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Effects of Lost Creek Dam on Winter Steelhead in the Rogue River

Phase II Completion Report

February 1990

EFFECTS OF LOST CREEK DAM ON WINTER STEELHEAD IN THE ROGUE RIVER. PHASE II COMPLETION REPORT.

Rogue Basin Fisheries Evaluation Project
Research and Development Section

Oregon Department of Fish and Wildlife

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CONTENTS

CONTENTS (continued)

FOREWORD

This report is the culmination of 11 years of research funded by the U.S. Army Corps of Engineers. A study of this duration has necessarily involved the collective effort of many people since its inception in 1977. For this reason, it is being presented as a staff report of personnel on the Rogue Basin Fisheries Evaluation Project. The completion report was drafted by Thomas Satterthwaite who was largely responsible for analyses contained in this report. Barry McPherson supervised the project and critically reviewed the analyses, conclusions, and recommendations in the final document. This report is the second of a series of completion reports planned for anadromous salmon and steelhead stocks produced in the Rogue River basin.

Research on winter steelhead was primarily an outgrowth of more intensive studies of chinook salmon and summer steelhead populations that began in the Rogue River in 1973. James Lichatowich was responsible for the original design and guidance of research on anadromous salmonids affected by the operation of Lost Creek Dam. These duties were subsequently assumed by Steven Cramer who served as program leader until 1985. Their leadership and insights on study designs were largely responsible for the ultimate success of research conducted by personnel in the Rogue Basin Fisheries Evaluation Project.

The mainstem and tributaries of the Rogue River collectively produce the largest population of wild anadromous salmonids in Oregon. The Rogue River supports recreational and commercial fisheries of immense importance to Oregon citizens and is nationally renowned for its diversity and productivity. Authorizing documents for Lost Creek Dam stipulate that fisheries enhancement is to be an important benefit of the dam, mainly through improved temperature and flow. We hope our studies will ensure that these benefits are achieved for present and future generations of Oregon citizens.

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22 November 1989

SUMMARY

In this report, we evaluate the effects of Lost Creek Dam on winter steelhead *Oncorhynchus mykiss* in the Rogue River. Field sampling began in 1977 and ended in 1987. Lost Creek Dam closed during February 1977, but the reservoir did not fill completely until the spring of 1978. A summary of our findings follows.

Adults

1. The operation of Lost Creek Dam did not significantly affect the abundance of wild adults that returned to areas upstream of Gold Ray Dam.

2. Estimated return to freshwater averaged 43,300 wild adults and 3,200 hatchery adults during 3 run years (1977-78 through 1979-80).

3. Adults entered the Rogue River primarily during November-March and contributed to recreational fisheries primarily during November-April.

4. A composite of discrete populations composed the annual return of wild adults.

5. Estimates of annual harvest rate averaged 26% on wild fish, 34% on hatchery fish, and 26% on the combined stocks for adults that returned to the Rogue River during 3 run years (1977-78 through 1979-80).

6. We estimated that anglers harvested an average of 7,900 winter steelhead annually in the Rogue River during 21 run years (1966-67 through 1986-87).

7. We estimated that smolt releases from Cole M. Rivers Hatchery increased harvest by an average of 1,200 adults and 3,600 half-pounders annually during the 10 years 1978-87.

8. Angler harvest during February-March correlated positively with fish abundance and negatively with flow. The reductions in flow during reservoir filling increased harvest by an average of 405 adults annually.

9. Angler effort decreased when turbidity was less than 5 JTU or greater than 15-20 JTU. Operation of the dam enhanced angler opportunities when river turbidity was high in downstream areas, but reduced opportunities when river turbidity was low.

10. Water temperature during March affected the migration timing of wild adults into the upper river. The operation of Lost Creek Dam did not affect migration timing of wild adults because operation of the dam had a minimal effect on river temperature during March.

11. Hatchery fish passed Gold Ray Dam later than wild fish. The effect of differential migration timing on angler catch is unknown because we did not survey the recreational fishery in the upper river.

