, and location of collection upstream from Rock Island Dam. Sources of data are (1) Schreck et al. (1986), (2) Hershberger et al. (1988), (3) Utter et al. (in press).

Location (Source of data)	Dates	Number Collected	Adult (A) or Juvenile (J)	Description
Winthrop Hatchery (3)	8-18-92	100	A	
Winthrop Hatchery (2)	9-86	100	A	50 fish sampled 9-2, 9
Twisp R. (2)	11-6-86	50	J	5 areas between RM 6 - 10
Twisp R. (2)	9-24-87	50	J	5 areas between RM 6 - 10
Chewak River (2)	11-6-86	58	J	7 areas between RM 1 -19
Lost River (2)	11-7-86	50	J	5 areas between RM 0.5 - 5
Leavenworth H. (3)	8-28-91	88	A	
Leavenworth H. (2)	86-88	100	A	25 fish sampled 8-13, 18, 20, 27
White R. (3)	89-92	113	A	2 miles upstream from Napeequa
White R. (2)	5-5-87	95	J	9 areas between RM 1.5 - 11
Nason Creek (3)	89, 92	47	A	mouth to Whitepine Creek
Nason Creek (2)	11-10-86	53	J	8 areas between RM 6 - 12
Nason Creek (2)	11-10-86	47	J	5 areas between RM 0 - 3.5
Chiwawa R. (3)	89-92	170	A	upstream from Riverbend
Chiwawa R. (3)	92	88	J	hatchery reared (see text)
Chiwawa R. (3)	91	100	J	hatchery reared (see text)
Chiwawa R. (2)	12-3-86 6-1-87	16 56	J J	RM 12.2 RM 12.2 - 15
Entiat R. (2)	10-16-86	95	J	4 areas between RM 7 - 10
Hanford Reach (3)	90	99	A	Fall run
Priest Rapids H. (3)	91	200	A	Fall run
Wenatchee R. (3)	91-92	409	A	Summer run
Methow River (1)	84	50	J	Spring run
Leavenworth H. (1)	85	100	J	Spring run
Wenatchee R. (1)	84	194	J	Spring run
Entiat R. (1)	84	128	J	Spring run
Hanford Reach (1)	85	100	J	Fall run
Priest Rapids H. (1)	84	100	J	Fall run

Table 20. List of enzymes, loci, variant alleles, and allele combinations used to assemble data set of Appendix 8. Locus names and abreviations follow the nomenclature guidelines of Shaklee et al. (1990). From Hershberger et al. (1988), and Utter et al. (submitted ms.).

Enzyme name/EC #	Locus	Mobility	Allele Equivalent	Combined with	Other Lucus Designations
Aspartate aminotransferase	sAAT-1,2*	85	90 (2)	105 (3)	AAT-1,2
2.6.1.1	sAAT-4*	130			AAT-4
		63			
Adenosine deaminase	ADA-1*	65	83 (2)		
3.5.4.4					
Aconitate hydratse	sAH*	86		112, 108 (3)	AH-1
4.2.1.3	mAH-4*	119			
Dipeptidase	PEP-A*	90			DPEP-1, GL-1
3.4.-.-		86		76 (2), 81 (3)	
Glucose-6-phosphate isomerase	GPI-B2*	60			GPI-3, PGI-3
5.3.1.9					
Glutathione reductase	GR*	85			
1.6.4.2					
Hydroxyacylglutathione hydrolase	HAGH*	143		131 (3)	
3.1.2.6					
Isocitrate dehydrogenase	sIDHP-1*	94	76 (2)	129, 92 (3)	IDH-3, ICD-3
1.1.1.42	sIDHP-2*	127		83 (2,3)	IDH-4, ICD-4
L-Lactate dehydrogenase	LDH-C*	90		84 (3)	LDH-5
1.1.1.27					
Malate dehydrogenase	mMDH-2*	200			
1.1.1.37	sMDH-B1,2*	121		126 (3)	MDH-3,4
		70		83 (3)	
Malic enzyme (NADP)	sMEP-1*	92			ME-1
1.1.1.40					
Mannose-6-phosphate isomerase	MPI*	109		95 (2,3)	
5.3.1.8					
Leucyl-tyrosine dipeptidase	PEP-LT*	110			
3.4.-.-					
Phosphoglycerate kinase	PGK-2*[1]	90		74 (2,3)	
2.7.2.3					
Superoxide dismutase	sSOD-1*	-260			SOD, TO
1.15.1.1					
Tripeptide aminopeptidase	PEP-B1*	130			TAPEP-1, LGG-1
3.4.-.-					
Triose-phosphate isomerase	TPI-2.2*	104			
5.3.1.1					

[1]Correction made of allele frequencies for PGK-2* of White R. 87 (10) collection based on examination of original data.

Table 21. Releases of chinook salmon in the mid-Columbia region from sources downstream from Rock Island Dam.

Year	Origin/Run of released fish		Release		Size
			Location	Numbers	
1942-45	McKenzie R. (Willamette)	spring	Icicle Ck.	239,400	smolt
	Lower Columbia River	fall	Icicle Ck.	70,900	parr
	Carson H.	summer	Entiat R.	8,200	smolt
1960-70	Spring Ck. H.	summer	Entiat R.	990,800	fry
	Spring Ck. H.	fall	Icicle Ck.	2,922,000	fry/smolt
	Spring Ck. H.	spring	Icicle Ck.	251,000	smolt
	Eagle Ck. (Willamette R.)	fall	Columbia R.	659,000	fry
	Eagle Ck. (Willamette R.)	spring	Icicle Ck.	86,000	smolt
1971-80	Carson H.	spring	Icicle Ck.	13,200,000	smolt
	Carson H.	spring	Entiat R.	1,677,000	smolt
	Carson H.	spring	Columbia R.	1,183,000	smolt
	Little White Salmon H.	spring	Icicle Ck.	1,127,000	smolt
	Little White Salmon H.	spring	Entiat R.	1,161,000	smolt
	Cowlitz H.	spring	Icicle Ck.	989,000	smolt
	Cowlitz H.	spring	Entiat R.	436,000	smolt
	Simpson H. (Chehalis R.)	fall	Columbia R.	715,000	parr, smolt
1981-90	Carson H.	spring	Icicle Ck.	155,000	smolt
	Carson H.	spring	Entiat R.	436,000	smolt
	Carson H.	spring	Columbia R.	762,000	smolt
	Little White Salmon H.	spring	Entiat R.	622,000	smolt
	Elokomin H.	fall	Columbia R.	296,000	smolt
	Bonneville H.	fall	Columbia R.	226,000	smolt
	Snake R.xPriest Rapids H.	fall	Columbia R.	1,136,000	smolt
	Priest Rapids H.	fall	Columbia R.	657,000	smolt

Table 22. Reported percent survival during the early life history of spring chinook.

Source	Location	Brood Year	Survival %				
			Egg-to-fry	Egg-to-parr	Fry-to-smolt	Parr-to-smolt	Egg-to-smolt
Bugert et al. 1991	Tucannon River, WA.	1988	14.6	---	53.8	---	7.9
Petrosky 1990	Upper Salmon River, ID.	1987	---	1.2-29.0	11-30	---	---
Bugert and Seidel 1988	Tucannon River, WA.	1985-87	33-42	---	40-51	---	13-22
Fast et al. 1988	Yakima River, WA.	1981-85	---	---	---	---	4.2-6.5
Burck 1974	Lookingglass Cr., OR	---	9.5	---	---	---	---
Knox et al. 1984	John Day River, OR.	1978-82	20.6	---	---	29.8	3.6-8.6
Lindsay et al. 1989	Deschutes River, OR.	1975-81	---	---	---	---	2.1-8.7
Fast et al. 1991	Yakima River, WA.	1985-86	21.9-90.0	---	---	---	---
Keifer and Forster 1991	Upper Salmon River, ID.	1991	---	5.1-6.7	---	---	---
Keifer and Lockhart 1993	Upper Salmon River, ID.	1984-90	---	5.2	---	9	---
	Crooked River, ID.	1989-90	---	12.2	---	11.1	---
Petersen et al. 1994	Chiwawa River, WA.	1991-92	---	---	---	---	10.1,2.93
Hillman and Miller 1993	Chiwawa River, WA.	1991-92	---	5.7,9.5	---	---	---
Mullan et al. 1992	Wenatchee basin, WA.	1976-88	---	2.7-4.3	---	50	1.35-2.15
	Entiat basin, WA.	"	---	3.1-4.7	---	50	1.55-2.35
	Methow basin, WA.	"	---	5.8-13.3	---	50	2.90-6.65
	Icicle Creek, WA.	1992	---	9.8	---	---	---
Hubble 1993	Chewack River, WA.	1992	---	13.0-32.0	---	---	---
Major and Mighell 1969	Yakima River, WA.	1969	---	---	---	---	5.4-16.4
Bjornn 1978	Lemhi River, ID.	1965-72	---	---	---	---	8.2
Richards and Cernera 1987	Bear Valley Creek, ID.	1986	---	2.11	---	---	---
Konopacky et al. 1986	Bear Valley Creek, ID.	1984-85	---	8.1-9.4	---	---	---
Amsberg et al. 1992[1]	Clearwater River, ID.	1990	---	---	---	25	---

[1]Survival derived from PIT-tagged parr released into mainstem Clearwater River and collected the following spring at Lower Granite, Little Goose and McNary dams detection facilities.

Table 23. Estimated median passage dates for mid-Columbia hatchery stocks that passed McNary Dam 1991-1993. Estimates taken from annual reports of the Fish Passage Center. The Ringold estimate for 1991 is the average of two reported median passage dates for two marked groups.

Hatchery	1991	1992	1993
Winthrop	5/18	5/16	5/14
Entiat	5/15	5/09	5/07
Leavenworth	5/19	5/18	5/18
Ringold	4/15	4/07	4/23

Table 24. Estimates of spill efficiency at mid-Columbia projects, with sources.

Project	Percent Passage	Source
Wells Dam	% passage=89%	Skalski 1993
Rocky Reach Dam	% passage=0.65*% spill	Raemild et al. 1984
Rock Island Dam	% passage=0.94*% spill +11.3	Ransom et al. 1988
Wanapum Dam	%passage=15.42*ln (% spill)	Dawson et al. 1984
Priest Rapids Dam	%passage=e^(0.82*ln (% spill))	Dawson et al. 1984

Table 25. Number of PIT-tagged spring chinook released at Rock Island Dam bypass and later detected at McNary Dam, 1989-1994.

				Range of Indices for Recovered Fish		
Year	Number Released at Rock Island Dam	Number Detected at McNary Dam	Tagging Period	Temperature (F)	Flow (kcfs)	Length (mm)
1989	2,778	855	4/21-5/18	43.9-51.6	100.8-172.1	60-204
1990	2,835	660	4/21-5/25	45.9-52.3	113.0-161.8	106-202
1991	3,180	633	4/19-5/23	43.9-51.1	138.1-207.3	110-215
1992	3,643	764	4/21-5/31	46.0-55.9	100.6-162.6	95-222
1993	2,891	271	4/26-5/29	42.0-53.0	69.3-190.2	87-216
1994	3,393	514	4/21-5/28	47.0-53.5	73.0-139.0	89-208
Total	**18,720**	**3,697**[1]	**Range 4/19-5/31**	**42.0-55.9**	**69.3-207.3**	**60-222**

[1]The actual number of fish detected a McNary Dam was 3,701. Three fish were omitted due to size, two in 1989 (27 and 298 mm), and one in 1992 (258 mm). One fish released in 1991 was omitted due to an unlikely travel time (1,122.6 days).

Table 26. Correlation matrix for PIT-tagged yearling chinook released from Rock Island Dam, 1989-1994, all years combined (*indicates a significant relationship at the $p<0.01$ level).

	Travel Time	Length	Date	Flow	Temperature
Travel Time	1.0	---	---	---	---
Length	-0.06301*	1.0	---	---	---
Date	-0.20335*	0.25164*	1.0	---	---
Flow	-0.11087*	0.18072*	0.38662*	1.0	---
Temperature	-0.19995*	0.20468*	0.85015*	0.16493*	1.0

Table 27. Travel time (TT) models for PIT-tagged yearling chinook released from Rock Island Dam, 1989-1994. The dependent variable is lnTT, n = 3,697 tag detections over the entire six-year period.

Model	Variable	Coefficient	P	r^2
1	Constant	4.0220		0.071
	Date	-0.0118	<0.0001	
2	Constant	4.0150		0.075
	Date	-0.0105	<0.0001	
	Flow	-0.0011	<0.0001	
3	Constant	4.3710		0.078
	Date	-0.0061	<0.0001	
	Flow	-0.0014	<0.0001	
	Temperature	-0.0179	0.0008	

Table 28. Numbers of yearling chinook collected, numbers transported by barge or truck, and the proportion of collected fish transported at McNary Dam, 1978-1994.

Year	Number collected	Number Trucked	Number Barged	Total	Proportion of collection transported	Source
1978	63,523	32,147	---	32,147	0.506	Park et al. 1979
1979	402,633	147,648	202,096	349,744	0.869	Park et al. 1980
1980	841,726	322,954	472,187	795,141	0.945	Park et al. 1981
1981	1,237,726	286,476	946,547	1,233,053	0.996	Koski et al. 1988
1982	822,009	61,552	728,366	789,918	0.961	Koski et al. 1988
1983	720,756	4,997	5,713	10,710	0.015	Koski et al. 1988
1984	1,261,187	97,807	726,657	824,464	0.65	Koski et al. 1988
1985	2,952,613	188,849	713,274	902,123	0.306	Koski et al. 1988
1986	2,486,407	64,309	225,459	289,768	0.363	Koski et al. 1988
1987	3,450,113	686,168	1,003,251	1,689,419	0.490	Koski et al. 1988
1988	2,971,263	1,010,910	1,842,043	2,852,953	0.960	Ceballos et al. 1993
1989	2,332,718	115,886	509,987	635,873	0.273	Ceballos et al. 1993
1990	2,344,063	113,526	1,702,531	1,816,057	0.775	Ceballos et al. 1993
1991	1,870,638	276,003	459,987	735,990	0.393	Ceballos et al. 1993
1992	2,554,039	455,602	2,002,488	2,458,090	0.962	Ceballos et al. 1993
1993	1,215,770	97,116	460,746	557,862	0.459	Weekly reports of FPC, 1993
1994	2,217,376	97,080	1,816,394	1,913,474	0.863	Weekly reports of FPC, 1994

Table 29. Estimated mean yearling chinook survival from the release site in the Methow River to the Priest Rapids tailrace, 1985-1987 (FPC 1988). Winthrop Hatchery spring chinook were used as experimental animals.

Year	Mean Spring Chinook Survival (95% CI)	Flow Index
1985	0.45 (0.22)	130
1986	0.47 (0.27)	142
1987	0.44 (0.60)	Not reported

Table 30. Mid-Columbia system survival estimates reported by Chapman and McKenzie (1981), and McKenzie et al. (1983, 1984).

Year	Pateros to Priest Rapids Dam	Pateros to Rock Island Dam	Rock Island Dam to Priest Rapids Dam
1980	0.23-0.40	---	---
1982	0.44	0.64	0.65
1983	0.45	0.60	0.75

Table 31. Summary of coded wire tag recoveries of spring chinook from the mid-Columbia River basin that were released somewhere else.

Year of recovery	Site of recovery	Release site	Number recovered	Reference
1978	Wells Dam	Ringold Hat, WA	2	PSMFC data base
1979	Wells Dam	Ringold Hat, WA	3	PSMFC data base
1980	Wells Dam	Ringold Hat, WA	2	PSMFC data base
	Entiat NFH	Ringold Hat, WA	3	PSMFC data base
1981	Wells Dam	Ringold Hat, WA	2	PSMFC data base
1986	Icicle R.	Deschutes R, OR	1	PSMFC data base
1987	Wells Dam	Trinity R, CA	3	PSMFC data base
1988	Wells Dam	Trinity R, CA	2	PSMFC data base
1989	Wells Dam	Trinity R, CA	2	PSMFC data base
	Wells Dam	Umatilla R., OR		PSMFC data base
	Icicle R.	Clearwater R, ID	1	S. Pastor, USFWS, pers. comm.
1990	Icicle R.	Cle Elum R, WA [1]	1	Hays and Peven 1991
	Icicle R.	Clearwater R, ID	1	S. Pastor, USFWS, pers. comm.
	Nason Cr.	Clearwater R, ID	1	Hays and Peven 1991
1992	Icicle R.	Bonneville Hat.	1	PSFMC data base
	Nason Cr.	Bonneville Hat.	2	PSFMC data base
	Chiwawa R.	Bonneville Hat.	1	PSFMC data base
	Wells Dam	Bonneville Hat.	1	PSFMC data base
	Methow R.	Youngs R, OR	1	PSFMC data base
	Chewuch R.	Bonneville Hat.	1	PSFMC data base
1993	Nason Cr.	Chiwawa R [2]	15	Peven 1994
	Nason Cr.	Ringold Hat, WA	2	Peven 1994
	Nason Cr.	Leavenworth NFH	1	Peven 1994
	White R.	Chiwawa R [2]	1	Peven 1994
	up. Wenatchee R.	Chiwawa R [2]	8	Peven 1994
	Icicle R.	Ringold Hat, WA	1	B. Kelly, USFWS, pers. comm.
1994	Icicle R.	Chiwawa R	1	B. Kelly, USFWS, pers. comm.

[1] The fish recovered in the Icicle R. was raised at the Leavenworth NFH and released in the Cle Elum R. (Yakima R. basin).

[2] A weir on the Chiwawa River was inefficient in passing adult Chinook upon their return to the Chiwawa and was the probable cause of the large amount of straying in 1993 (see section on artificial propagation).

Table 32. Adult passage conversion rates for spring chinook salmon in the lower Columbia and Snake rivers, 1977-1992.

Year	Bonneville Dam to McNary Dam[1]	Conversion Per Project	McNary Dam to Ice Harbor Dam	Ice Harbor Dam to Lower Granite Dam[2]	Conversion Per Project	Bonneville Dam to Lower Granite Dam
1977	0.769	0.916	1.005	0.857	0.950	0.662
1978	0.635	0.859	1.005	0.833	0.941	0.558
1979	0.512	0.800	0.858	0.814	0.934	0.358
1980	0.421	0.750	1.011	0.686	0.882	0.292
1981	0.608	0.847	1.142	0.864	0.953	0.600
1982	0.486	0.786	1.009	0.880	0.958	0.432
1983	0.746	0.907	0.835	0.804	0.930	0.500
1984	0.663	0.872	1.006	0.828	0.939	0.552
1985	0.852	0.948	1.087	0.814	0.934	0.754
1986	0.812	0.933	0.952	0.845	0.946	0.653
1987	0.852	0.948	0.931	0.937	0.979	0.743
1988	0.787	0.923	1.045	0.900	0.965	0.740
1989	0.621	0.853	0.970	0.864	0.952	0.520
1990	0.781	0.921	0.875	0.887	0.961	0.606
1991	0.614	0.850	1.053	0.666	0.873	0.430
1992	0.813	0.933	0.967	0.859	0.951	0.675
Average	**0.686**	**0.878**	**0.987**	**0.834**	**0.944**	**0.567**

[1]Values based on Bonneville Dam counts minus McNary Dam counts minus Zone 6 harvest minus estimated turnoff.