12. An average of 31% of the wild adults had previously returned to freshwater on a false spawning run as half-pounders.

13. Some wild adults spawned in the mainstem upstream of Gold Ray Dam, but most spawned in tributary streams throughout the basin.

Juveniles

1. Eggs and fry of mainstem spawners were occasionally dewatered during rapid reductions in outflow from the dam.

2. The importance of the mainstem for rearing juvenile winter steelhead remains uncertain.

3. Operation of Lost Creek Dam had a minimal effect on the emergence timing of fry in downstream areas.

4. The effects of Lost Creek Dam on biology of juvenile winter steelhead could not be assessed because data was collected from scales of adults that represented a composite of populations in the Rogue River basin.

5. Smolts migrated to the ocean at younger ages compared with other populations of steelhead on the west coast of North America.

6. Younger smolts were more likely than older smolts to make a half-pounder run.

RECOMMENDATIONS

Reservoir Management and Operation of Lost Creek Dam

1. During April-July, short-term reductions in outflow should be limited so that the level of water at Dodge Bridge does not decrease by more than 0.3 m. Adoption of this recommendation would minimize disruption of spawning and dewatering of eggs and alevins of winter steelhead (*see* **Abundance**, page 55). This recommendation need not apply during flood control operations, because of increased flow from tributary streams.

2. During May-July, the rate of decrease in outflow should be limited to an average of 50 cfs/hour, with a maximum incremental change of 200 cfs. Adoption of this recommendation would minimize the potential for dewatering of newly emergent fry of winter steelhead. Satterthwaite (1987) discussed how the rate of change in outflow affected the dewatering of chinook salmon fry. This recommendation need not apply during flood control operations because of increased flow from tributary streams.

Management and Evaluation of Fishery Resources

The following recommendations are directed primarily to the Oregon Department of Fish and Wildlife, the lead agency for management of fishery resources in the Rogue River basin. Cooperation of other state and federal agencies may be needed to implement recommendations.

1. The importance of major factors that affect the production of wild winter steelhead produced in areas upstream of Gold Ray Dam should be determined. Return of each brood can be estimated by analysis of scales obtained from adults trapped at Gold Ray Dam. Variations in brood year abundance can then be examined for relationships with variations in parental abundance and environmental factors (*see* **Abundance**, page 35).

   Adoption of a goal for abundance of this population at return to Gold Ray Dam would improve management of winter steelhead throughout the basin. Estimates of harvestable surplus would be useful in development of harvest regulations. Harvest regulations directed at this population should ensure adequate protection of populations in other areas of the basin. Populations in downstream areas are harvested at lower rates, with the possible exception of populations in tributaries open to angling (*see* **Harvest Rate:**, page 40).

2. Index areas should be established to monitor long-term trends in the production of juvenile winter steelhead within the basin. Monitoring should target yearlings and subyearlings because of the difficulty in estimating the abundance of smolts and adults. Juvenile abundance should be estimated during the late summer using sampling procedures best suited to specific sites. Index areas should be within streams accessible to adults during years of low flow, contain winter steelhead but not summer steelhead, and remain cool enough to maintain juveniles throughout the summer. Index areas should be spread throughout the basin. Agencies responsible for management of state and federal lands should cooperate in joint surveys of fish and habitat resources.

3. Abundance of juvenile steelhead in the Rogue River upstream of Gold Ray Dam should be estimated for a minimum of 3 years. Water clarity may allow for snorkel counts of yearlings during the late summer. If populations are judged to be significant, the amount of hiding cover available to juvenile steelhead during the winter should be estimated (*see* **Abundance**, page 54).

4. Discrete stocks of winter steelhead within the Rogue River basin should be identified. Differences in life history characteristics among adults that return to the Applegate and Illinois rivers may reflect genetic differences between stocks. We believe multiple populations exist in the basin (Rivers 1964). Populations within all major drainages should be examined for unique genetic resources. Knowledge of the distribution of stocks within the basin is needed for development of effective strategies to maintain and enhance a diversity of wild fish populations (ODFW 1986). We believe that maintenance of diversity in wild fish populations to be important in providing sustainable production of winter steelhead in the basin.

5. Outplanting of juveniles and adults from the current stock of Rogue River winter steelhead at Cole M. Rivers Hatchery should be restricted to areas upstream of Gold Ray Dam. Supplementation of populations in other areas, if desired, should use locally adapted broodstock. Outplanting of fish from less adapted stocks can reduce, rather than enhance, stock productivity for populations of wild fish (Chilcote et al. 1986; Nickelson et al. 1986).

6. To maintain genetic diversity for sustainable production within the hatchery program, wild adults should be periodically included among broodstock spawned at Cole M. Rivers Hatchery. If available, use wild winter steelhead that return to the base of Elk Creek Dam. If that source is no longer available, trap adults in Big Butte Creek during April. A geneticist should develop guidelines for including wild broodstock in the hatchery program.

7. Evaluate alternatives to allow for increased harvest of hatchery winter steelhead. Daily limits could be modified to allow for retention of additional hatchery fish. Effects of any resultant increase in angler effort should be minimal on the production of wild winter steelhead because harvest rate does not limit subsequent production (*see* **Harvest Rate:**, page 40).

8. Harvest estimates of winter steelhead from salmon-steelhead cards should be improved. Greater spatial delineation would help differentiate catches of summer steelhead and winter steelhead (*see* **Harvest**, page 17). For the Rogue River, three catch areas should be included on salmon-steelhead cards: (1) mouth-Galice, (2) Galice-Gold Ray Dam, and (3) above Gold Ray Dam.

INTRODUCTION

This report presents the findings of 11 years (1977-87) of work with winter steelhead *Oncorhynchus mykiss* in the Rogue River basin of southwestern Oregon. The Oregon Department of Fish and Wildlife (ODFW) conducted this study, funded by the United States Army Corps of Engineers (USACE), to (1) determine the effects of Lost Creek Dam on anadromous fish and (2) develop operating strategies that optimize the production and harvest of fishery resources in downstream areas.

The Congress of the United States of America authorized the construction of Lost Creek Dam at river kilometer (RK) 253 (Figure 1) to create a reservoir to be used for multiple purposes, including the enhancement of fishery resources in downstream areas (United States Congress 1962). An updated economic review in 1971 indicated that planners projected fishery enhancement to be the third largest benefit accrued annually from the operation of the dam (USACE 1972). Spawning and rearing habitat for salmon *Oncorhynchus* spp. and steelhead blocked or inundated by the dam was to be mitigated by releases of fish reared at Cole M. Rivers Hatchery (RK 252). Benefits to anadromous fish in downstream areas were expected to accrue by operating the dam to (1) decrease peak flow during the winter, (2) increase flow during the summer, and (3) decrease water temperature during the summer.

To regulate the outflow temperature from Lost Creek Dam, USACE constructed an intake structure capable of withdrawing water from five different levels of the reservoir (Figure 2). Selective opening of intake ports allows for the mixing of water from various temperature strata in the reservoir. Choice of outflow temperature is greatest during the early summer when the reservoir is full and has thermally stratified. Control of release temperature diminishes in the late summer as the reservoir level drops and the highest intake ports become dewatered. In the fall, after the reservoir destratifies, control of release temperature becomes minimal (USACE 1983).

Figure 1. Lost Creek Dam and Cole M. Rivers Hatchery.