[2]Values based on Ice Harbor Dam counts minus Lower Granite Dam counts minus hatchery returns.

Table 33. Fallback of spring chinook at Columbia River dams, with sources. Does not include Stuehrenberg et al. (1994)(see Figure 92 for those data).

Dam	Year	Percent Fallback	Source
Bonneville	1984	13.0	Shew et al. 1988
The Dalles	1980	13.6	Johnson et al. 1982
John Day	1982	7.5	Johnson et al. 1982
	1984	6.0	Shew et al. 1985
	1985	8.5	Shew et al. 1985
McNary	1985	2.2	Shew et al. 1985
Ice Harbor	1982	9.3	Turner et al. 1984
	1964	10.3	Johnson 1964
Little Goose	1976-1977	4.0	Haynes and Gray 1980
	1981	4.5	Turner et al. 1983
Lower Granite	1975	17.6	Liscom and Monan 1976
	1981	4.0	Turner et al. 1983

Table 34. Estimated number of yearling chinook collected, arriving at turbine intakes, estimated number arriving at dam, numbers transported, and proportion of total arrivals transported, by week at McNary Dam, 1984-1986. Assumes FGE=0.75, from USACE et al. (1992)[1] and that fish move in proportion to flow volumes through turbines and spill. Period covered corresponds with period when transportation controls were released at Priest Rapids tailrace. Numbers in thousands.

Week	Number collected	Number at turbine intake	Q proportion at turbine	Estimated number	Number transported	Proportion transported
			1984			
May 1-7	270.7	360.9	0.71	510.5	33.1	0.064
8-14	300.7	400.9	0.66	607.4	75.6	0.124
15-21	219.9	293.2	0.55	533.1	33.7	0.063
22-28	162.1	216.1	0.57	379.1	40.9	0.108
29-4	38.3	51.0	0.54	94.4	25.6	0.271
Jun 5-11	13.1	17.5	0.57	30.7	12.4	0.404
12-18	6.0	8.0	0.53	15.1	6.8	0.448
			1985			
Apr 28-4	335.0	446.7	1.00	446.0	131.2	0.294
May 5-11	529.5	706.0	0.86	820.9	62.9	0.077
12-18	603.1	804.0	0.95	846.3	54.1	0.064
19-25	424.4	565.9	0.97	583.1	35.9	0.062
26-1	253.5	338.0	0.95	355.8	30.7	0.086
Jun 2-8	103.1	137.5	1.00	137.5	34.5	0.251
			1986			
Apr 24-30	206.6	275.4	0.85	324.0	23.0	0.071
May 1-2	289.8	386.4	0.93	415.5	34.2	0.082
8-14	504.2	672.3	0.90	747.0	40.9	0.055
15-21	486.0	648.0	0.89	728.0	38.3	0.039
22-28	305.3	407.1	0.79	515.3	24.3	0.047
29-4	82.3	109.8	0.61	180.0	27.3	0.152
Jun 5-11	31.8	42.4	0.60	707.7	29.7	0.420

[1]From Table 4.2-10, USACE et al. (1992).

Appendix 1

Appendix 1. Releases of spring chinook in the Wenatchee River basin. Data obtained from Leavenworth NFH, Mullan (1987) and B. Kelly, USFWS, personal communication.

Release Year	Month/ season of Release	Release Location	#'s/type released	Hatchery	Brood Origin	Race
1941	OCTOBER	ICICLE CR	135,500/P	LEAV NFH	RI D	S & SU
1942	MAY	ICICLE CR	200,800/P	LEAV NFH	RI D	S & SU
	FALL	ICICLE CR	443,833/F	ENT NFH	RI D	S
	OCTOBER	ICICLE CR	239,400/P	LEAV NFH	McKENZIE R	S
1943	OCTOBER	ICICLE CR	117,600/P	LEAV NFH	RI D	S
1944	MAY	ICICLE CR	356,100/F	LEAV NFH	RI D	S
	MAY	NASON CR	365,100/F	LEAV NFH	RI D	S
	MAY	WEN R	188,300/F	LEAV NFH	RI D	S
	MAY	CHIWAWA R	144,100/F	LEAV NFH	RI D	S
1948	FEBRUARY	ICICLE CR	804,300/F	LEAV NFH	ICICLE CR	S
1967	MARCH	ICICLE CR	251,000/S	LEAV NFH	EAGLE CR NFH	S
1968	MARCH	ICICLE CR	86,000/S	LEAV NFH	EAGLE CR NFH	S
1971	MARCH	ICICLE CR	64,000/S	LEAV NFH	CARS NFH	S
1972	MARCH	ICICLE CR	290,000/S	LEAV NFH	CARS NFH	S
1973	APRIL	ICICLE CR	585,920/S	LEAV NFH	CARS NFH	S
1974	APRIL	ICICLE CR	480,000/S	LEAV NFH	CARS NFH	S
1975	APRIL	ICICLE CR	695,401/S	LEAV NFH	CARS NFH	S
1976	MARCH	ICICLE CR	771,600/S	LEAV NFH	COWLITZ H	S
	APRIL	ICICLE CR	598,900/S	LEAV NFH	ICICLE CR	S
	JULY	ICICLE CR	38,000/S	LEAV NFH	CARS NFH	S
1977	APRIL	ICICLE CR	1,832,000/S	LEAV NFH	CARS NFH	S
1978	APRIL	ICICLE CR	217,000/S	LEAV NFH	COWLITZ H	S
	APRIL	ICICLE CR	1,320,000/S	LEAV NFH	CARS NFH	S
	APRIL	ICICLE CR	342,000/S	LEAV NFH	ICICLE CR	S
1979	APRIL	ICICLE CR	721,000/S	LEAV NFH	L WHT NFH	S
	APRIL	ICICLE CR	335,519/S	LEAV NFH	ICICLE CR	S
	APRIL	ICICLE CR	97,517/S	LEAV NFH	CARS NFH	S
1980	APRIL	ICICLE CR	1,410,825/S	LEAV NFH	CARS NFH	S
	APRIL	ICICLE CR	406,000/S	LEAV NFH	L WHT NFH	S

Appendix 1. Continued.

Release Year	Month/ season of Release	Release Location	#'s/type released	Hatchery	Brood Origin	Race
1980	APRIL	ICICLE CR	412,500/S	LEAV NFH	ICICLE CR	S
1981	APRIL	ICICLE CR	1,157,977/S	LEAV NFH	ICICLE CR	S
	APRIL	ICICLE CR	1,019,400/S	LEAV NFH	CARS NFH	S
	APRIL	ICICLE CR	203,770/S	LEAV NFH	L WHT NFH	S
1982	APRIL	ICICLE CR	1,723,286/S	LEAV NFH	ICICLE CR	S
	APRIL	ICICLE CR	155,000/S	LEAV NFH	CARS NFH	S
1983	APRIL	ICICLE CR	1,906,488/S	LEAV NFH	ICICLE CR	S
1984	JANUARY	PESHASTIN CR	400,320/F	LEAV NFH	ICICLE CR	S
	JANUARY	ICICLE CR	368,880/F	LEAV NFH	ICICLE CR	S
	APRIL	ICICLE CR	626,400/F	LEAV NFH	ICICLE CR	S
	APRIL	ICICLE CR	2,316,480/S	LEAV NFH	ICICLE CR	S
	JULY	ICICLE CR	203553/P	LEAV NFH	ICICLE CR	S
1985	APRIL	ICICLE CR	2,190,000/S	LEAV NFH	ICICLE CR	S
	OCTOBER	ICICLE CR	52,800/S	LEAV NFH	ICICLE CR	S
1986	MARCH	ICICLE CR	200,100/P	LEAV NFH	CARS NFH	S
	APRIL	ICICLE CR	1,969,668/S	LEAV NFH	ICICLE CR	S
	JUNE	ICICLE CR	128,964/P	LEAV NFH	CARS NFH	S
	JULY	ICICLE CR	44,800/P	LEAV NFH	CARS NFH	S
	JULY	ICICLE CR	104,110/S	LEAV NFH	ICICLE CR	S
1987	JANUARY	ICICLE CR	842,000/F	LEAV NFH	ICICLE CR	S
	APRIL	ICICLE CR	2,336,868/S	LEAV NFH	ICICLE CR	S
	MAY	ICICLE CR	21,075/P	LEAV NFH	ICICLE CR	S
	JUNE	ICICLE CR	421,556/P	LEAV NFH	ICICLE CR	S
	JULY	ICICLE CR	80,900/S	LEAV NFH	ICICLE CR	S
1988	JANUARY	ICICLE CR	99,000/F	LEAV NFH	ICICLE CR	S
	FEBRUARY	ICICLE CR	410,530/P	LEAV NFH	ICICLE CR	S
	MARCH	ICICLE CR	96,000/P	LEAV NFH	ICICLE CR	S
	APRIL	ICICLE CR	124,887/P	LEAV NFH	ICICLE CR	S
	APRIL	ICICLE CR	2,207,294/S	LEAV NFH	ICICLE CR	S

Appendix 1. Concluded.

Release Year	Month/ season of Release	Release Location	#'s/type released	Hatchery	Brood Origin	Race
	MAY	ICICLE CR	114,800/P	LEAV NFH	ICICLE CR	S
	JUNE	ICICLE CR	94,209/P	LEAV NFH	ICICLE CR	S
	DECEMBER	ICICLE CR	1,044,000/F	LEAV NFH	ICICLE CR	S
1989	MARCH	ICICLE CR	219,000/P	LEAV NFH	ICICLE CR	S
	APRIL	ICICLE CR	2,109,923/S	LEAV NFH	ICICLE CR	S
	APRIL	ICICLE CR	9,120/P	LEAV NFH	ICICLE CR	S
1989	MAY	ICICLE CR	129,754/S	LEAV NFH	ICICLE CR	S
	MAY	ICICLE CR	148,864/P	LEAV NFH	ICICLE CR	S
	DECEMBER	ICICLE CR	1,946,336/F	LEAV NFH	ICICLE CR	S
1990	APRIL	ICICLE CR	2,251,503/S	LEAV NFH	ICICLE CR	S
	APRIL	ICICLE CR	400,000/P	LEAV NFH	ICICLE CR	S
	MAY	ICICLE CR	52,734/S	LEAV NFH	ICICLE CR	S
	MAY	ICICLE CR	134,000/P	LEAV NFH	ICICLE CR	S
	DECEMBER	ICICLE CR	310,000/F	LEAV NFH	ICICLE CR	S
1991	JANUARY	ICICLE CR	63,000/F	LEAV NFH	ICICLE CR	S
	APRIL	ICICLE CR	2,258,034/S	LEAV NFH	ICICLE CR	S
	APRIL	ICICLE CR	110,272/P	LEAV NFH	ICICLE CR	S
	MAY	ICICLE CR	285,536/P	LEAV NFH	ICICLE CR	S
1992	MARCH	ICICLE CR	530,700/P	LEAV NFH	ICICLE CR	S
	APRIL	ICICLE CR	2,286,828/S	LEAV NFH	ICICLE CR	S
1993	APRIL	ICICLE CR	1,757,931/S	LEAV NFH	ICICLE CR	S
1994	APRIL	WEN R	1,000/S	LEAV NFH	ICICLE CR	S
	APRIL	ICICLE CR	1,522,846/S	LEAV NFH	ICICLE CR	S

Data from Leavenworth NFH , Mullan (1987) and B. Kelly, USFWS, personal communication.

Appendix 2

Appendix 2. Releases of spring chinook in the Entiat River basin. Data obtained from Leavenworth NFH, Entiat NFH, Mullan (1987), and B. Kelly, USFWS, personal communication.

Release year	Month/ Season of Release	Release Location	#'s/type Released	Hatchery	Brood Origin	Race
1941	AUGUST	ENT R	483,000/P	LEAV NFH	RI D	S & SU
	OCTOBER	ENT R	157,800/P	LEAV NFH	RI D	S & SU
1942	MARCH	ENT R	25,000/S	ENT NFH	RI D	S & SU
	MAY	ENT R	25,400/S	ENT NFH	RI D	S & SU
	SEPTEMBER	ENT R	85,500/P	LEAV NFH	RI D	S & SU
	OCTOBER	ENT R	443,800/P	ENT NFH	RI D	S
1943	MARCH	ENT R	591,000/P	ENT NFH	RI D	S
1976	MARCH	ENT R	436,634/S	ENT NFH	COWLITZ H	S
	OCTOBER	ENT R	268,400/S	ENT NFH	CARS NFH	S
1977	APRIL	ENT R	631,200/P	ENT NFH	CARS NFH	S
	JULY	ENT R	400,000/S	ENT NFH	L WHT NFH	S
1978	APRIL	ENT R	217,798/S	ENT NFH	CARS NFH	S
	APRIL	ENT R	165,710/S	ENT NFH	L WHT NFH	S
1979	APRIL	ENT R	448,238/S	ENT NFH	CARS NFH	S
1980	APRIL	ENT R	596,162/S	ENT NFH	L WHT NFH	S
	APRIL	ENT R	61,936/S	ENT NFH	CARS NFH	S
1981	APRIL	ENT R	247,963/S	ENT NFH	CARS NFH	S
	APRIL	ENT R	326,844/S	ENT NFH	L WHT NFH	S
	APRIL	ENT R	48,566/S	ENT NFH	LEAV NFH	S
1982	APRIL	ENT R	481,302/S	ENT NFH	ENT R	S
	APRIL	ENT R	380,577/S	ENT NFH	CARS NFH	S
	APRIL	ENT R	135,962/S	ENT NFH	LEAV NFH	S
1983	APRIL	ENT R	136,191/S	ENT NFH	CARS NFH	S
	APRIL	ENT R	621,844/S	ENT NFH	L WHT NFH	S
	APRIL	ENT R	197,935/S	ENT NFH	LEAV NFH	S
1984	FEBRUARY	ENT R	150,000/F	ENT NFH	ENT R	S
	APRIL	ENT R	386,436/S	ENT NFH	ENT R	S
	APRIL	ENT R	259,022/S	ENT NFH	CARS NFH	S
1985	APRIL	ENT R	894,631/S	ENT NFH	ENT R	S

Appendix 2. Concluded.

Release year	Month/ Season of Release	Release Location	#'s/type Released	Hatchery	Brood Origin	Race
1986	APRIL	ENT R	835,090/S	ENT NFH	ENT R	S
1987	APRIL	ENT R	925,000/S	ENT NFH	ENT R	S
1988	FEBRUARY	ENT R	263,018/F	ENT NFH	ENT R	S
	FEBRUARY	ENT R	24,942/F	ENT NFH	ENT R	S
	APRIL	ENT R	838,940/S	ENT NFH	ENT R	S
	MAY	ENT R	10,800/P	ENT NFH	ENT R	S
	NOVEMBER	ENT R	56,493/S	ENT NFH	ENT R	S
1989	JANUARY	ENT R	49,605/F	ENT NFH	WINT NFH	S
	FEBRUARY	ENT R	66,540/P	ENT NFH	ENT R	S
	APRIL	ENT R	791,263/S	ENT NFH	ENT R	S
1990	JANUARY	ENT R	43,951/F	ENT NFH	ENT R	S
	APRIL	ENT R	53,506/S	ENT NFH	ENT R & WINT NFH	S
	APRIL	ENT R	246,900/S	ENT NFH	WINT NFH	S
	APRIL	ENT R	338,900/S	ENT NFH	WINT NFH	S
	NOVEMBER	ENT R	34,426/S	ENT NFH	ENT R	S
1991	APRIL	ENT R	818,707/S	ENT NFH	ENT R	S
	MAY	ENT R	377,946/P	ENT NFH	ENT R	S
1992	APRIL	ENT R	343,150/S	ENT NFH	ENT R	S
	MAY	ENT R	361,590/P	ENT NFH	ENT R	S
1993	APRIL	ENT R	376,462/S	ENT NFH	ENT R	S
	MAY	ENT R	332,178/P	ENT NFH	ENT R	S
1994	APRIL	ENT R	378,729/S	ENT NFH	ENT R	S
	MAY	ENT R	399,429/P	ENT NFH	ENT R	S

Data from Leavenworth NFH, Entiat NFH, Mullan (1987), and B. Kelly, USFWS, personal communication.

Appendix 3

Appendix 3. Releases of spring chinook in the Methow River basin. Data obtained from Leavenworth NFH, Winthrop NFH, Mullan (1987), and B. Kelly, USFWS, personal communication.

Release year	Month/ season of Release	Release Location	#'s/type released	Hatchery	Brood Origin	Race
1941	OCTOBER	MET R	182,000/P	LEAV NFH	RI D	S & SU
1942	MAY	MET R	25,000/P	LEAV NFH	RI D	S
1943	AUGUST	MET R	30,100/F	LEAV NFH	RI D	S
1944	APRIL	MET R	653,800/F	WINT NFH	LEAV NFH	S
1945	FEBRUARY	MET R	3,600/F	WINT NFH	MET R	S
1946	MARCH	MET R	49,712/F	WINT NFH	MET R	S
1947	FEBRUARY	MET R	548,957/F	WINT NFH	MET R	S
1948	FEBRUARY	MET R	912,900/F	WINT NFH	MET R	S
1949	MARCH	MET R	23,300/F	WINT NFH	MET R	S
1950	APRIL	MET R	61,000/F	WINT NFH	MET R	S
	JULY	MET R	117,400/P	WINT NFH	MET R	S
	OCTOBER	MET R	112,100/S	WINT NFH	MET R	S
1951	MARCH	MET R	150,341/F	WINT NFH	MET R	S
1952	APRIL	MET R	151,140/F	WINT NFH	MET R	S
1953		MET R	180,000/P	WINT NFH	MET R	S
1954		MET R	356,300/P	WINT NFH	MET R	S
1955		MET R	347,400/P	WINT NFH	MET R	S
1956		MET R	69,487/P	WINT NFH	MET R	S
1957	MARCH	MET R	66,937/F	WINT NFH	MET R	S
1958	OCTOBER	MET R	77,688/S	WINT NFH	MET R	S
1959	JUNE	MET R	9,074/P	WINT NFH	MET R	S
1960	MARCH	MET R	99,105/F	WINT NFH	MET R	S
1961	OCTOBER	MET R	57,349/S	WINT NFH	MET R	S
1962	OCTOBER	MET R	34,808/S	WINT NFH	MET R	S
1976	MARCH	MET R	271,139/S	WINT NFH	COWLITZ R	S
1977	JANUARY	MET R	700,000/F	WINT NFH	L WHT NFH	S
	APRIL	MET R	412,000/S	WINT NFH	L WHT NFH	S
1979	APRIL	MET R	427,240/S	WINT NFH	CARS NFH	S
1980	APRIL	MET R	60,000/S	WINT NFH	MET R	S

Appendix 3. Continued.

Release year	Month/ season of Release	Release Location	#'s/type released	Hatchery	Brood Origin	Race
1980	APRIL	MET R	1,147,000/S	WINT NFH	L WHT NFH	S
1981	APRIL	MET R	620,300/S	WINT NFH	CARS NFH	S
	APRIL	MET R	268,000/S	WINT NFH	LEAV NFH	S
	APRIL	MET R	78,000/S	WINT NFH	MET R	S
1982	APRIL	MET R	100,200/S	WINT NFH	MET R	S
	APRIL	MET R	612,500/S	WINT NFH	LEAV NFH	S
	OCTOBER	TWISP R	51,236/S	WINT NFH	MET R	S
1983	APRIL	MET R	782,988/S	WINT NFH	CARS NFH	S
	DECEMBER	MET R	363,200/S	WINT NFH	MET R	S
1984	APRIL	MET R	281,300/P	WINT NFH	MET R	S
	APRIL	MET R	601,500/S	WINT NFH	MET R	S
	APRIL	MET R	20,381/S	WINT NFH	MET R	S
1985	APRIL	MET R	1,042,320/S	WINT NFH	MET R	S
	APRIL	MET R	36,704/S	WINT NFH	MET R	S
	APRIL	MET R	18,458/S	WINT NFH	MET R	S
	APRIL	MET R	35,186/S	WINT NFH	MET R	S
	APRIL	MET R	34,957/S	WINT NFH	MET R	S
1986	APRIL	MET R	401,501/S	WINT NFH	MET R	S
	APRIL	MET R	34,466/S	WINT NFH	MET R	S
	APRIL	MET R	49,334/S	WINT NFH	MET R	S
	APRIL	MET R	48,991/S	WINT NFH	MET R	S
	APRIL	MET R	528,502/S	WINT NFH	LEAV NFH	S
1987	APRIL	MET R	1,069,693/S	WINT NFH	MET R	S
1988	APRIL	MET R	1,004,964/S	WINT NFH	MET R	S
	APRIL	MET R	85,236/S	WINT NFH	CARS NFH	S
1989	JANUARY	MET R	250,000/F	WINT NFH	MET R	S
	APRIL	MET R	865,734/S	WINT NFH	MET R	S
1990	APRIL	MET R	1,121,395/S	WINT NFH	MET R	S
	JULY	MET R	203,471/S	WINT NFH	KLICKITAT R	S

Appendix 3. Concluded.

Release year	Month/ season of Release	Release Location	#'s/type released	Hatchery	Brood Origin	Race
1991	FEBRUARY	MET R	164,900/P	WINT NFH	LEAV NFH	S
	APRIL	MET R	95,033/S	WINT NFH	MET R	S
	APRIL	MET R	516,139/S	WINT NFH	KLICKITAT R	S
	APRIL	MET R	350,935/S	WINT NFH	LEAV NFH	S
	APRIL	MET R	92,949/S	WINT NFH	MET R	S
	MAY	MET R	283,741/P	WINT NFH	LEAV NFH	S
	MAY	MET R	135,123/P	WINT NFH	MET R	S
1992	APRIL	MET R	624,771/S	WINT NFH	LEAV NFH	S
	JULY	MET R	175,947/P	WINT NFH	LEAV NFH	S
1993	APRIL	MET R	861,291/S	WINT NFH	LEAV NFH	S
	APRIL	MET R	89,333/S	WINT NFH	MET R	S
1994	APRIL	MET R	77,372/S	WINT NFH	LEAV NFH	S
	APRIL	MET R	478,941/S	WINT NFH	MET R	S

Appendix 4

Appendix 4. Releases of spring chinook into the mainstem Columbia River. Data obtained from Leavenworth NFH, Entiat NFH, Winthrop NFH, Mullan (1987), and B. Kelly, USFWS, personal communication.

Release Year	Month/ season of Release	Release Location	#'s/type released	Hatchery	Brood Origin	Race
1976	MAY	COL R (PRST RPDS)	149,900/S	LEAV NFH	ICICLE CR	S
1977	MAY	COL R (PRST RPDS)	104,000/S	LEAV NFH	CARS NFH	S
1978	APRIL	COL R (BEEBE BR)	39,237/S	ENT NFH	CARS NFH	S
	MAY	COL R (PRST RPDS)	101,200/S	LEAV NFH	ICICLE CR	S
	MAY	COL R (BEEBE BR)	64,734/S	ENT NFH	L WT NFH	S
	MAY	COL R (VERNITA BR)	33,588/S	ENT NFH	L WT NFH	S
	MAY	COL R (PATEROS)	285,000/S	LEAV NFH	CARS NFH	S
1979	MAY	COL R (PRST RPDS)	94,804/S	LEAV NFH	ICICLE CR	S
		COL R (WANAPUM D)	330,011/S	LEAV NFH	L WT NFH	S
		COL R (WANAPUM D)	94,208/S	LEAV NFH	CARS NFH	S
	MAY	COL R	158,204/S	WINT NFH	WLS D	S
1981	MAY	COL R (PRST RPDS)	356,720/P	LEAV NFH	LEAV NFH	S
1982	APRIL	COL R	175,000/S	LEAV NFH	CARS NFH	S
	MAY	COL R	225,000/S	LEAV NFH	CARS NFH	S
1983	APRIL	COL R (FERC)	361,500/S	LEAV NFH	CARS NFH	S
1985	APRIL	COL R (PRST RPDS)	37,477/S	WINT NFH	MET R	S
1986	APRIL	COL R (PRST RPDS)	35,894/S	WINT NFH	MET R	S
1987	APRIL	COL R (PRST RPDS)	35,273/S	WINT NFH	MET R	S

Appendix 5

Appendix 5. Releases of spring chinook from WDFW supplementation hatcheries. Data obtained from Chelan and Douglas PUD, unpublished data.

Release Year	Month/ season of Release	Release Location	#'s/type released	Brood Origin
1991	MAY	CHIWAWA	43,000/S	CHIWAWA
1992	APR-MAY	CHIWAWA	53,170/S	CHIWAWA
1993	APRIL	CHIWAWA	62,138/S	CHIWAWA
1994	APRIL	CHIWAWA	85,113/S	CHIWAWA
1994	APRIL	CHEWUCH	40,862/S	CHEWUCH
1994	APRIL	TWISP	35,861/S	TWISP

Appendix 6

DRAFT EVALUATION PLAN

FOR THE

ROCK ISLAND HATCHERY-BASED COMPENSATION PROGRAM

June 1, 1992

GOAL

The Evaluation Plan will document whether the hatchery facilities are capable of producing the Phase I hatchery compensation required under the Rock Island Project Settlement Agreement (Agreement) in a manner that is consistent with the maintenance of genetically distinct stocks and natural productivity in the mid-Columbia River system above Rock Island Dam. The Evaluation Plan will also estimate the survival of the hatchery fish from release-to-adult. This information will be useful in negotiating Phase II compensation levels.

BACKGROUND

The purpose of the Agreement's hatchery-based compensation program is to replace fish killed by the Rock Island Project. Various estimates have been made regarding the number of fish killed at Rock Island Dam and the number of adults those fish would have contributed to harvest and escapement. These estimates have not been validated by sufficient field experimentation. In the Agreement, hatchery compensation is divided into two phases. Phase I sets a negotiated production level for compensation during the development of juvenile fish bypass systems and improvements to adult fishways. Phase II production will be based on new estimates of the number of fish killed at Rock Island Dam after juvenile fish protection measures have been implemented. The new estimates of mortality will be determined from field studies at the Rock Island Project.

Under the Agreement, the Fishery Agencies and Tribes developed a production plan, specifying the stocks to be reared and sites for trapping and acclimation facilities. Following completion of genetic studies, the production plan was modified and served as the base for establishing the design criteria for the hatchery complex. The current production plan is defined in the Design Memorandum-Rock Island Fish Hatchery Complex, Chapter 2-Biological Criteria and protocols for broodstock collection and release of juveniles.

The Agreement calls for "an evaluation of hatchery production and its interrelationship with natural production to be used to assist in adjusting the production program". The Evaluation Plan is organized into four main objectives that address this section of the Agreement. Since the purpose of the Rock Island Hatchery Complex is compensation, the evaluation should focus on the capability of the hatchery facilities to meet the compensation requirements of the Agreement. The Evaluation Plan's primary function, defined in Objective 1, is to document whether the Rock Island Hatchery Complex can meet the production requirements of Phase I. To compensate for fish killed at the Rock Island Project, hatchery releases must be sufficient, given their survival from release to adult return, to produce a number of adults equal to the number that the killed fish would have produced. The Evaluation Plan should document the survival rate of the hatchery fish from release-to-adult, as defined in Objective 2.

The Agreement requires that the hatchery program be consistent with maintenance of genetically distinct stocks. The Agreement specifically required that facilities designed for Phase I production be capable of collecting, rearing and releasing up to five discrete stocks of salmon and steelhead. The Phase I facilities include adult collection sites and juvenile release and acclimation sites to maintain the integrity of these stocks. The production program and hatchery genetic guidelines specify broodstock selection and mating procedures to maintain the genetic integrity of the stocks used for hatchery production. The release procedures established for the hatchery are intended to acclimate and imprint the hatchery fish to prevent straying of returning hatchery adults into the spawning areas of other distinct stocks, where interbreeding could occur. The release procedures are also intended to imprint the fish so that returning hatchery adults spawn with the donor stock, replacing the naturally produced adults that would have been the progeny of fish taken for hatchery broodstock. The Evaluation Plan should determine whether these initial hatchery operations, specifically broodstock selection and mating procedures and acclimation and release methods, are adequate to prevent degradation of genetically distinct stocks or reduction in the reproductive success and long-term fitness of these or other stocks (Objectives 3 and 4). Also, the Evaluation Plan should determine whether sufficient numbers of returning hatchery adults spawn successfully with the donor stock to replace adults removed for hatchery broodstock.

This Draft Evaluation Program states specific objectives with defined working hypotheses (H_w) and data requirements, followed by specific tasks to obtain the required data. These objectives and tasks will be used to determine whether the goals of the hatchery-based compensation program (Phase I) are being met. The time frame or frequency of these tasks is defined. The Evaluation Program should be dynamic, with provision for assignment of new Tasks directed at solving problems that may become apparent from the initial evaluations.

Objective 1: Determine if the Rock Island Hatchery Complex is capable of meeting the production requirements of the Agreement. The specific production capabilities of each facility are defined in the Rock Island Fish Hatchery Complex - Design Memorandum. [Excerpts provided in Appendix 1].

Rationale: The production facilities were designed to produce specified numbers of smolts for four stocks of salmon, released in five locations, and one stock of steelhead (released directly from tank truck). The facility design incorporated several concepts intended to improve the egg-to-adult survival of the fish. For the purposes of this evaluation, the phrase "egg-to-adult survival" includes survival from point of broodstock collection to returning adults. This objective addresses survival from egg-to-release. The survival from release-to-adult will be considered under Objective 2. The capability of the facilities to produce the required number of smolts under the specific design features (delayed ponding, programmed growth and size at release, general health and egg-to-smolt survival) will be evaluated under the tasks from this objective. The tasks are directed toward data collection that will lead to solutions that will assure the attainment of the design production capability of the Rock Island Hatchery Complex.

Task 1-1.

Determine if the egg-to-release survivals of fish within the hatchery complex equal or exceed the survivals utilized in the design of the facilities and program (Table 1). Data will be collected and reported seasonally and/or annually. H_w: The wild stocks can be reared in the Rock Island Hatchery with survival from egg-to-release that equals or exceeds survival levels presented in Table 1.

The survival rates documented by Senn's "Compendium of Low-Cost Pacific Salmon and Steelhead Facilities" were used, with modification for local conditions, as the standard for comparison with the Rock Island Hatchery Complex. The modified standards are presented in Table 1. The hatchery personnel will keep records of cultural techniques for each life stage in Table 1, such as: number of times adults handled for observation and inoculation; fish and egg condition at time of spawning; ponding; densities at splits and feeding schedule of juveniles; and transport loading densities and conditions. Any problems with operation of the facilities will also be noted. The survivals in the Rock Island Hatchery Complex are generally expected to equal or exceed the standards. If survival of a particular life stage is below the standard, then the hatchery operation records could lead to correction of the problem or studies to determine the cause and remedy. Survival from egg-to-release is generally high at most hatcheries, therefore the survival to release of fish cultured in the Rock Island Hatchery Complex is not expected to be much higher than Table 1. Wild stocks with no previous cultural history may be more sensitive to the hatchery environment. The greater benefits expected from design features at the Rock Island Hatchery Complex derive from increased post-release survival to adulthood and conservation of the genetic integrity of the stocks.

Table 1. Survival standards for the Rock Island Hatchery Complex

	Chinook Salmon		Sockeye	Steelhead
Stock	Spring	Summer	Salmon	Trout
Adults				
Pre-spawn survival (%)	80	80	80	90
Percent females suitable for spawning	98	98	98	90
Incubation				
Percent survival fertilize to eyed egg	92	92	92	92
Percent survival eyed egg to ponding	98	98	98	98
Rearing				
Percent survival 30 days after ponding	97	97	97	97
Percent survival 100 days after ponding	93	93	93	93
Percent survival from ponding to smolt	72	72	72	72
Transport				
Percent survival from transport to release	95	95	--	95
Overall				
Percent survival from fertilization to release	65	65	65	65

Task 1-2.

Determine if the adult collection traps and weirs are capable of collecting the required number of adults that represent the timing and age composition of the donor population with minimal injuries and stress to the fish. Data will be collected and reported seasonally and/or annually. H_w: Adult collection facilities can safely capture sufficient broodstock with run timing and age composition representative of the donor population.

The adult broodstock will be collected from fishway traps at Wells, Dryden and Tumwater dams and a weir on the Chiwawa River. These trapping sites must be capable of capturing sufficient fish for broodstock selection of naturally produced fish throughout the run timing of target stocks (see Objective 3). Trapping must not injure or stress the fish to the point that pre-spawn mortality is excessive. The trap operation must also be safe for the hatchery personnel and, for the Chiwawa weir, safe for the public users of the river. Hatchery personnel will keep daily records of trap operation and maintenance, number and condition of fish trapped, and river stage (Chiwawa and Dryden). If low collection rates are a problem, trap data can be correlated with fishway operations and flow data.

Task 1-3.

Monitor fish health, specifically as related to cultural practices that can be adapted to prevent fish health problems. Data will be collected and reported seasonally and/or annually. H_w: The wild stocks can be cultured in the Rock Island Hatchery Complex without elevated incidence of disease that contributes to excessive pre- or post-release mortality or release of infected fish that would raise disease levels in the donor population.

Standard hatchery fish health monitoring will be conducted (minimum of monthly checks by fish health specialist), with intensified efforts to monitor presence of specific pathogens that are known to occur in the donor populations. Significant fish mortality to unknown cause(s) will be sampled for histopathological study.

Incidence of viral pathogens in broodstock will be determined by sampling fish at spawning in accordance with the Salmonid Disease Control Policy of the Fisheries Co-Managers of Washington State. Stocks of particular concern may be sampled at the 100% level and may require segregation of eggs/progeny in early incubation or rearing.

Incidence of Renibacterium salmoninarum (Rs, causative agent of bacterial kidney disease) in broodstock will also be determined by sampling fish at spawning. To obtain true prevalence data, all collected broodstock should be sampled. The enzyme-linked immunosorbent assay (ELISA) is both sensitive and quantitative. It has been developed to test kidney tissue for levels of antigens of the Rs bacteria, making it a good assay to use for both males and females at spawning and possibly very fresh adult mortality. Data from the females can be used to segregate eggs/progeny based on levels of Rs antigen, protecting "low/negative" progeny from the potential horizontal transmission of Rs bacteria from "high" progeny. An alternative assay, the fluorescent antibody technique (FAT) could be used to test ovarian fluid of spawned females for presence of Rs bacteria. FAT is not as sensitive as ELISA and has not been shown to be as reliable a basis for segregation of progeny. Progeny of any segregation study will also be tested by ELISA; at a minimum each segregation group would be sampled at release. ELISA may also be used to help determine efficacy of gallimycin treatments to juveniles.

Autopsy-based condition assessments (OSI) will be used to assess hatchery-reared smolts at release. Over time, autopsies give baseline data for a stock which permits comparison with established norms and with previous autopsies. Condition of naturally-selected free-ranging fish from "Blue ribbon" waters have been used to represent the desirable standard by which departures can be measured or observed (Ron Goede, unpublished). OSI's may be performed at other key times during hatchery-rearing and on wild or natural fish at outmigration.

Objective 2: Determine whether the survival from release-to-adult of fish released from the Rock Island Hatchery Complex is sufficient to acheive the program goal to compensate for fish killed by the Rock Island Project.

Rationale: The Agreement set Phase I production levels by negotiation, with the intent of compensating for fish losses during the development of fish protection measures at Rock Island Dam. The negotiators had to assume a smolt-to-adult survival rate to set levels for hatchery compensation. The survival from juvenile release to adult for fish released from the Rock Island Hatchery Complex should, on average, be high enough so that the hatchery releases produce the number of adults that would have been produced by fish killed at the Rock Island Project. Phase II compensation will be set in accord with results of studies of survival of fish that pass through the Rock Island Project. Actual release-to-adult survival rates for the Rock Island Hatchery Phase I compensation will be useful for negotiation of Phase II compensation levels.

A target level of smolt-to-adult survival is needed for evaluation of the hatchery program for each stock of fish produced. The target survivals should change in response to annual variations in systematic influences, such as marine survival and mainstem Columbia River passage conditions. The relative smolt to adult survival rates at other mid-Columbia River hatcheries will be used to gauge the effects of systematic influences. The target survivals (Table 2) are agreed to by the Rock Island Coordinating Committee for the purposes of this hatchery evaluation as representations of the average survival (juvenile release to adult) required to compensate for fish killed at Rock Island Dam. Baseline smolt to adult survivals at comparison hatcheries are also in Table 2. The adjusted target survival for a brood year will be computed by multiplying the target survival by the ratio of the annual survival to baseline survival for the appropriate comparison hatchery. These comparison hatcheries are proposed to be Leavenworth NFH for Wenatchee spring chinook and Wells Hatchery for Methow/Okanogan and Wenatchee summer chinook (both yearling and subyearling) and Wenatchee steelhead. Survival rates should be estimated for these hatcheries, on a yearly basis if possible, from existing tagging programs. Yearly estimates are needed to account for annual changes in downstream migration and ocean survival conditions. Sockeye have no recent cultural history, but fall releases of pre-smolts from the Leavenworth Hatchery in the 1960s had average survival of 0.67% (Mullan, 1986). The annual strength of naturally produced sockeye runs to the Wenatchee system may provide some subjective indicators of natural variation in marine and downstream migrant survival rates.

Table 2. Target release-to-adult survivals for fish released from the Rock Island Hatchery Complex.

STOCK	TARGET	COMPARISON	
		LEAVENWORTH	WELLS
Chiwawa Spring Chinook	0.26%[1]	0.28%[3]	
Wenatchee Summer Chinook	0.23%[1]		0.14%[4]
Okanogan Summer Chinook	0.15%[2]		0.14%[4]
Methow Summer Chinook	0.15%[2]		0.14%[4]
Wenatchee Steelhead	2.0%[1]		2.60%[5]
Wenatchee Sockeye	0.90%[1]		

[1] Escapement measured at Rock Island Dam.

[2] Escapement measured at Wells Dam.

[3] Escapement to the Leavenworth Hatchery (average for brood years 1978-84, Mullan, 1990).

[4] Escapement to Wells Hatchery, ave. BYs 1974-81 for five yearling releases (size 8-17 fish/lb.). Subyearling releases (size 36-90 fish/lb.) for the same brood years averaged 0.046% escapement. (from Table 20 in Mullan, 1985, adapted from Seidel, 1983).

[5] Escapement to Wells Hatchery, ave. BYs 1979-86 (Williams, pers. comm.).