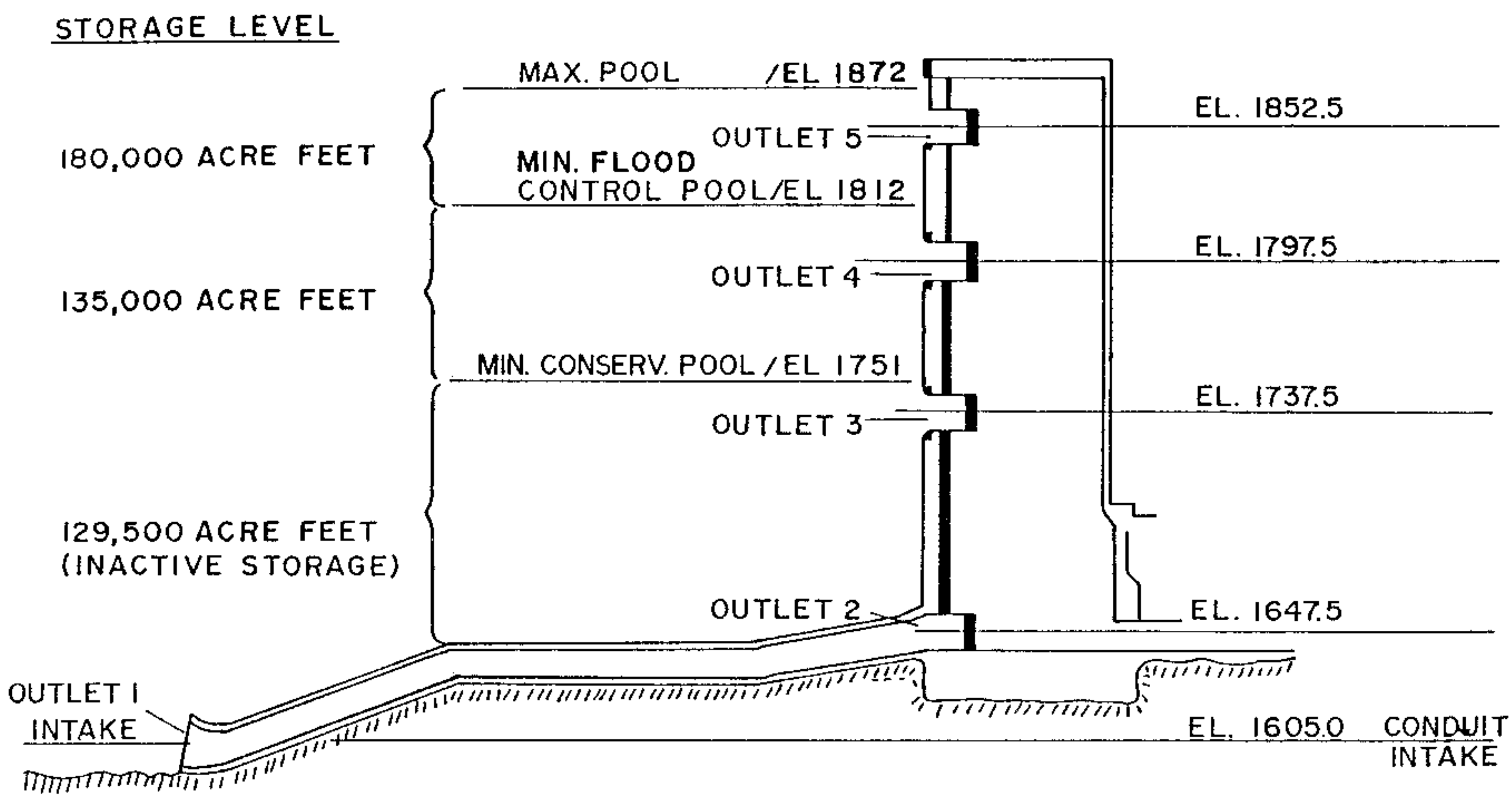

Figure 2. Schematic of the multiport intake structure for water withdrawal from five levels within Lost Creek Lake.

Guidelines for release of stored water were intended to be flexible, reflecting the annual variation in water yield and user demand. During years when the reservoir fills, 180,000 acre-feet of storage is available for flow augmentation (USACE 1972). Of this total, 125,000 acre-feet was authorized for fishery enhancement (United States Congress 1962). The remaining 55,000 acre-feet of storage was dedicated to other uses: irrigation supply, municipal and industrial supply, and environmental enhancement. Dedicated storage that is not purchased is also available for downstream enhancement of fishery resources (USACE 1972).