If adult returns indicate that the target survival levels were not met, then studies should be directed toward improvement of fish culture conditions. If Rock Island Hatchery Complex fish survive better than target rates, then the program should be analyzed to design studies to optimize survival. Survival of the hatchery product indicates the relative success or failure of the fish culture conditions. Many variables in the hatchery may cause greater or lesser post-release survival. Optimization of survival is in the best interests of all parties to the Agreement, but there are too many variables (e.g. density, time and size at release, health, diet, social behavior, etc.) to attempt to define the best studies for optimization at this time. If fish from the Rock

Island Hatchery Complex fail to survive at target rates (Table 2) then studies will be directed at improving the culture conditions based on experience with the hatchery facilities, the results of tasks under Objective 1, and examination of downstream migration timing obtained from the Fish Passage Center's smolt monitoring program. To detect any post release survival problems, prescribe and implement changes in the program or cultural techniques, and evaluate the effects of those changes will take many years. Table 3 illustrates the time frame required to implement and evaluate potential experiments to improve release-to-adult survival for stocks of fish released from the Rock Island Hatchery Complex.

Task 2-1.

Estimate the harvest contribution and escapement to the mid-Columbia for each stock released from the Rock Island Hatchery Complex. This should be done annually during Phase I. H_w: The escapement and harvest contribution can be estimated for each stock to obtain an estimate of survival from release-to-adult for the hatchery production.

Sampling programs for estimation of escapement of these stocks are not part of any current sampling program on the Columbia River. Sampling locations must be selected, procedures defined, approval obtained and the sampling program carried out. Possible recovery programs could include: (1) coded wire traps at hydroelectric projects; (2) tag recoveries on the spawning grounds; and (3) PIT tags. Standard trap operations at hydroelectric projects for detection of coded wire tags (given that an external mark is also applied to CWT fish released from the Rock Island Hatchery Complex) may be adequate for some stocks, with additional work needed to calibrate the trapping efficiency for expansion. Augmented tag recovery efforts in fisheries on the Columbia River may be necessary to obtain reliable estimates of contribution from fish produced in the Rock Island Hatchery Complex.

Subtask 2-1-1.

Select recovery sites and design sampling schemes for estimation of escapement for each stock. In the case of fishway traps or PIT tag detection at hydroelectric projects, obtain approval from the project owners and install detectors. Obtain agency approval and permits for sampling.

Subtask 2-1-2.

Consult with PSMFC and entities responsible for tag recovery from Columbia River fisheries to determine if additional effort is needed for some stocks.

Subtask 2-1-3.

Determine the statistical requirements for the estimates of escapement and harvest contribution. Determine the number of coded wire tags and other marks needed in relation to the number of recoveries expected.

Subtask 2-1-4.

Mark each stock subjected to ocean fisheries or main-stem Columbia River commercial or tribal fisheries with sufficient coded wire tags to estimate harvest contribution. It may be necessary to mark all stocks with easily recognizable external marks (e.g. fin clips or freeze brands) in sufficient numbers to estimate contribution to terminal harvest and escapement.

Fin clips or other external marks are needed to estimate escapement (returns to the mid-Columbia River), even for stocks receiving coded wire tags. Escapement may be estimated from trap sampling at main-stem hydroelectric projects (e.g. Priest Rapids or Wells) or at broodstock collection points. Since other hatcheries or research activities may have coded wire tagged fish of the same species and run returning at these sites, external marks unique to the Rock Island Hatchery Complex will be needed for sampling at fishway or broodstock collection weirs. Extensive spawning ground sampling will be required to obtain mark recoveries from escapement.

Table 3. Example survival estimation and program modification time frame.

RETURN YEAR	CHIWAWA SP. CHINOOK	WENATCHEE SU. CHINOOK	OKANOGAN SU. CHINOOK	METHOW SU. CHINOOK	WENATCHEE STEELHEAD	WENATCHEE SOCKEYE
1992	Begin jack recovery data	Begin jack recovery data	Begin jack recovery data	Begin jack recovery data	Est. survival 1989 BY 1 ocean	Begin jack recovery data
1993	Est. survival 1989 brood yr	Est. survival 1989 brood yr	Est. survival 1989 brood yr	Est. survival 1989 brood yr	Est. survival 1989-90 brood year	Est. survival 1989 brood year
1994	Est. survival 1989-90 BYs	Est. survival 1989-90 BYs	Est. survival 1989-90 BYs	Est. survival 1989-90 BYs	Est. survival 1990-91 BYs	Est. survival 1990 BY
1995	Est. survival Program modification Effective 94 BY	Est. survival Program modification Effective 94 BY	Est. survival Program modification Effective 94 BY	Est. survival Program modification Effective 94 BY	Est. survival Program modification Effective 94 BY	Est. survival Program modification Effective 94 BY
1996	Est. survival Program modification Effective 95 BY	Est. survival Program modification Effective 95 BY	Est. survival Program modification Effective 95 BY	Est. survival Program modification Effective 95 BY	Est. survival Program modification Effective 95 BY	Est. survival Program modification Effective 95 BY
1997	Est. survival 1992-93 BY	Est. survival 1992-93 BY	Est. survival 1992-93 BY	Est. survival 1992-93 BY	Est. survival 1994 BY 1 ocean	Est. survival 1992-93 BY
1998	Est. survival 1994 BY	Est. survival 1994 BY	Est. survival 1994 BY	Est. survival 1994 BY	Est. survival 94-95 BYs	Est. survival 1994 BY
1999	Est. survival 94-95 BYs	Est. survival 94-95 BYs	Est. survival 94-95 BYs	Est. survival 94-95 BYs	Program modification Effective 98 BY	Est. survival 94-95 BYs
2000	Program modification Effective 99 BY	Program modification Effective 99 BY	Program modification Effective 99 BY	Program modification Effective 99 BY	Program modification Effective 99 BY	Program modification Effective 99 BY

Task 2-2.

Compile survival data from release-to-adult for comparison hatcheries from existing data. Coordinate with the entities operating these facilities to assure that such data will continue to be available. This should be done annually during Phase I. H_w: Estimates of release-to-adult survival can be made for the production from the hatcheries chosen for comparison.

Survival estimates can be made from coded wire tag releases and a combination of other methods, including fish counts at fishways, counts at hatchery racks or return sites, and harvest data. The estimates from the existing data should be analyzed for precision and accuracy. For summer chinook, yearling smolt releases are still experimental. Survival estimates are needed for both yearling smolt and subyearling releases for comparisons from the Wells Hatchery. The survival rate for smolts will be used for adjustment of target survival rates. The subyearling survival rate will indicate potential benefits from changing the cultural practices to include subyearling releases.

Task 2-3.

Analyze and report the survivals for production from the Rock Island Hatchery Complex and the comparison hatcheries. This should be done annually. H_w: Survival from release-to-adult of fish released from the Rock Island Hatchery Complex is not less than the adjusted target survival rate.

If survival of fish from Rock Island Hatchery Complex is lower than the adjusted target survival rate over two or more brood years, examine incidental recoveries of downstream migrants in the Water Budget Monitoring Program and other research for travel time, smolt condition, or other differences that may have caused the poor survival. Examine in detail the cultural and disease records for the release group. Recommend different cultural practices and/or facility modifications directed at improving survival from release-to-adult. Continue evaluation to document the results of the modified cultural practices and/or facilities.

Objective 3: Determine if actions taken under the Rock Island Phase I hatchery program conserve the reproductive success, genetic integrity, and long-term fitness of natural spawning populations of salmon in the mid-Columbia system above Rock Island Dam.

Rationale: The Rock Island hatchery-based compensation program in the Agreement is intended to replace fish killed at Rock Island Dam while conserving the genetic integrity and reproductive capacity of naturally spawning populations above Rock Island Dam. This intent is embodied in broodstock collection and mating, rearing, and release protocols established in the current production plan developed under the Agreement, as well as the Agreement's provision for "an evaluation of hatchery production and its interrelationship with natural production to be used to assist in adjusting the production program". The Agreement's intent is to replace losses as an increment to the existing production potential above Rock Island Dam. This requires an evaluation program to assure that the compensation program does not change the genetic characteristics of donor and other stocks or reduce the potential of individual populations to produce offspring in their respective natural environments.

There are four ways in which the Rock Island Hatchery Complex could fail to meet this objective. Straying of hatchery fish into non-target spawning habitat and interbreeding with other stocks could alter the genome of those stocks through introgression of genes or gene complexes not present in those stocks. Similarly, some individuals collected for broodstock could be from the wrong stock, causing introgression of alien genes into the donor stock. Inadvertent selection pressure in broodstock selection and mating could alter the fitness or genome of the donor stocks through genetic drift or loss of genetic variation. Returning adults from the hatchery program may have a lower productivity than naturally produced adults, either through lower spawning success or subsequent survival of their progeny. Removal of wild adults for hatchery broodstock could increase genetic drift and reduce genetic diversity by reducing the effective population size of the donor stock. This could happen if returning hatchery adults in the next generation fail to replace the natural adults that would have been produced by the broodstock or they fail to produce viable progeny, particularly for donor stocks with small populations.

The cultural practices established for broodstock selection and mating are critical for maintaining the genetic diversity and co-adapted gene complexes in the donor population. Broodstock trapping should take fish at random from the donor population, including both early and late run fish and different age classes in approximately the proportions that occur in the donor stock. Broodstock collection and mating procedures should follow genetic guidelines. Means to visually identify hatchery reared adults are needed for broodstock collection and management of the population. A genetic monitoring program is needed to test whether the broodstock and mating procedures are conserving the genetic diversity of the donor stocks.

Spawning and carcass surveys of both the donor stocks and other stocks in the same watershed are needed to determine that hatchery salmon do not stray and interbreed with other stocks. Spawning and carcass surveys are infeasible for steelhead and difficult for sockeye. Straying of steelhead within the watershed is not a concern given current steelhead management and release procedures. For salmon, surveys of the donor stock must be intensive to determine that sufficient hatchery fish spawn with the donor stock to replace the fish taken for broodstock. Carcass surveys of the other stocks should concentrate on detecting straying and interbreeding of hatchery fish with stocks other than the donor.

Task 3-1.

Monitor chinook stocks in watersheds where broodstock are collected and monitor the hatchery broodstock for genetic stock identification (GSI), evidence of introgression of foreign genes, accelerated genetic drift, or loss of genetic variation in the donor stocks that could be caused by the hatchery program. H_w: Evidence of introgression, genetic drift, and loss of genetic diversity can be determined from an electrophoretic monitoring program of the adults spawning in the streams and taken for broodstock.

The hatchery broodstock constitute a random sample of the donor stocks. A monitoring program should test for genetic changes in the donor stock and stocks in adjacent streams that could result from failure of hatchery procedures to maintain genetic diversity in the donor streams. Electrophoresis is a technique well suited to test for accelerated genetic drift in allele frequencies. Monitoring of asymmetry in bilateral meristic or morphometric characters can detect loss of genetic variation in the donor stock.

Subtask 3-1-1.

Develop a broodstock monitoring program for electrophoretic analysis of allele frequency variation at selected monomorphic and polymorphic loci. This should be done annually for three years or until adequate baseline data has been established, then periodically once every five or ten years. H_w: Allele frequency variations between generations are no greater than expected from random genetic drift.

Polymorphism at a loci previously monomorphic in the donor stock could indicate mixture with another stock.

Subtask 3-1-2.

Develop a broodstock monitoring program for asymmetry in bilateral characters. This should be done annually for three years until adequate baseline data has been established, then periodically once every five or ten years. H_w: The average asymmetry does not increase progressively over time.

A progressive increase in average asymmetry could indicate a loss of genetic variation.

Subtask 3-1-3.

Collect electrophoretic samples of the chinook stocks in the watersheds receiving chinook produced in the Rock Island Hatchery Complex to establish baseline genetic stock identification profiles.

Loss of genetic diversity in the populations reared in the hatchery or adjacent naturally producing populations cannot be detected without baseline GSI profiles before hatchery produced adults are entering the spawning population.

Task 3-2.

Conduct carcass surveys for marked hatchery fish on the spawning areas of salmon stocks that are not part of the Rock Island Hatchery program. This should be done annually. H_w: Returning adults from the Rock Island Hatchery Complex do not stray and interbreed with other genetically distinct stocks.

The potential sites for straying include tributaries to the Wenatchee River, the Wenatchee River above Tumwater Canyon, and several hatchery broodstock collection sites, including Leavenworth and Winthrop NFHs and the Wells Hatchery.

Task 3-3.

Conduct intensive spawning and carcass surveys on the spawning areas of the donor stocks to the Rock Island Hatchery Complex. This should be done annually. H_w: Brood stock withdrawals in the parent generation do not exceed numbers of hatchery-reared progeny adults that spawn in the wild in the donor stream.

Define annual and long-term changes in the spawning distribution of the donor stock. Determine from mark recoveries if enough hatchery adults spawn within the established spawning area of the donor stock to replace adults taken for broodstock. Determine if hatchery-reared adults reproduce effectively in terms of distribution with the naturally produced spawners, timing, and utilization of habitat.

Subtask 3-3-1.

Determine egg retention of marked and unmarked fish in the donor stock by opening carcasses of females. H_w: Numbers of eggs retained by marked and unmarked females do not differ.

Subtask 3-3-2.

Relate redd count to escapement in donor stream to develop adult multiplier for redds (eg. adults per redd). Estimate proportion of carcasses of hatchery origin. Estimate numbers of marked adults that spawn in each donor stream (Hatchery Spawning Escapement = Redds X Proportion Hatchery X Redd Multiplier). Where direct count is possible, e.g. Chiwawa River, these manipulations can be checked or may be avoided.

Subtask 3-3-3.

Measure all carcasses in donor stream. Determine ages. Aggregate each release group across years. Estimate total spawner number. Compare total spawner number to number of donor adults in the parent year when sex products are taken for the hatchery egg supply. H_w: Number of fish taken from the donor stream as broodstock does not exceed the number of progeny spawners in the donor stream.

Task 3-4.

Monitor indicators of the fitness of a selected donor population for changes in reproductive success and juvenile production as hatchery reared adults contribute to the population. H_w: Natural production in the donor population is not diminished when hatchery reared fish return to spawn in the natural habitat.

The productivity of the donor population may be affected by the hatchery program, either through genetic effects or because of physical effects resulting from broodstock trapping, environmental or nutritional effects in the hatchery environment, or behavioral differences between naturally produced and hatchery reared adults. One of the donor stocks will be monitored to evaluate both short-term and long-term reproductive success and juvenile production in relation to adult escapement. Short-term evaluations will focus on differences in pre-spawning survival of hatchery reared adults and survival from egg to some juvenile life stage of progeny from hatchery reared adults. Long-term evaluation will focus on annual monitoring of juvenile production from the donor stock and a similar stock in a nearby tributary. The sub-tasks will first evaluate monitoring methods over two years to determine which method is most reliable and efficient for long-term monitoring.

Subtask 3-4-1.

Collect returning hatchery reared adults at the Chiwawa broodstock collection weir and hold them with the naturally produced adults collected for broodstock. Spawn pairs of hatchery reared adults and incubate eggs, pond fry and rear to juvenile stage in the same manner as done for the hatchery production fish. Compare pre-spawn loss, fecundity, fertility, and egg - juvenile survival between hatchery reared and naturally produced matings.

Subtask 3-4-2.

Evaluate alternative methods for long-term monitoring of juvenile production from the Chiwawa River. This will include downstream migrant trapping from summer through the spring smolt migration period and snorkling survey estimates of standing crop of chinook parr in mid summer.

Subtask 3-4-3.

Implement a long-term monitoring program of adult escapement, spawning success, and juvenile production estimation in the Chiwawa River and a selected control stream for comparison.

Objective 4: Determine whether smolts released from the rearing and acclimation facilities disperse and migrate downstream without impacting the natural population.

Rationale: The production plan for the Rock Island Phase I hatchery program calls for smolt releases of chinook and steelhead. Smolt release, rather than release at other life stages, was selected for two reasons. Survival from egg-to-adult of smolt releases is expected to be higher than survival of hatchery fish released at other life stages. Since naturally produced adults are taken from the system for hatchery broodstock, the goal has been to maximize the survival and contribution to future spawning populations of the progeny of the broodstock. An equally important goal of the Rock Island hatchery program has been to avoid impairing the production and survival of the naturally spawning populations. Smolt releases are intended to minimize adverse interactions between hatchery releases and natural production, such as intra- and interspecific competition for food or habitat and predation. This goal will be met if chinook and steelhead released from the Rock Island Hatchery Complex migrate rapidly out of the tributaries and down the Columbia River.

The chinook and steelhead facilities have been designed to provide for volitional release of fish from the rearing and acclimation facilities. The theory is that the fish will smolt while in the hatchery ponds and voluntarily exit through the pond discharge when they are physiologically ready to migrate. Fish can be denied the opportunity to leave the ponds (keep the screens in place) until river flows and other natural variables are judged to be appropriate for survival of downstream migrating smolts. The fish may or may not exit the rearing ponds as desired, either exiting before physiological changes are completed or not migrating out of the ponds within the spring migration time window of the natural population. In the case of the Leavenworth NFH, spring chinook exhibit very few signs of smoltification while in the hatchery ponds, but after non-volitional release into the river the fish rapidly smolt and migrate downstream within a few days. The optimal release procedures for each stock of fish will be determined through observation, operational experience, and, if needed, experimentation with release procedures.

Observations and monitoring of fish behavior and migration rate are needed at the rearing or acclimation pond, in the river at point of release, and at sampling locations in the Columbia River. Observations at the pond could include estimation of the daily emigration rate. Snorkel observations below the discharge pipe or at the point of release (steelhead) could determine whether fish migrate and disperse or linger in the immediate area of the release where they could be subject to increased predation or adversely affect naturally produced fish. Recoveries of marked fish at hydroelectric projects in the Columbia River can provide estimates of travel time and be used to determine if the fish were ready to migrate at release. These observations could also indicate whether fish from the Rock Island Hatchery Complex migrated through the Columbia River concurrent with the naturally produced fish and during the period when flows and spill for fish protection were in effect.

Task 4-1.

Monitor fish behavior and emigration rates from the rearing/acclimation ponds. This should be done for the first two or three years of releases to develop operating experience. The results from these years releases will determine whether further work is needed.

The hatchery personnel should note changes in fish behavior as the migration season approaches. Ideally, fish would not be allowed to emigrate from the rearing/acclimation pond until river conditions (increasing flows) and fish protection measures in the Columbia River are operating to increase survival of migrating smolts. However, fish may physiologically smolt before migration conditions are favorable. If smolting fish are showing signs of stress from being held captive in the hatchery, it may be better to allow emigration earlier than anticipated. Fish may exit the ponds without showing physical or behavioral signs of smoltification. A monitoring program to determine fish condition at time of emigration would provide information that may prove useful in understanding results of observations and monitoring of migrating fish after they leave the rearing/acclimation pond.

Determination of the emigration rate will provide information that may be necessary to optimize the cultural and release strategies for each stock. Tunnel counters are the preferred means to quantify emigration. Subsampling with inclined plane traps or other methods may be needed if tunnel counters are ineffective.

Task 4-2.

Develop a plan for snorkel observation of fish behavior below and above the discharge at salmon rearing/acclimation ponds and at point of release for steelhead. Five observations per stock are needed as follows: prior to release; during the first 25%, middle, and final 25% of fish emigration from the ponds; and one week post-release.

Snorkel observations should determine if fish emigrating from the rearing and acclimation ponds are taking up residence below the pond outfall or if they disperse and move downstream. If fish are holding in the area of the release for an extended period, they may have exited from the pond before they were physiologically prepared to migrate. To minimize risk to the natural population (and predation on the hatchery fish) the hatchery fish could be held in the ponds longer if observations show that the earliest emigres were not ready to migrate.

Appendix 7

Excepts from the

Methow Basin Spring Chinook Salmon Supplementation Plan

DRAFT

(Feb. 27, 1995)

M. Erho

and

B. Bugert

Passed out at the March 1, 1995 Wells Coordinating Committee

EVALUATION PLAN

Embodied in the MBSCSP, and the concept of supplementation in general, are a broad array of questions concerning natural production and stock restoration. These questions relate to the conceptual framework of supplementation theory, which in essence assumes that artificial propagation of Pacific salmon can increase numbers of naturally spawning populations with no impacts to the long-term viability of the target populations, and minimal effects upon non target species. Several critical uncertainties were identified in the development of the MBSCSP. The first deals with the physical facilities provided to accomplish the goals of the plan. The remaining critical uncertainties concern the potential risk imposed upon the Methow Basin spring chinook salmon stocks by the supplementation plan and the efficacy of the supplementation plan as a means to restore these stocks.

<u>First critical uncertainty</u>: **Are the facilities provided adequate to meet the needs of the MBSCSP in terms of broodstock collection, incubation, rearing, and acclimation?**

* Can the egg to returning adult survival meet or exceed the survival rate of naturally produced fish from that donor population?

* Can the broodstock collection facilities safely capture sufficient salmon in a manner that is consistent with guidelines established in the broodstock collection protocol for that stock?

<u>Second critical uncertainty</u>: **Does implementation of the MBSCSP conserve the genetic integrity and long-term fitness of naturally spawning populations of spring chinook salmon in the Methow Basin.**

* Do marked and unmarked salmon differ in spawning success?

* In the Twisp and Chewuch rivers, is habitat use and redd density per unit of stream proportionate between marked and unmarked salmon?

* Are the allele frequency variations between generations no greater than expected from random genetic drift?

* Is the effective population size of a donor stream adversely affected by broodstock collection procedures?

* Does the average bilateral meristic asymmetry of the supplemented populations increase progressively over time?

* Do the progeny to parent ratios of hatchery reared salmon meet or exceed those levels necessary to maintain long-term viability of the supplemented stocks?

<u>Third critical uncertainty</u>: **Do salmon released from Methow FH interact adversely with natural production in the Methow River Basin?**

* Do the returning adults from Methow FH stray excessively and interbreed with other genetically distinct stocks?

* Do the salmon released from the acclimation ponds impact naturally-rearing salmon and steelhead in the river?

* Is natural production in the donor population diminished when hatchery- reared salmon return to spawn in the natural habitat?

A means to address the critical uncertainties specific to the MBSCSP form the basis for the evaluation of the supplementation plan. The Evaluation Plan states three specific objectives, to obtain the data required to address each critical uncertainty. It is expected that these objectives, and their associated tasks, will form the basis for development of an annual evaluation implementation plan (or plans) which will include details of the specific hypothesis to be tested, methods, analysis, and report development, as outlined in Appendix G (Guidelines for Preparation of Study Proposals). The objectives and tasks (outlined in Appendix D) will be used to determine whether the goals of the Phase I hatchery-based compensation plan are being met, and whether the Guiding Principles are being adhered to. Some tasks may be directed toward all three populations--others must be done only on a given stream, to be consistent with the Implementation Strategy. The time frame or frequency of the tasks is defined in Appendix E.

The Evaluation Plan should be dynamic, with provision for assignment of new tasks directed at solving problems that may become apparent from the initial evaluations. A time line has been developed for evaluating progress toward meeting the objectives of the supplementation plan. Check points have been established for evaluating the program to allow for changes in strategies from an "adaptive management" perspective (Appendix E). It is recognized that all tasks listed in the evaluation cannot be done simultaneously without compromising either the survival of salmon, or the scientific merit of a given task. A process to identify the relative need and merit of a given task is described in Appendix F, which should allow managers the ability to establish priorities in evaluations.

<u>Objective 1</u>: **Determine if Methow FH is capable of meeting the Phase I production requirements of the Agreement.**

The capability of the facilities to produce the intended number and quality of smolts under the specific design features will be evaluated in this objective. Tasks are directed toward data collection that will lead to solutions to attain the design production capability of Methow FH. For the purposes of this evaluation, the term "propagation survival" includes the life history from the point of broodstock collection to time of release. This guideline will be the basis for evaluation in Objective 1. "Overall survival", which includes propagation survival and survival from release to spawning adult, will be considered as an adjunct to this objective. Survival guidelines will be rigorous, relative to other Columbia River hatcheries. The guidelines stated in Table 2, will meet or exceed those developed by FishPro (1990), which were used in the design of Methow FH.

Propagation survival: The Evaluation Plan will determine if the propagation survival (defined in Appendix A) in the hatchery meets or exceeds the guidelines presented in Table 2. The hatchery and evaluations personnel will keep records of cultural techniques for each life stage. Any problems with operation of the facilities will also be noted. If survival of a particular life stage is below the guideline, then the hatchery operation records could lead to identification and subsequent correction of the problem or studies to determine the cause and remedy.

Table 2. Propagation survival guidelines for spring chinook salmon at Methow FH.

Developmental stage	Criterion	Survival (%)
Adults/gametes	Collection to spawning	90
Incubation	Fertilization to start tank	90
Rearing	Start tank to ponding	86
Acclimation	Ponding to release	99
Propagation	Collection to release	69

Overall survival:. The Evaluation Plan will also assess the fisheries contribution and return survival of salmon released from Methow FH. This will ensure that the hatchery complex is successful in replacing those salmon initially collected for broodstock, and in meeting the longterm objective of sustainable natural production (see Objective 2). The adult replacement rate (i.e., adult spawner to adult return) of hatchery salmon will be measured to determine if it meets or exceeds the replacement rate of natural salmon from that donor population. Survival from release to adult will be measured primarily from coded-wire tag recoveries from returns to the donor streams, but information on contribution to various fisheries will be gathered as well. All salmon released from Methow FH will be marked (coded-wire tag and adipose clip). This mark is required for assessment of survival rates, broodstock management, and determination of stray rates.

Broodstock collection: Broodstock will be collected from traps on the Methow, Chewuch, and Twisp rivers. Ideally, these trapping sites should be capable of randomly collecting natural salmon throughout the run timing of target stocks (see Objective 2). Trapping must not injure or stress the fish to the point that pre-spawn mortality exceeds the guideline set in Table 2. The Evaluation Plan will determine if the traps are capable of collecting adults which represent the demographics of the donor population, in sufficient numbers to meet desired production levels, and with minimal impact to the collected fish or those allowed to spawn naturally. The traps and weirs should not alter the location or temporal pattern of riverine spawners. Trap operations on the Twisp and Chewuch rivers may affect the movement and spawning activities of naturally-spawning salmon (Meekin 1993). An evaluation of the trap design and operations will be required to determine if such impacts do occur, and if so, to develop an appropriate means to mitigate these effects. Salmon that die in the trap, or are killed by the weir during upstream migration will be included in the collection tally. Moribund salmon that drift downstream and die on the weir are to be considered river mortalities.

Objective 2: Determine that actions taken under the MBSCSP conserve the genetic integrity and long-term fitness of naturally spawning populations of salmon in the Methow Basin.

Genetic integrity: To be consistent with the Columbia River Basin Fish and Wildlife Program and the underlying assumptions of the Fishery Parties, Methow FH should replace fish killed at Wells Dam without compromising the genetic integrity of existing stocks, including both the donor and other stocks. There are four ways the MBSCSP could fail to meet this objective:

1. Excessive straying of hatchery fish into non-target spawning habitat and interbreeding with other stocks could alter the genome of those stocks through introgression of genes or gene complexes not present in those stocks.

2. Some individuals collected for broodstock could be from the wrong stock, causing introgression of alien genes into the donor stock.

3. Inadvertent selection pressure in broodstock selection and mating could alter the genome of the donor stocks through genetic drift or loss of genetic variation.

4. Removal of salmon for hatchery broodstock could increase genetic drift and reduce genetic diversity by reducing the effective population size of the donor stock. This could happen if returning hatchery adults in the next generation fail to replace the natural adults that would have been produced by the broodstock, particularly for donor stocks with small populations.

The cultural practices established for broodstock selection and mating are critical for maintaining genetic diversity in the donor population. Broodstock trapping should take fish at random from the donor population, including both early and late run fish and different age classes in approximately the proportions that occur in the donor stock (Kapuscinski and Miller 1993). Mating procedures should follow a spawning protocol (Seidel 1983, Withler 1988, Leary et al. 1989). A genetic monitoring program is needed to test whether the broodstock and mating procedures are maintaining the genetic character and diversity of the donor stocks (Meffe 1986).

Spawning and carcass surveys of both the donor stocks and other stocks in several watersheds are needed to determine if hatchery salmon stray and interbreed with other stocks (Scholz et al. 1978, Unwin and Quinn 1993). Surveys in the supplemented streams must be intensive, to determine that sufficient hatchery salmon spawn with the donor stock to replace the salmon taken for broodstock. The Evaluation Plan should retrieve information from carcass surveys by other entities on streams and hatcheries outside the Methow Basin to determine the extent of straying and possible interbreeding of hatchery fish with stocks other than the donor.

Winthrop FH, located adjacent to Methow FH, is operated by U.S. Fish and Wildlife Service under authority of the Grand Coulee Fish Maintenance Project (USFWS 1994). At this time, the management objective of Winthrop FH is not consistent with that of Methow FH. The principle area of conflict is the selection of appropriate broodstock. Under current hatchery management strategies, the only acceptable founder population for the Methow stock are salmon indigenous to the mainstem Methow River, yet there currently is no means to collect these broodstock. Winthrop FH typically propagates Methow stock, but may import salmon from outside the basin if escapement is low. A feasible solution to this dilemma is to manage both hatcheries on a collaborative basis, in which a common stock salmon is to be propagated at both facilities (Appendix C). The Evaluation Plan will gather information on the genetic status of the Methow stock, and recommend the appropriate means to collect, propagate, and release them from Methow FH.

The Evaluation Plan will monitor the Methow FH broodstock for evidence of introgression of foreign genes, accelerated genetic drift, or loss of genetic variation in the donor stocks that could be caused by the hatchery program (Busack 1990). The broodstock should constitute a random sample of the donor stocks (Meffe 1986). A monitoring program should test for genetic changes in the donor stock that could result from failure of hatchery procedures to maintain the stock's genetic integrity.

The Evaluation Plan will develop a monitoring program for electrophoretic analysis of allele frequency variation at selected monomorphic and polymorphic loci. Allele frequency variations between generations should be no greater than expected from random genetic drift. Polymorphism at a locus previously monomorphic in the donor stock could indicate mixture with another stock (Utter et al. 1987). A program to monitor asymmetry in bilateral characters will be developed. A progressive increase in average asymmetry over time could indicate a loss of genetic variation (Leary et al. 1984, 1985), or other stressors to the population (Valentine et al. 1972, MacGregor and MacCrimmon 1976).

The Evaluation Plan will determine appropriate numbers (and proportions) of the run-at-large to collect for hatchery broodstock (Ryman and Laikre 1991). Efforts should be made to estimate a minimum viable population (MVP) size, which includes salmon that are spawned both in the hatchery and in the river. Evaluations will focus on determination of effective size (Gall 1987) in the Twisp River population (though other donor streams may be used if required). Effective size monitoring will be based upon four components: 1. variation in family sizes among single-pair matings of salmon in the hatchery (Nunney 1991); 2. the sex ratio of the donor population, both in the hatchery and in the river (Waples 1990); 3. long-term monitoring of yearly variations in escapement to the donor stream (Shaffer 1981, Simon et al. 1986, Ellner and Hairston 1994); and 4. estimates of effective size derived from electrophoretic data (Pamilo and Varvio-Aho 1980, Waples and Teel 1990).

Long-term fitness: The Evaluation Plan will conduct spawning and carcass surveys on the spawning areas of the donor stocks to Methow FH. The number of broodstock taken in the parent generation should not exceed the number of hatchery-reared progeny that return to spawn naturally in the donor stream. Progeny-to-parent ratios of hatchery-reared salmon will be monitored to determine those levels necessary to maintain long-term viability of the supplemented stocks. Surveys are required for marked hatchery fish on the spawning areas of salmon stocks that are not part of the MBSCSP. Surveys of strays to other basins will be coordinated with hatchery evaluations under other compensation plans.

Annual and long-term changes in the spawning distribution of the donor stock will be monitored. Hatchery-reared adults should reproduce similarly to natural salmon in terms of distribution, timing, and habitat use. The number of progeny spawners in the donor stream should meet or exceed the number of fish established in the Management Plan and those that would have been produced had the adults collected for broodstock been allowed to spawn naturally.

The Evaluation Plan will monitor indicators of the fitness of a selected donor population for changes in reproductive success and juvenile production as hatchery salmon contribute to the natural spawners. The productivity of the donor population may be affected by the hatchery program, either through genetic effects or because of physical effects resulting from broodstock trapping, environmental or nutritional effects in the hatchery environment, or behavior al differences between natural and hatchery adults (Fleming and Gross 1992). Evaluations will be based upon juvenile production in a donor stream (Chewuch River) in relation to adult escapement before and after significant hatchery production begins. Several methods might be used to assess juvenile production: 1. annual estimates of parr production on representative index sites in selected habitat types on a natural river environment; 2. annual estimates of smolt yield on a population; and 3. a well-controlled study on a manageable reach of river to measure juvenile production against escapement to that river.

Objective 3: Determine if salmon released from Methow FH interact adversely with natural production in the Methow River Basin.

An important goal of Methow FH is to reduce potential for adverse interactions between hatchery releases and natural production, such as intra- and interspecific competition for food or habitat, and predation (Riddell and Swain 1991). The potential for this goal to be met will be improved if salmon released from Methow FH are healthy and migrate rapidly.

Methow FH has been designed to provide for volitional release of salmon from the acclimation ponds. The expectation is that the salmon will undergo par/smolt transformation while in the ponds and voluntarily exit through the pond discharge when they are physiologically and behaviorally ready to migrate (Hansen and Jonsson 1985). The optimal release strategy will be determined through observation, operational experience, and, if needed, experimentation with release procedures (Bohlin et al. 1993). Ideally, salmon would emigrate from the acclimation pond when physiologically prepared to do so, and this would coincide with good downstream migration conditions (Rottiers and Redell 1993). However, fish may physiologically smolt before migration conditions are favorable. Fish may exit the ponds without showing physical or behavioral signs of smoltification.

An evaluation of fish behavior and migration is needed at the acclimation ponds, in the river at point of release, and at sampling locations in the Columbia River. Observations are needed prior to, during, and after release. Observations should determine: 1. if fish can be reared in a manner that enables them to adapt well to the river environment (Olla and Davis 1989); and 2. if fish emigrating from the acclimation ponds remain near the pond outfall or if they disperse and move downstream (Bilby and Bisson 1987).

Determination of the emigration rate will provide information that may be necessary to optimize the cultural and release strategies for each stock. Sampling with PIT tag interrogators, tunnel counters, or inclined plane traps may be needed. Physiological, behavioral, and morphological indicators of par-smolt transformation may be used to assist in volitional release strategies. Snorkel observations below the pond could determine whether fish migrate and disperse or linger in the immediate area of the release where they could be subject to increased predation or adversely affect naturally produced fish. Retrieval of data from recoveries of marked fish at hydroelectric projects in the Columbia River can provide estimates of travel time and may be used to refine the volitional release strategies. These data could also indicate whether fish from Methow FH migrated through the Columbia River concurrent with naturally-produced fish and during the period when flows and spill for fish protection were in effect.

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Appendix 8

Appendix 8. Allele frequencies in populations of Table 19. Blank spaces for an allele/population indicate no data.

Locus	Population 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
sAAT-1,2*															
(N)	100	92	28	50	58	48	100	95	113	95	71	48	39	170	86
A	1.000	1.000	1.000	1.000	.991	.979	1.000	1.000	1.000	.995	.993	1.000	.962	.994	.988
B	.000	.000	.000	.000	.009	.021	.000	.000	.000	.005	.007	.000	.038	.006	.012
sAAT-4*															
(N)	77	55	36	28	37	39	79	82	105	22	61	47	32	107	76
A	.955	.964	.958	1.000	.932	.936	.975	.970	.986	1.000	.959	.968	.969	.944	1.000
B	.000	.000	.000	.000	.000	.000	.000	.024	.000	.000	.000	.000	.000	.000	.000
C	.045	.036	.042	.000	.068	.064	.025	.000	.014	.000	.041	.032	.031	.056	.000
ADA-1*															
(N)	100	80	50	50	58	48	100	88	113	50	70	50	44	130	88
A	.975	.981	.940	.980	.940	.948	.950	.966	.929	1.000	.929	.980	.920	.946	.949
B	.025	.019	.060	.020	.060	.052	.050	.034	.071	.000	.071	.020	.080	.054	.051
sAH*															
(N)	100	89	46	50	58	48	100	100	112	50	68	50	45	129	88
A	1.000	.978	1.000	.990	.991	.979	1.000	1.000	.991	1.000	1.000	1.000	1.000	.988	1.000
B	.000	.022	.000	.010	.009	.021	.000	.000	.009	.000	.000	.000	.000	.012	.000
mAH-4*															
(N)	100						100		113		70			133	88
A	.985						.975		1.000		1.000			1.000	.905
B	.015						.025		.000		.000			.000	.095
PEP-A*															
(N)	100	95	41	50	58	49	100	89	113	95	70	50	40	133	88
A	1.000	1.000	.951	.970	.957	1.000	.990	.989	.947	.979	.993	1.000	.962	.985	1.000
B	.000	.000	.049	.020	.043	.000	.005	.011	.035	.021	.007	.000	.025	.004	.000
C	.000	.000	.000	.010	.000	.000	.005	.000	.018	.000	.000	.000	.013	.011	.000
D	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
GPI-B2*															
(N)	100						100		113		71			133	88
A	1.000						.995		.969		.993			.966	.882
B	.000						.005		.031		.007			.034	.118
GR*															
(N)	100	58	48	50	58	49	100	87	113	95	71	50	40	133	88
A	.995	.974	.990	1.000	1.000	1.000	1.000	1.000	.996	1.000	.993	.990	1.000	.989	1.000
B	.005	.026	.010	.000	.000	.000	.000	.000	.004	.000	.007	.010	.000	.011	.000
HAGH*															
(N)	100	60	36	50	58	45	100	92	113	50	71	50	37	133	88
A	.900	.942	.972	.980	.888	.822	.910	.935	.858	1.000	.887	.900	.919	.914	1.000
B	.100	.058	.028	.020	.112	.178	.090	.065	.142	.000	.113	.100	.081	.086	.000
sIDHP-1*															
(N)	100	100	46	50	58	49	100	92	113	93	71	49	45	133	88
A	.810	.790	.674	.780	.569	.673	.785	.761	.580	.715	.761	.724	.833	.665	.722
B	.190	.210	.326	.220	.431	.388	.185	.239	.420	.285	.239	.276	.167	.335	.278
sIDHP-2*															
(N)	100	99	46	50	58	48	100	92	113	95	71	49	44	133	88
A	1.000	.995	1.000	1.000	1.000	1.000	.995	1.000	.991	1.000	.993	1.000	1.000	.992	1.000
B	.000	.005	.000	.000	.000	.000	.005	.000	.009	.000	.007	.000	.000	.008	.000
LDH-C*															
(N)	98	81	48	50	58	49	100	99	112	95	68	42	37	130	88
A	1.000	1.000	1.000	1.000	.905	1.000	1.000	.995	.996	1.000	1.000	.976	1.000	.996	1.000
B	.000	.012	.000	.000	.095	.000	.000	.005	.004	.000	.000	.024	.000	.004	.000

Appendix 8. Continued.