Flood control was identified as the primary benefit associated with the construction of Lost Creek Dam. Other benefits would accrue by allocating conservation storage to irrigation, future water supply, and fishery enhancement. "No storage specifically for wildlife enhancement, power generation, water quality control, or recreation" was identified (United States Congress 1962).

The authorizing document also outlined minimum outflow and maximum water temperature to be released from Lost Creek Dam, but clearly stated that these guidelines should be modified as additional information became available: "It should also be noted that project operation plans must be sufficiently flexible to permit desirable modifications in scheduled fishery releases, within the limits of storage provided therefore, if experience and further study indicates such action to be desirable for overall project benefits" (United States Congress 1962). Including provisions for modifications in releases for fisheries benefits was far-sighted because biologists can rarely predict postproject responses accurately because of the complexity of aquatic ecosystems (Rosenberg et al. 1986).

Flexibility in scheduling temperature and flow releases from Lost Creek Dam provides an opportunity to implement an operating strategy that optimizes the production and harvest of anadromous salmonids in the river downstream of the dam. To identify the most appropriate operating strategy, we examined the effect of water temperature, flow, and turbidity on the biology and harvest of wild and hatchery winter steelhead in the Rogue River basin. Preliminary findings from our work were reported in numerous annual progress reports and were summarized by Cramer et al. (1985).

Winter steelhead produced in the Rogue River basin are an important fishery resource. Estimates from salmon-steelhead cards indicated that the Rogue River accounted for an average of 12% of the winter steelhead harvested by anglers that fished Oregon coastal streams during the 1970-71 through 1986-87 run years. Production costs are minimal because wild fish account for more than 90% of the winter steelhead that return to the basin. Wild winter steelhead are widely distributed throughout the basin, although their distribution is imprecisely known (Rivers 1964). Presently, ODFW manages winter steelhead in the Rogue River basin as three distinct stocks (Rogue, Applegate, and Illinois).

In this report, we estimate the effects of Lost Creek Dam on winter steelhead and present recommendations to enhance the production and harvest of winter steelhead. Use of water releases from Lost Creek Dam to increase stock productivity would be a low cost method of fishery enhancement. This report represents one of a series of completion reports for fisheries work funded by USACE in the Rogue River basin.

STUDY AREA

The Rogue River basin encompasses 13,150 square kilometers of southwestern Oregon and a small portion of northwestern California (Figure 3). Approximately 13% of the basin is upstream of Lost Creek Dam. The Rogue River originates in the Cascade Mountains and flows west, breaching the Coast Range prior to reaching the Pacific Ocean. Two major tributaries, the Illinois and Applegate rivers, originate in the Siskiyou Mountains and flow north where they enter the Rogue River at RK 44 and RK 154, respectively.

The estuary of the Rogue River is relatively small, covering an area of about 630 acres at mean high tide. Ratti (1979) reported that about 80% of the estuary could be classified as a riverine subsystem and 20% could be classified as a marine subsystem. Tideflats, marshes, and eelgrass beds are noticeably absent in the Rogue River estuary.

Two USACE dams affect the timing of water yield in the Rogue River basin. Lost Creek Dam at RK 253 on the Rogue River began operation during February 1977 and affects flow in the Rogue River. Applegate Dam, at RK 75 on the Applegate River, began operation during November 1980 and affects flow in the Rogue River downstream of Grants Pass. Operation of Applegate Dam has a lesser effect on flow in the Rogue River because the normally used storage capacity of Applegate Lake is one-third that of Lost Creek Lake.

On an average year, the Rogue River basin yields about 7.4 million acre-feet of water (Friday and Miller 1984). The Illinois and Applegate rivers average approximately 40% and 7% of the water yielded annually in the basin. The Rogue River upstream of Lost Creek Dam accounted for an average of 18% of the water yield in the basin.