	Population											
Locus	16	17	18	19	20	21	22	23	24	25	26	27
sAAT-1,2*												
(N)	100	40	94	99	200	409						
A	.975	1.000	1.000	.995	1.000	.999						
B	.025	.000	.000	.005	.000	.001						
sAAT-4*												
(N)	83	35	74	97	164	377						
A	.994	1.000	.939	.979	.988	.999						
B	.000	.000	.000	.000	.000	.001						
C	.006	.000	.061	.021	.012	.000						
ADA-1*												
(N)	98	72	71	99	200	409						
A	.939	.986	.986	.990	.995	.991						
B	.061	.014	.014	.010	.005	.009						
sAH*												
(N)	100	61	94	99	200	407	53	100	184	128	100	100
A	1.000	1.000	.989	.808	.805	.769	.990	1.000	.999	.980	.810	.840
B	.000	.000	.011	.192	.195	.231	.010	.000	.001	.002	.190	.160
mAH-4*												
(N)	100											
A	1.000											
B	.000											
PEP-A*												
(N)	100	72	94	98	200	409						
A	.955	.924	.995	.990	.967	.972						
B	.000	.076	.005	.010	.030	.027						
C	.000	.000	.000	.000	.002	.001						
D	.045	.000	.000	.000	.000	.000						
GPI-B2*												
(N)	100											
A	.926											
B	.024											
GR*												
(N)	100	71	85	99	200	409						
A	.975	.993	.976	.975	.978	.976						
B	.025	.000	.024	.025	.023	.024						
C	.000	.007	.000	.000	.000	.000						
HAGH*												
(N)	100	48	52	99	200	409						
A	.870	1.000	.981	1.000	.993	.998						
B	.130	.000	.019	.000	.007	.002						
sIDHP-1*												
(N)	100	68	94	99	200	409						
A	.680	.750	.819	1.000	.993	.994						
B	.320	.250	.181	.000	.007	.006						
sIDHP-2*												
(N)	100	72	94	99	200	409						
A	1.000	1.000	.894	.869	.805	.782						
B	.000	.000	.106	.126	.195	.218						
LDH-C*												
(N)	100	72	86	96	200	405	53	100	184	128	100	100
A	1.000	1.000	1.000	.984	.983	.974	1.000	1.000	1.000	1.000	.990	.980
B	.000	.000	.000	.016	.018	.026	.000	.000	.000	.000	.010	.020

Appendix 8. Continued.

Locus	Population 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
mMDH-2*															
(N)	100						100		112		68			130	88
A	.695						.750		.885		.803			.803	.900
B	.305						.250		.115		.197			.197	.100
sMDH-B1,2*															
(N)	100	100	50	50	56	48	100	100	113	95	71	50	44	170	86
A	.990	.995	1.000	.980	.955	.990	.990	.990	.938	.932	.979	.990	.989	.971	.971
B	.010	.005	.000	.020	.045	.010	.010	.010	.062	.068	.021	.010	.011	.026	.000
C	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.003	.029
sMEP-1*															
(N)	100						100		113		71			170	
A	.095						.095		.027		.035			.071	.035
B	.905						.905		.973		.965			.969	.965
MPI*															
(N)	100	99	49	50	58	49	100	95	113	95	71	49	39	132	88
A	.940	.838	.847	.830	.871	.918	.860	.937	.792	.921	.915	.918	.923	.913	.807
B	.060	.136	.143	.020	.129	.082	.140	.063	.208	.079	.085	.082	.077	.087	.193
C	.000	.025	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
PEP-LT*															
(N)	99	88	48	50	58	40	100	95	113	76	69	47	40	133	88
A	.914	.989	1.000	.950	.966	.988	.950	.911	.960	.987	.899	1.000	.938	.936	.994
B	.086	.011	.000	.050	.034	.013	.050	.089	.040	.013	.101	.000	.063	.064	.006
PGK-2*															
(N)	99	99	50	50	58	48	100	77	113	95	71	37	44	133	88
A	.106	.182	.030	.050	.069	.052	.180	.156	.119	.053	.127	.095	.148	.117	.080
B	.894	.818	.970	.950	.931	.948	.820	.844	.881	.947	.873	.905	.852	.883	.920
sSOD-1*															
(N)	100	100	49	50	58	49	100	93	113	88	71	49	39	133	88
A	.755	.835	.684	.620	.672	.694	.755	.839	.872	.784	.782	.806	.808	.737	.574
B	.245	.165	.316	.380	.328	.306	.245	.161	.128	.216	.218	.194	.192	.263	.426
PEP-B1*															
(N)	100	84	34	50	58	49	100	93	113	70	71	47	40	133	88
A	.840	.958	.941	.960	.905	.908	.840	.919	.779	.964	.803	.957	.988	.812	.847
B	.160	.042	.059	.040	.095	.092	.160	.081	.221	.036	.197	.043	.013	.188	.153
TPI-2.2*															
(N)	100						100		113		71			133	88
A	.915						.905		.841		.965			.955	.959
B	.085						.085		.159		.035			.045	.041

Appendix 8. Concluded.

Locus	Population 16	17	18	19	20	21	22	23	24	25	26	27
mMDH-2*												
(N)	100											
A	.717											
B	.283											
sMDH-1,2												
(N)	100	55	94	99	200	409						
A	.945	.973	.957	.995	.965	.951						
B	.000	.027	.043	.015	.018	.022						
C	.050	.000	.000	.005	.015	.027						
sMEP-1*												
(N)	100											
A	.041											
B	.959											
MPI*												
(N)	99	56	93	99	200	409	53	100	184	128	100	100
A	.975	.946	.769	.652	.685	.655	.970	.830	.900	.900	.540	.740
B	.025	.054	.231	.348	.315	.344	.030	.170	.100	.100	.460	.260
C	.000	.000	.000	.000	.000	.001						
PEP-LT*												
(N)	91	23	94	98	200	406						
A	.962	.978	.973	.801	.783	.771						
B	.038	.022	.027	.199	.218	.229						
PGK-2*												
(N)	100	44	94	99	199	409	53	100	184	128	100	100
A	.080	.148	.197	.591	.698	.560	.030	.120	.090	.030	.650	-
B	.920	.852	.803	.409	.392	.440	.970	.880	.910	.970	.350	-
sSOD-1*												
(N)	100	47	94	99	200	409	53	100	184	128	100	100
A	.820	.755	.769	.535	.507	.482	.770	.710	.820	.760	.530	.500
B	.180	.245	.331	.465	.493	.518	.230	.290	.180	.240	.470	.500
PEP-B1*												
(N)	100	34	80	99	199	409	53	100	184	128	100	100
A	.845	.794	.969	.747	.741	.729	.970	.870	.910	.940	.820	.680
B	.155	.206	.031	.253	.249	.271	.030	.130	.090	.060	.180	.320
TPI-2.2*												
(N)	100											
A	.975											
B	.025											

Appendix 9

Appendix 9. Estimated travel time for Winthrop Hatchery spring chinook from the mouth of the Methow River to McNary Dam (Berggren and Filardo 1993). Flow indices reported in those documents are presented. In some years several groups were released on different dates. FPC travel time for migration 1991-1993 were reported from hatchery release site; estimates reported were decreased by 2 days to reflect travel time from the mouth of the Methow River in accordance with procedures of Berggren and Filardo (1993).

Winthrop Hatchery

Year	Release Date	Travel Time	Flow
1983	4/13	27	159
1984	4/23	23	143
1985	4/16	31	130
1985	4/20	29	133
1985	4/24	28	134
1986	4/21	26	143
1986	4/25	25	140
1986	4/29	22	137
1987	4/20	23	133
1987	4/24	22	145
1987	4/28	23	150
1988	4/19	24	96
1989	4/18	25	135
1990	4/17	28	143
1991	4/11	37	174
1992	4/15	29	127
1993	4/15	27	89

Appendix 9. Travel time estimates for spring chinook, from release at Leavenworth Hatchery to McNary Dam. Travel time estimates and flow indices were obtained from appendices in FPC annual reports for the years 1985-1992. In cases where several marked groups were released on a single date, we averaged those values and reported that mean.

Leavenworth Hatchery

Year	Release Date	Travel Time	Flow
1985	4/13	38	128
1986	4/23	29	136
1987	4/22	19	118
1988	4/21	22	97
1989	5/03	19	149
1989	4/19	28	147
1990	5/04	18	132
1990	4/18	26	152
1991	4/17	32	169
1992	4/20	28	125
1993	4/22	26	86

Appendix 9. Travel time estimates for spring chinook, from release at Entiat Hatchery to McNary Dam. Travel time estimates and flow indices were obtained from appendices in FPC annual reports for the years 1985-1992. In cases where several marked groups were released on a single date, we averaged those values and reported that mean.

Entiat Hatchery

Year	Release Date	Travel Time	Flow
1988	4/21	19	100
1989	4/20	19	140
1990	4/19	20	152
1991	4/04	41	184
1992	4/15	24	113
1993	4/01	36	57

Appendix 10

Appendix 10. Estimated travel time for freeze-branded groups from hatchery production releases, 1984-1993, as reported in FPC annual reports.

Hatchery	Travel Time		Release		Passage	Median		
Origin	From	To	Number	Date	Index	Travel Time	Speed (m/d)	Flow (kcfs)
1993								
Ringold	Release	McNary	13,500	4/3/93	4,333	19	2.9	58.5
Ringold	Release	McNary	14,000	4/3/93	4,493	21	2.7	58.5
Ringold	Release	McNary	13,600	4/3/93	3,150	19	2.9	58.5
Entiat	Release	McNary	1,192	4/1/93	101	36	5.5	56.6
Leavenworth	Release	McNary	397	4/22/93	49	29	7.0	100.3
Leavenworth	Release	McNary	402	4/22/93	57	23	9.0	89.3
Leavenworth	Release	McNary	393	4/22/93	52	21	9.8	84.4
Winthrop	Release	McNary	505	4/15/93	41	30	9.5	85.5
Winthrop	Release	McNary	498	4/15/93	43	28	9.9	89.3
Winthrop	Release	McNary	486	4/15/93	38	33	8.5	100.3
1992								
Winthrop	Release	McNary	15,113	4/15/92	4,290	30	9.4	126.1
Winthrop	Release	McNary	11,669	4/15/92	3,408	32	8.8	128.7
Winthrop	Release	McNary	14,070	4/15/92	3,433	31	9.1	126.1
Entiat	Release	McNary	16,021	4/15/92	4,531	24	8.4	112.9
Entiat	Release	McNary	16,533	4/15/92	3,451	23	8.8	112.7
Leavenworth	Release	McNary	16,297	4/20/92	4,843	28	7.3	126.1
Leavenworth	Release	McNary	16,640	4/20/92	4,579	28	7.3	126.1
Leavenworth	Release	McNary	21,341	4/20/92	6,056	27	7.6	121.4
Ringold	Release	McNary	18,098	4/3/92	8,400	4	14.0	87.1
Ringold	Release	McNary	9,246	4/3/92	4,102	3	18.7	87.1
1991								
Entiat	Release	McNary	17,102	4/4/91	2,831	41	4.9	184.2
Entiat	Release	McNary	17,212	4/4/91	2,718	41	4.9	184.2
Leavenworth	Release	McNary	18,090	4/17/91	4,175	32	6.4	168.6
Leavenworth	Release	McNary	15,964	4/17/91	3,402	32	6.4	168.6
Leavenworth	Release	McNary	14,594	4/17/91	3,011	32	6.4	168.6
Ringold	Release	McNary	18,160	4/2/91	10,061	15	3.7	168.2

Appendix 10. Continued.

Hatchery Origin	Travel Time From	Travel Time To	Release Number	Release Date	Passage Index	Median Travel Time	Median Speed (m/d)	Median Flow (kcfs)
Ringold	Release	McNary	13,655	4/2/91	7,265	12	4.7	168.2
Winthrop	Release	McNary	15,873	4/11/91	2,335	37	7.6	169.8
Winthrop	Release	McNary	16,086	4/11/91	2,529	38	7.4	175.4
Winthrop	Release	McNary	16,477	4/11/91	2,637	38	7.4	175.4
1990								
Winthrop	Release	McNary	14,143	4/17/90	1,663	31	9.1	169.9
Winthrop	Release	McNary	16,745	4/17/90	2,816	31	9.1	169.9
Winthrop	Release	McNary	16,261	4/17/90	2,954	30	9.4	169.9
Entiat	Release	McNary	17,152	4/19/90	3,811	20	10.1	151.9
Entiat	Release	McNary	16,791	4/19/90	4,505	20	10.1	151.9
Leavenworth	Release	McNary	16,785	4/18/90	4,416	27	7.6	152.1
Leavenworth	Release	McNary	15,572	4/18/90	4,522	26	7.9	152.1
Leavenworth	Release	McNary	15,521	4/18/90	4,029	26	7.9	152.1
Leavenworth	Release	McNary	12,400	5/4/90	2,401	17	12.0	130.9
Leavenworth	Release	McNary	12,100	5/4/90	2,806	18	11.4	133.1
Leavenworth	Release	McNary	13,100	5/4/90	2,844	18	11.4	133.1
Leavenworth	Release	McNary	14,200	5/4/90	2,532	17	12.0	130.9
Ringold	Release	McNary	19,711	3/31/90	8,132	8	7.0	150.7
Ringold	Release	McNary	20,125	3/31/90	8,785	7	8.0	151.9
1989								
Leavenworth	Release	Rock Island	31,395	5/3/89	198	9	4.8	146.0
Leavenworth	Release	Rock Island	32,795	5/3/89	190	8	5.4	139.9
Leavenworth	Release	Rock Island	32,320	5/3/89	137	8	5.4	139.9
Leavenworth	Release	Rock Island	31,960	5/3/89	132	9	4.8	146.0
Leavenworth	Release	Rock Island	16,289	4/19/89	53	13	3.3	141.5
Leavenworth	Release	Rock Island	17,526	4/19/89	60	16	2.7	143.1
Leavenworth	Release	Rock Island	16,271	4/19/89	41	13	3.3	141.5
Winthrop	Release	Rock Island	15,570	4/18/89	32	27	4.5	151.7
Winthrop	Release	Rock Island	16,704	4/18/89	35	25	4.8	146.6

Appendix 10. Continued.

Hatchery Origin	Travel Time From	Travel Time To	Release Number	Release Date	Passage Index	Median Travel Time	Median Speed (m/d)	Median Flow (kcfs)
Entiat	Release	Rock Island	17,500	4/20/89	42	8	5.1	135.2
Entiat	Release	Rock Island	17,500	4/20/89	33	10	4.1	140.2
Leavenworth	Rock Island	McNary	31,395	N/A	9,511	10	16.1	158.3
Leavenworth	Rock Island	McNary	32,795	N/A	10,011	11	14.7	158.3
Leavenworth	Rock Island	McNary	32,320	N/A	11,142	11	14.7	158.3
Leavenworth	Rock Island	McNary	31,960	N/A	9,910	10	16.1	158.3
Leavenworth	Rock Island	McNary	16,289	N/A	5,074	15	10.8	149.8
Leavenworth	Rock Island	McNary	17,526	N/A	5,894	11	14.7	149.8
Leavenworth	Rock Island	McNary	16,271	N/A	5,362	15	10.8	149.8
Winthrop	Rock Island	McNary	15,570	N/A	3,355	1	161.4	158.3
Winthrop	Rock Island	McNary	16,704	N/A	4,012	2	80.7	153.7
Entiat	Rock Island	McNary	17,500	N/A	5,244	10	16.1	143.2
Entiat	Rock Island	McNary	17,500	N/A	4,818	7	23.1	143.8
Leavenworth	Release	McNary	31,395	5/3/89	9,511	19	10.8	149.3
Leavenworth	Release	McNary	32,795	5/3/89	10,011	19	10.8	149.3
Leavenworth	Release	McNary	32,320	5/3/89	11,142	19	10.8	149.3
Leavenworth	Release	McNary	31,960	5/3/89	9,910	19	10.8	149.3
Leavenworth	Release	McNary	16,289	4/19/89	5,074	28	7.3	148.6
Leavenworth	Release	McNary	17,526	4/19/89	5,894	27	7.6	143.8
Leavenworth	Release	McNary	16,271	4/19/89	5,362	28	7.3	148.6
Winthrop	Release	McNary	15,916	4/18/89	4,425	28	10.1	146.1
Winthrop	Release	McNary	15,570	4/18/89	3,355	28	10.1	146.1
Winthrop	Release	McNary	16,704	4/18/89	4,012	27	10.4	147.7
Entiat	Release	McNary	17,500	4/20/89	5,244	18	11.2	144.6
Entiat	Release	McNary	17,500	4/20/89	4,818	17	11.9	140.4
1988								
Leavenworth	Release	Rock Island	138,641	4/22/88	808	15	2.9	84.8
Leavenworth	Release	Rock Island	47,476	4/20/88	337	10	4.3	93.9

Appendix 10. Continued.

Hatchery Origin	Travel Time From	Travel Time To	Release Number	Release Date	Passage Index	Median Travel Time	Median Speed (m/d)	Median Flow (kcfs)
Winthrop	Release	Rock Island	93,277	4/19/88	799	28	4.3	126.8
Entiat	Release	Rock Island	32,172	4/21/88	121	6	6.8	88.3
Leavenworth	Rock Island	McNary	138,641	N/A	45,993	7	23.1	109.3
Leavenworth	Rock Island	McNary	47,476	N/A	16,436	12	13.5	89.0
Entiat	Rock Island	McNary	32,172	N/A	8,723	13	12.4	97.1
Leavenworth	Release	McNary	138,641	4/22/88	45,993	22	9.3	94.1
Leavenworth	Release	McNary	47,476	4/20/88	16,436	22	9.3	99.6
Winthrop	Release	McNary	93,277	4/19/88	23,650	27	10.4	86.0
Entiat	Release	McNary	32,172	4/21/88	8,723	19	10.6	99.5
Ringold	Release	McNary	43,331	4/6/88	22,710	10	5.6	95.6
1987								
Winthrop	Release	McNary	46,667	4/20/87	9,705	26	10.8	150.7
Winthrop	Release	McNary	44,102	4/24/87	6,349	25	11.3	164.7
Winthrop	Release	McNary	46,318	4/28/87	7,403	25	11.3	172.8
Leavenworth	Release	McNary	37,863	4/22/87	13,410	19	10.8	117.7
Ringold	Release	McNary	40,467	4/1/87	10,665	8	7.0	93.5
1986								
Winthrop	Release	Rock Island	34,466	4/21/86	169	25	4.8	141.6
Winthrop	Release	Rock Island	34,485	4/25/86	132	27	4.5	125.1
Winthrop	Release	Rock Island	34,353	4/29/86	133	22	5.5	128.8
Leavenworth	Release	Rock Island	40,602	4/23/86	313	17	2.5	141.6
Winthrop	Rock Island	McNary	34,466	N/A	9,413	3	53.8	140.2
Winthrop	Rock Island	McNary	34,485	N/A	6,986	1	161.4	130.4
Winthrop	Rock Island	McNary	34,353	N/A	8,292	3	53.8	130.4
Leavenworth	Rock Island	McNary	40,602	N/A	12,371	12	13.5	138.7

Appendix 10. Continued.