In the lower portion of the basin, river flow varies markedly between seasons. Discharge upstream of the mouth of the Illinois River averages 1,400 cfs during September and 26,600 cfs during January. The variation in flow is less pronounced in the upper portion of the basin. Flow into Lost Creek Lake averages 1,000 cfs in September and 2,000 cfs in January (Moffatt et al. 1990). Reservoir inflow usually peaks between April and June, when the snowpack in the Cascade Mountains melts at a rapid rate.

Weather patterns in the northeast Pacific greatly affect weather within the Rogue River basin. Wet, mild, winters and dry, warm, summers characterize the climate. Air temperature near Medford usually peaks between 32° and 35°C during July and August. During December and January, air temperature usually peaks between 8° and 10°C. Snow accumulates at the higher elevations during the winter and is the principle source of water yield during the spring and summer. Annual precipitation averages about 50 cm in the inland valley surrounding Medford. Coastal and headwater regions receive an average annual precipitation of about 200 cm and 300 cm, respectively (OWRD 1985). About 50% of the precipitation falls from November through January; less than 2% falls during July and August.

A large number of anadromous fish inhabit the Rogue River basin. Chinook salmon *O. tshawytscha* and steelhead are the most abundant salmonids. Coho salmon *O. kisutch* are common in tributary streams. Chum salmon *O. keta* and pink salmon *O. gorbuscha* are occasionally found in tributaries of the lower river. Resident salmonids include rainbow trout *O. mykiss*, cutthroat trout

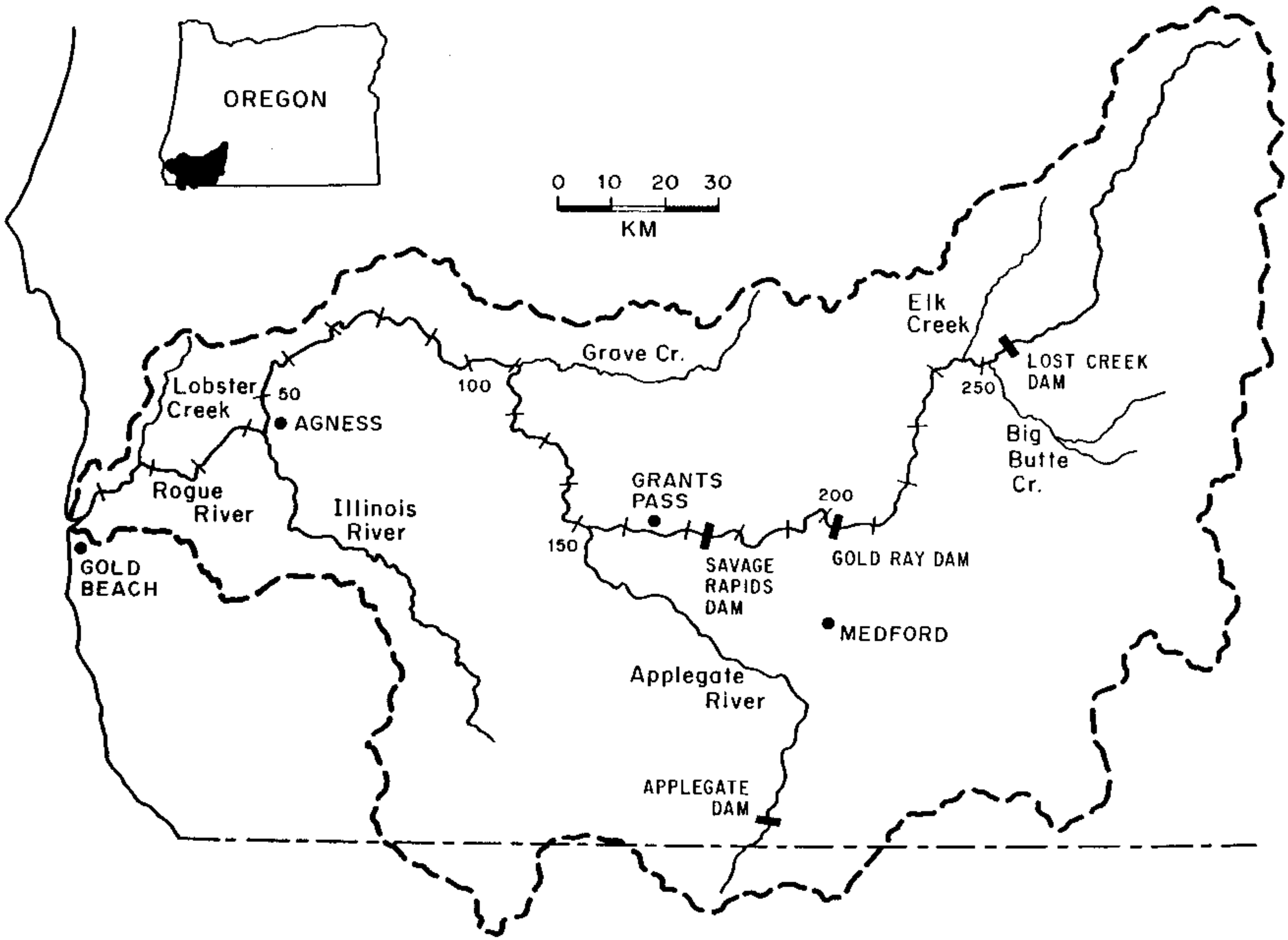

Figure 3. Map of the Rogue River basin. Numbers indicate kilometers from the river mouth.

O. clarki, brown trout *Salmo trutta*, and brook trout *Salvelinus fontinalis*. Few resident salmonids inhabit areas accessible to anadromous salmonids. Other commonly seen game fishes include largemouth bass *Micropterus salmoides*, bluegill *Lepomis macrochirus*, green sturgeon *Acipenser medirostris*, white sturgeon *A. transmontanus*, American shad *Alosa sapidissima*, and brown bullhead *Ictalurus nebulosus*. Nongame fishes abundant in the basin include redside shiner *Richardsonius balteatus*, Klamath smallscale sucker *Catostomus rimiculus*, common carp *Cyprinus carpio*, prickly sculpin *Cottus asper*, riffle sculpin *C. gulosus*, and Pacific lamprey *Lampetra tridentata*. The distribution of northern squawfish *Ptychocheilus oregonensis* is rapidly expanding after an illegal introduction in 1979.

For discussion purposes, we divided the Rogue River into four general areas. The upper river refers to the area between Lost Creek Dam and Gold Ray Dam (RK 253-202). The middle river refers to the area between Gold Ray Dam and Grave Creek (RK 202-110). The canyon refers to the area between Grave Creek and Agness (RK 110-44). The lower river refers to the area between Agness and the estuary (RK 44-6). Gradient in the upper river averages 2.3 m/km, in the middle river averages 1.6 m/km, in the canyon averages 2.4 m/km, and in the lower river averages 0.7 m/km.

APPROACH

We chose not to use the instream flow incremental methodology (Bovee 1982) for the development of flow recommendations. Although this approach has proved useful in some instances, the assumed direct relationship between weighted usable area and fish production is not always appropriate (Moyle and Baltz 1985; Mathur et al. 1985; Irvine et al. 1987). Our work centered primarily upon assessing the biological implications of modifications in flow, water temperature, and turbidity. During the planning of the study, changes in these physical factors were expected to be significant in the area of the river inhabited by winter steelhead.

The study comprised four objectives:

1. Determine the changes in temperature, flow, and turbidity that result downstream from Lost Creek Dam.

2. Determine the effects of Lost Creek Dam and develop operational criteria as related to the rearing and migration of juvenile winter steelhead.

3. Determine the effects of Lost Creek Dam and develop operational criteria as related to the abundance, migration, and life history of adult winter steelhead.

4. Determine the effects of Lost Creek Dam and develop operational criteria as related to the harvest of winter steelhead.