Hatchery Origin	Travel Time From	Travel Time To	Release Number	Release Date	Passage Index	Median Travel Time	Median Speed (m/d)	Median Flow (kcfs)
Winthrop	Release	McNary	34,466	4/21/86	9,413	28	10.1	138.6
Winthrop	Release	McNary	34,485	4/25/86	6,986	28	10.1	139.5
Winthrop	Release	McNary	34,353	4/29/86	8,292	25	11.3	138.7
Leavenworth	Release	McNary	40,602	4/23/86	12,371	29	7.1	135.9
Ringold	Release	McNary	50,000	4/3/86	19,466	6	9.3	143.3
1985								
Winthrop	Release	Rock Island	35,186	4/20/85	179	26	4.6	131.5
Winthrop	Release	Rock Island	36,704	4/16/85	130	27	4.5	147.1
Winthrop	Release	Rock Island	12,568	4/16/85	47	26	4.6	149.8
Winthrop	Release	Rock Island	34,959	4/24/85	193	22	5.5	131.5
Winthrop	Release	Rock Island	5,890	4/16/85	19	29	4.2	138.1
Leavenworth	Release	Rock Island	30,422	4/13/85	215	26	1.7	149.6
Winthrop	Rock Island	McNary	35,186	N/A	6,131	6	26.9	129.5
Winthrop	Rock Island	McNary	36,704	N/A	7,386	6	26.9	128.8
Winthrop	Rock Island	McNary	12,568	N/A	2,586	7	23.1	128.8
Winthrop	Rock Island	McNary	34,959	N/A	6,194	9	17.9	119.4
Winthrop	Rock Island	McNary	5,890	N/A	1,195	6	26.9	127.6
Leavenworth	Rock Island	McNary	30,422	N/A	7,535	12	13.5	127.6
Winthrop	Release	McNary	35,186	4/20/85	6,131	32	8.8	129.5
Winthrop	Release	McNary	36,704	4/16/85	7,386	33	8.5	128.8
Winthrop	Release	McNary	12,568	4/16/85	2,586	33	8.5	128.8
Winthrop	Release	McNary	34,959	4/24/85	6,194	31	9.1	119.4
Winthrop	Release	McNary	5,890	4/16/85	1,195	35	8.1	127.6
Leavenworth	Release	McNary	30,422	4/13/85	7,535	38	5.4	127.6
1984								
Winthrop	Release	McNary	20,319		1,627	26	10.8	146.6

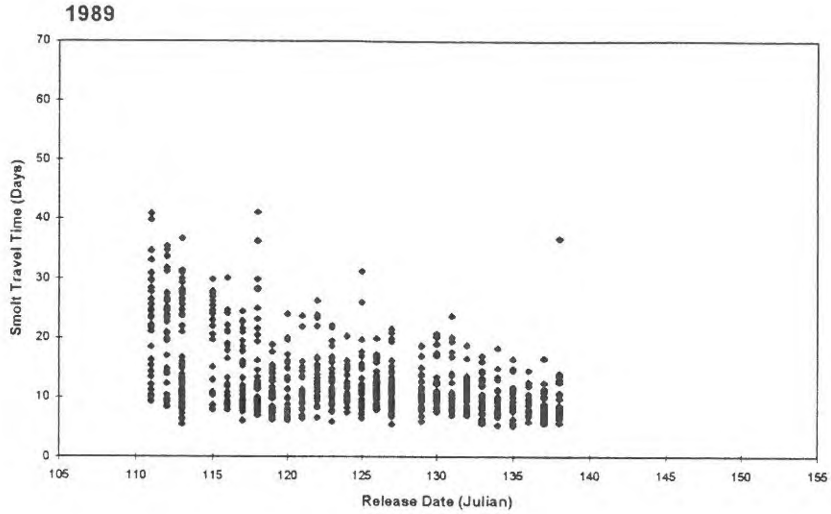
Appendix 10. Concluded.

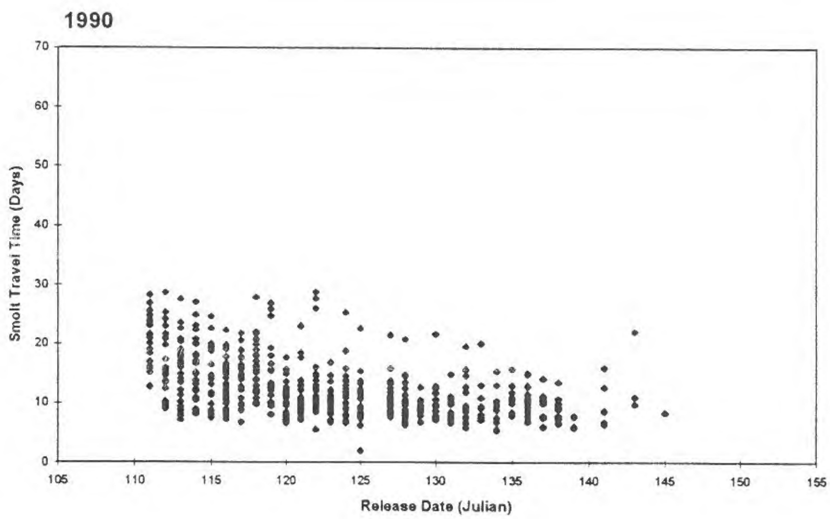
Hatchery	Travel Time		Release		Passage	Median		
Origin	From	To	Number	Date	Index	Travel Time	Speed (m/d)	Flow (kcfs)

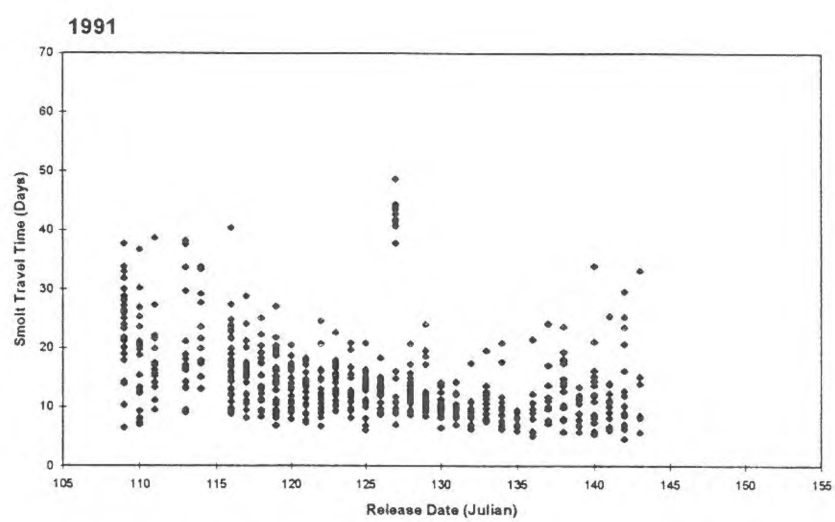
Winthrop release in 1988 omitted due to negative travel time estimate.

Appendix 11

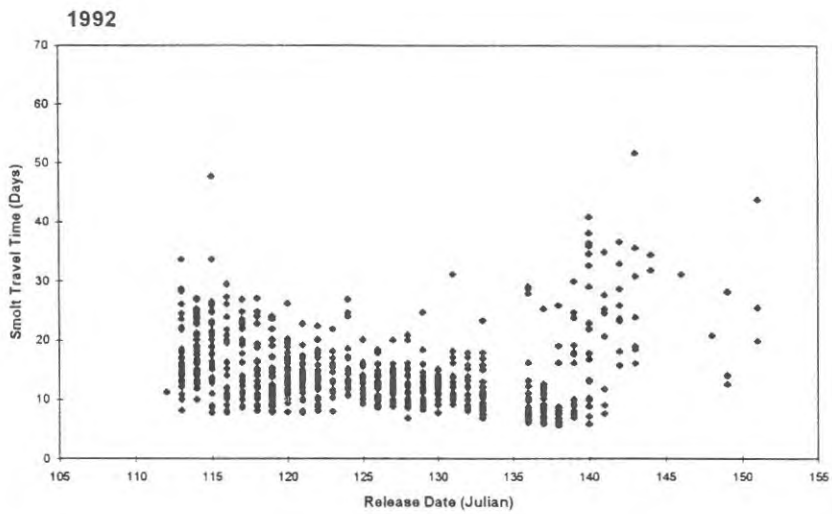
Appendix 11. Smolt travel time plotted against release date (Julian), flow (kcfs), fish length (mm), and temperature (F) for years 1989-1994, from annual reports of the Fish Passage Center.

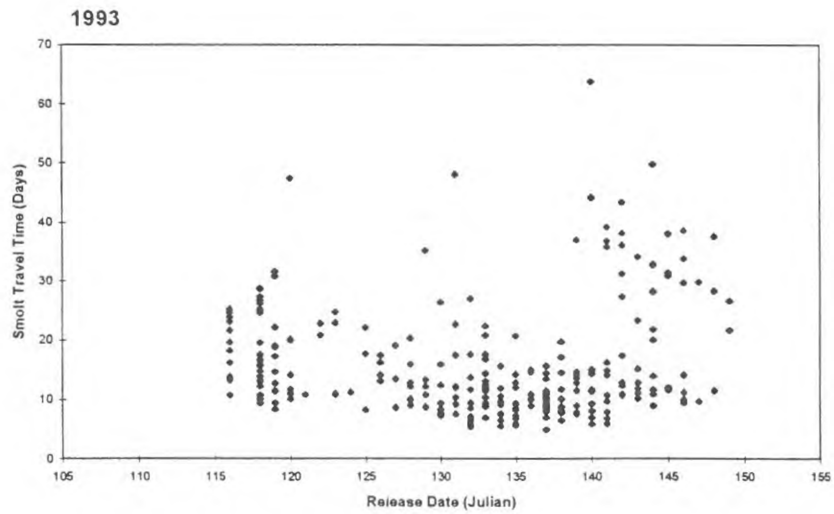


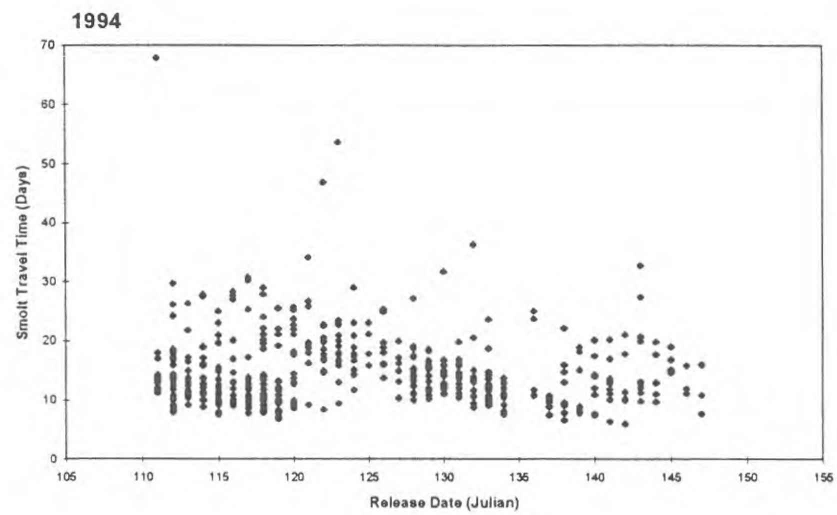




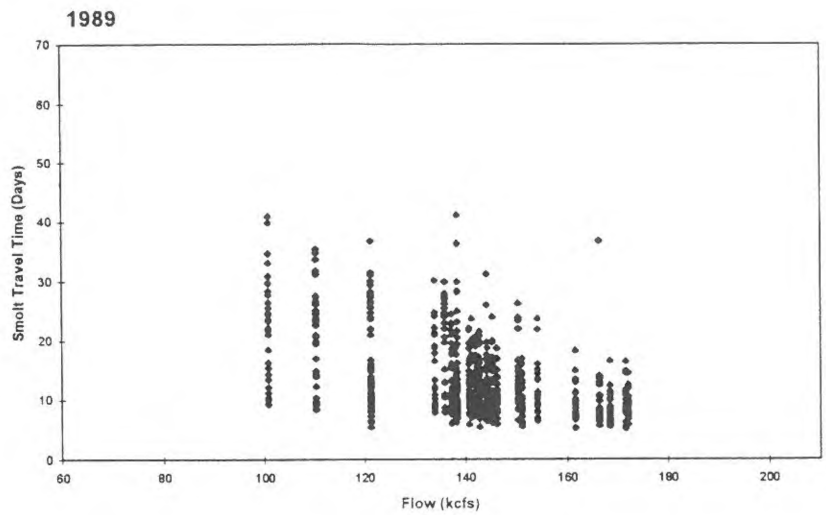
Appendix 11. Continued.

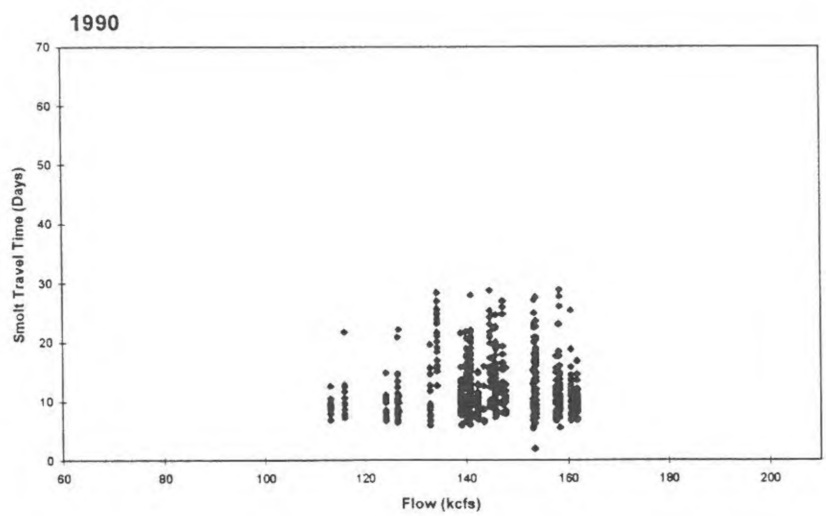


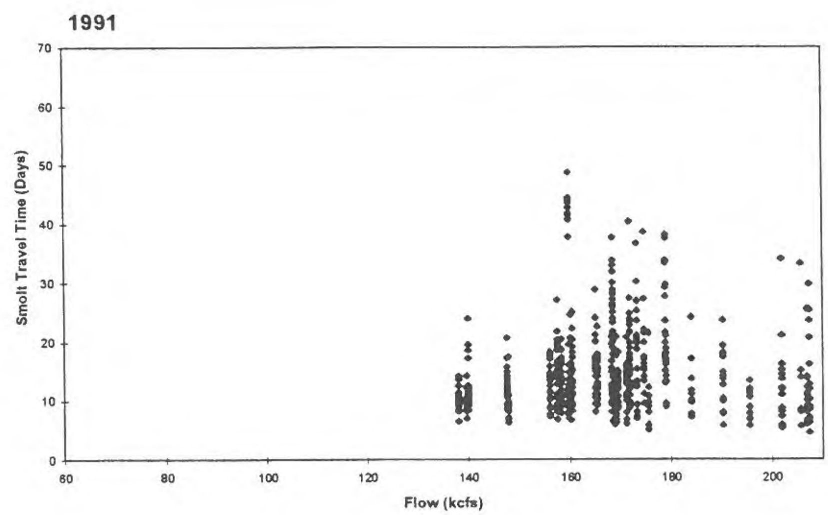




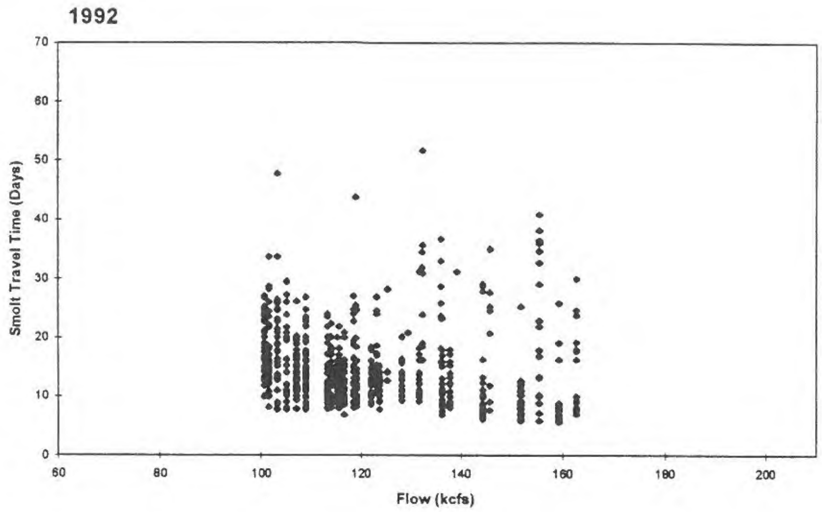
Appendix 11. Continued.

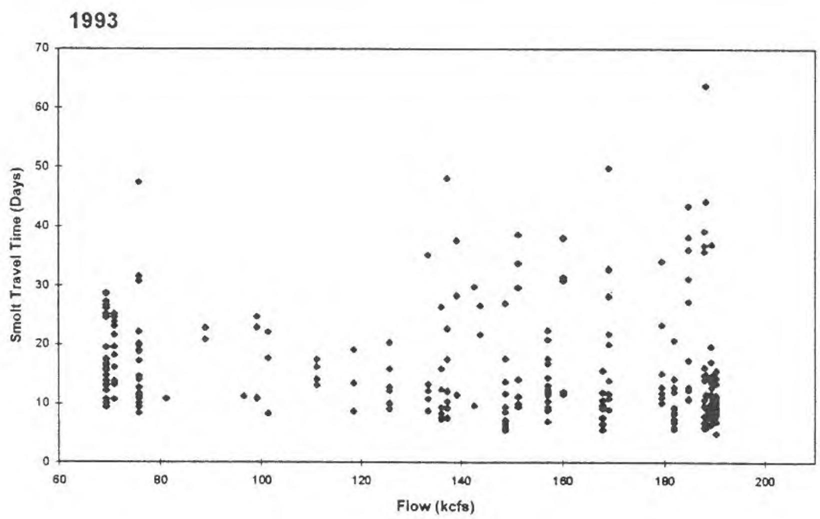


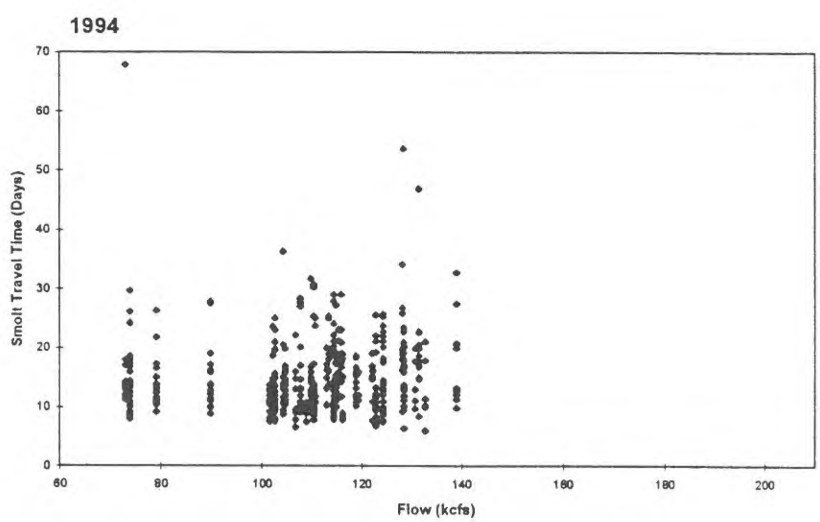




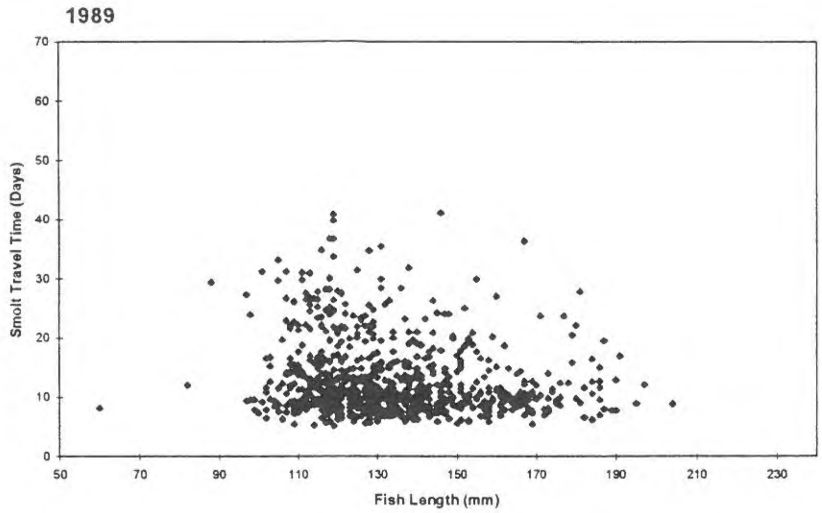
Appendix 11. Continued.

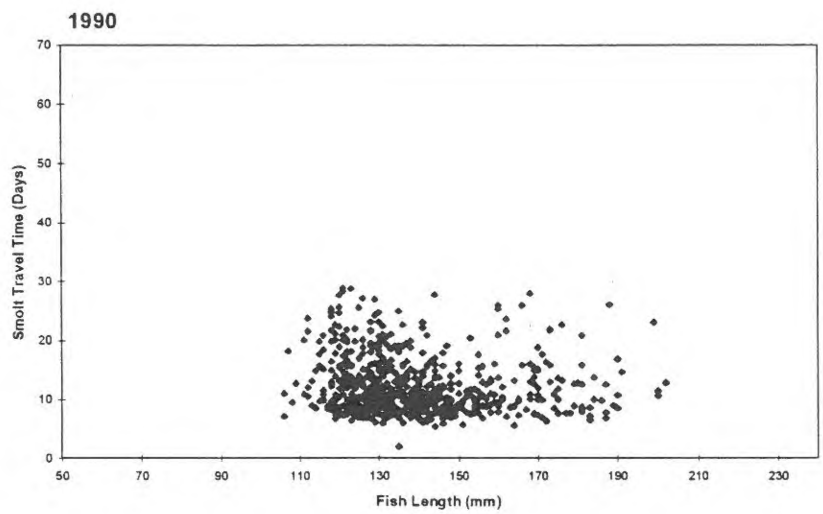


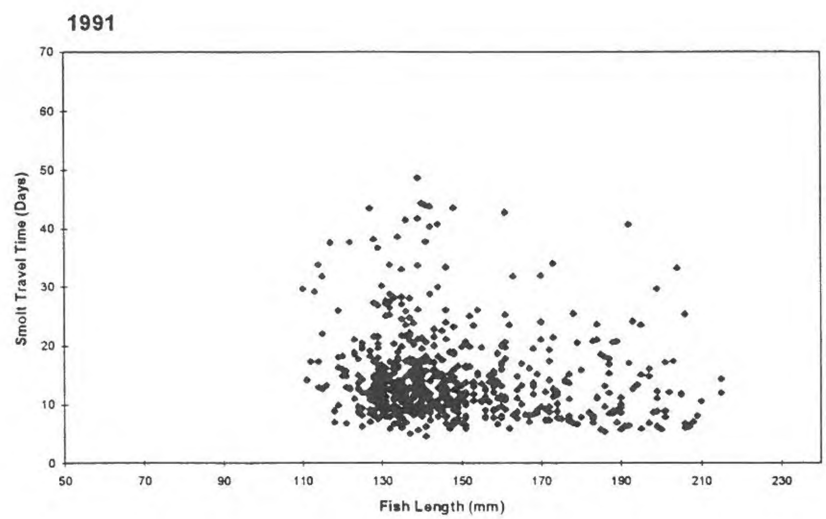




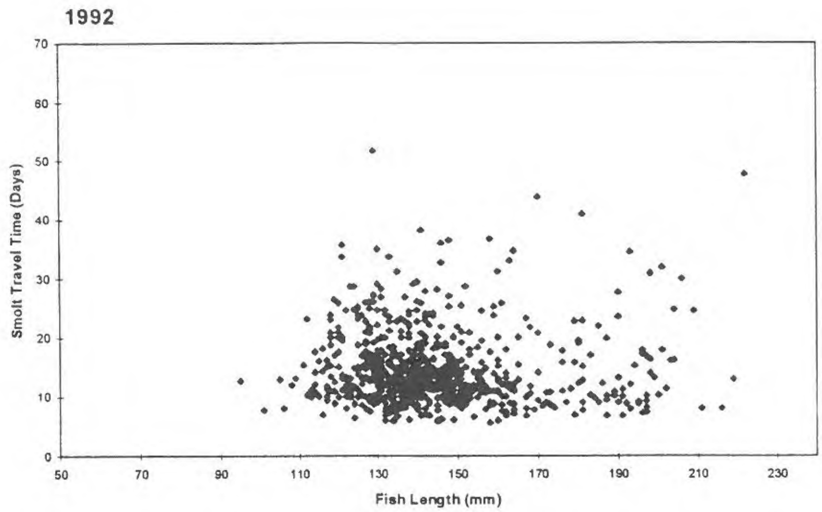
Appendix 11. Continued.

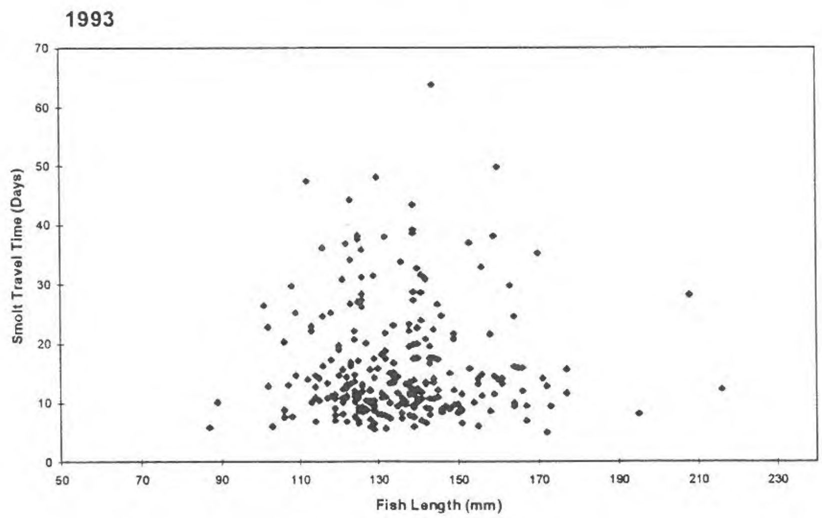


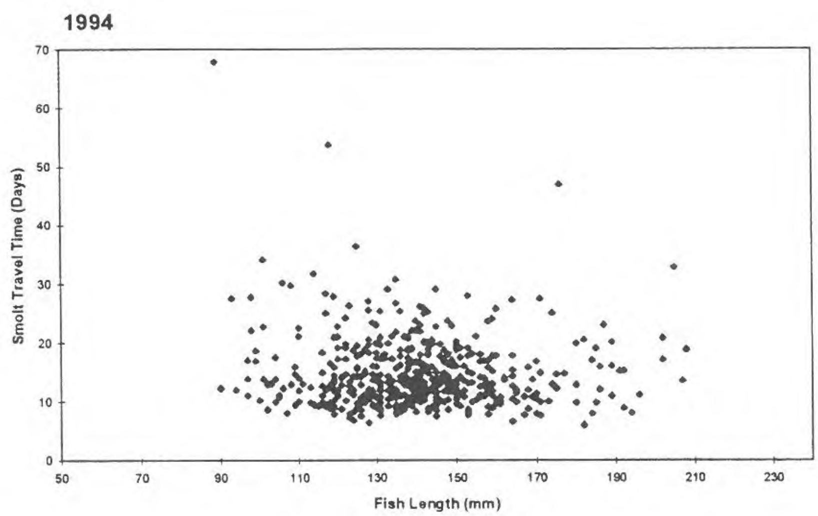




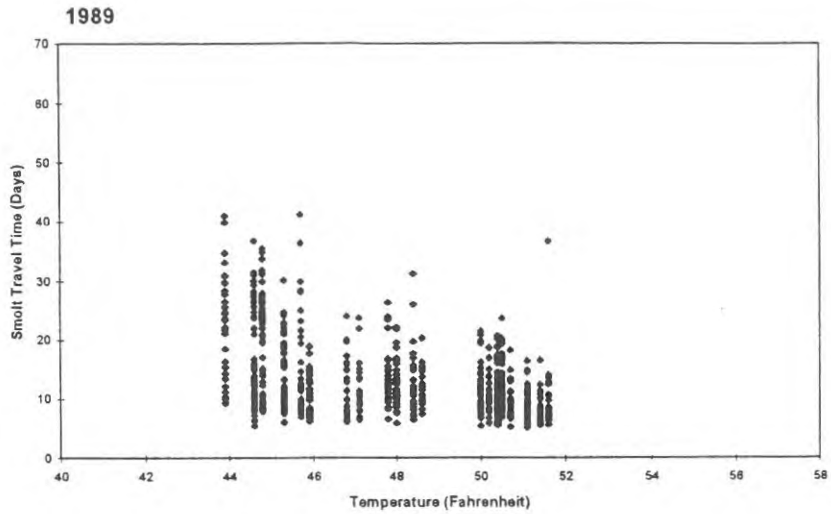
Appendix 11. Continued.

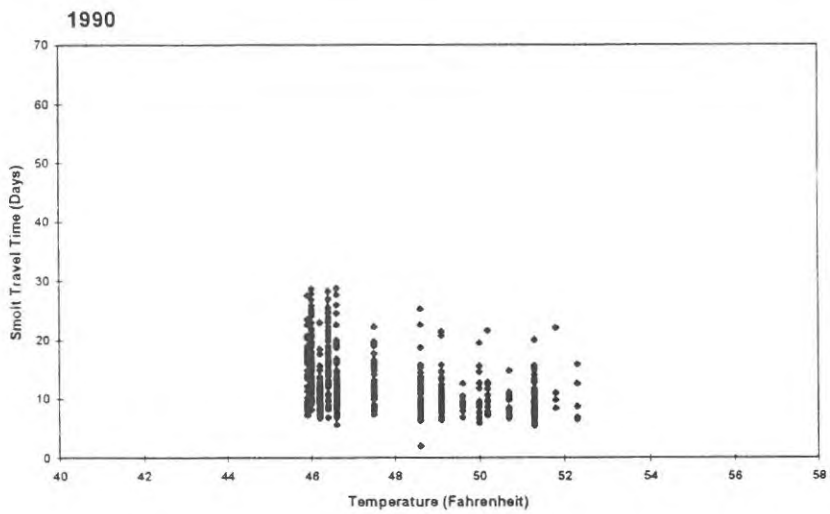


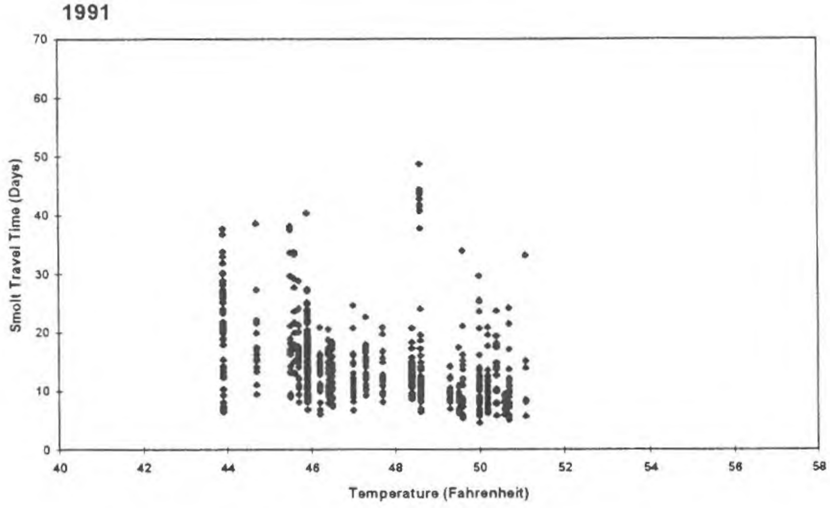




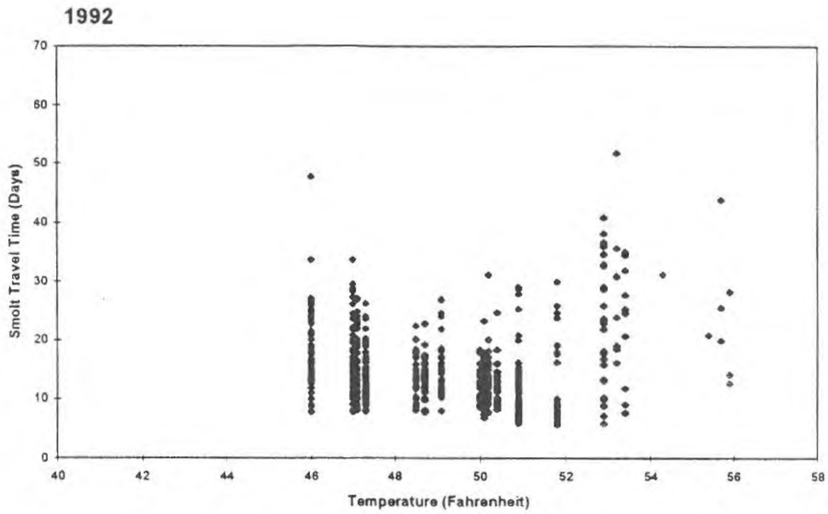
Appendix 11. Continued.

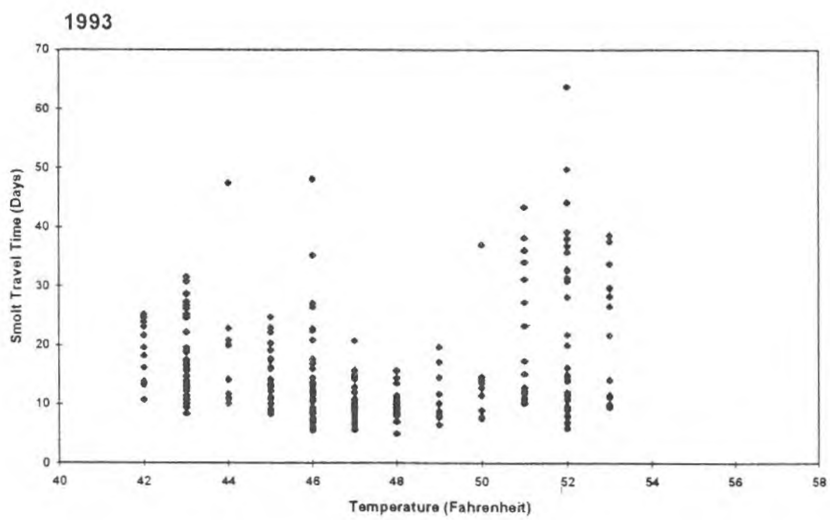


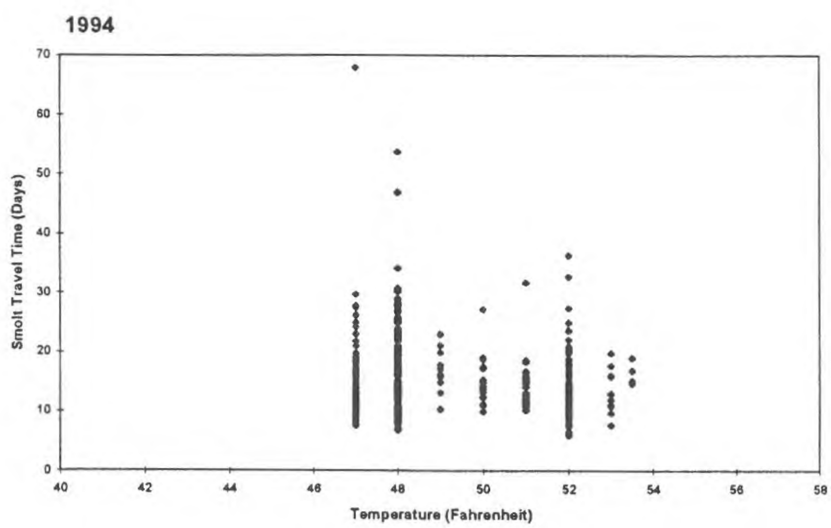




Appendix 11. Concluded.







Appendix 12

Appendix 12. Columbia River Salmon Passage model 1.5, (CRiSP1.5), survival estimates for Winthrop Hatchery spring chinook from release to Priest Rapids Dam and Bonneville Dam tailraces 1983-1990.

	Survival to PRD Tailrace			Survival to BON Tailrace			
Year	**Base**	**Bypass**	**Spill**	**Base**	**Bypass**	**Spill**	**Trans**
1983	27.9	34.5	27.8	13.1	16.3	12.8	37.7
1984	40.0	49.8	39.2	21.4	27.9	21.2	53.8
1985	33.7	43.0	34.9	15.8	23.0	18.1	45.9
1985	35.8	45.7	37.0	16.5	24.5	19.2	48.9
1985	38.4	49.0	39.6	17.5	26.1	20.5	52.5
1986	38.4	48.9	39.4	20.2	28.5	22.4	52.3
1986	40.4	51.5	41.5	21.1	30.0	23.5	55.1
1986	42.3	53.9	43.2	21.4	30.9	24.0	57.9
1987	31.9	40.6	33.1	14.7	21.0	16.7	43.7
1987	33.9	43.1	35.1	15.4	22.3	17.8	46.6
1987	36.5	46.4	37.8	16.1	23.8	18.9	50.4
1988	30.0	38.3	30.2	13.4	21.0	16.1	41.9
1989	31.8	40.3	32.7	15.8	22.0	17.5	44.2
1990	31.0	39.3	31.5	14.9	22.6	17.7	42.9
Average	35.1	44.6	35.9	17.0	24.3	19.0	48.1