We used three avenues to meet our objectives. First, we used the North Umpqua River as a statistical control for comparison with the abundance of adults returning to the upper river. Second, we compared biological parameters of winter steelhead that inhabited the Rogue River before and after full operation of the dam was started. Third, we estimated the relationships between biological and physical factors in order to simulate biological responses to changes in physical factors. Each method had associated strengths and weaknesses.

We chose to use the North Umpqua River as a control stream because the annual return of winter steelhead has been estimated since 1946 (Anderson et al. 1986). In addition, the stream is close to the Rogue River and exhibits some similar morphological characteristics. However, none of the winter steelhead in the North Umpqua River make a half-pounder migration. Tributaries of the Rogue River were not used as statistical controls because (1) we could not differentiate juvenile summer from juvenile winter steelhead, (2) adult returns could not be estimated for a reasonable cost, and (3) fish originating from tributaries inhabited the Rogue River for a portion of their life.

Temporal comparisons were of some use. Sampling conducted prior to full operation of the dam provided information on the inter-annual variability within life history parameters. Sensitivity analyses after the first years of the study led to termination of work with algal and invertebrate communities. High variability among the data indicated a low probability of associating any changes in production or community structure with the operation of the dam. Initial sampling indicated life history parameters of winter steelhead exhibited much less variability.

However, temporal comparisons had some limitations. Given the expected variability, many years of data are required to make effective comparisons. We had only 5 years of returns for adults that reared as juveniles during the postimpoundment period. Although the dam was operational in 1977, low water yield resulted in little water for flow augmentation. Storage releases had little effect on physical factors in downstream areas. Consequently, we treated data from 1978 as the first postimpoundment year.

Comparisons of conditions during preimpoundment and postimpoundment periods were susceptible to effects from sources other than the treatment. Data were not independent of each other. For example, weather patterns differed before and after full operation began at Lost Creek Dam. Water yield from the basin was highly variable in the preimpoundment years and was low during the early postimpoundment years. We were aware of the potential for this type of bias, and, when a change was observed, we attempted to identify the responsible factor(s).

Identification of factors responsible for changes in biological parameters was approached by correlation and regression analyses. We reviewed the literature for background information on causative relationships among biological and physical factors. Factors that appeared to be most important were included as independent variables in regression analyses. We used regression analysis to estimate relationships between biological and physical factors.

METHODS

Physical Factors

The United States Geological Survey (USGS) operated automated gages at numerous sites in the Rogue River basin during the study. USACE personnel used data from the Rogue River basin, including that from these gages, to adapt a water quality model for estimating the effects of the operation of Lost Creek and Applegate dams on water quality parameters in downstream areas. Hamlin and Nestler (1987) describe the development of a QUAL II model specific to the Rogue River basin.

The QUAL II model was used to simulate flow, water temperature, and turbidity for regulated and unregulated conditions. Regulated conditions simulated the Rogue River with Lost Creek and Applegate dams operating. Unregulated conditions simulated the Rogue River as though the dams had not been built. Simulations encompassed the time periods of January 1978 through September 1986 for flow and January 1978 through December 1986 for water temperature and for turbidity. Model simulations produced estimates of daily means for physical factors at six gages operated by USGS (Table 1). The operation of Lost Creek Dam affected water quality and quantity at all gages. After November 1980, the operation of Applegate Dam affected physical parameters in the Rogue River at the two gages downstream of the Applegate River.

Table 1. Stations with water quality parameters simulated by USACE.

Station	River kilometer	Parameter simulated
Near McLeod	249	Flow, water temperature, and turbidity
Dodge Bridge	224	Flow, water temperature, and turbidity
Raygold	201	Flow, water temperature, and turbidity
Grants Pass	165	Flow, water temperature, and turbidity
Marial	78	Water temperature and turbidity
Agness	48	Flow

We used the results of modeling to estimate the effect of dam operations on water quality and quantity in downstream areas used by anadromous fish. We received data for flow simulations from Rock Peters, USACE, Portland District, on 24 April 1989. We received data for water temperature and turbidity simulations from Carla Haake, USACE, Portland District, on 25 May 1989.

In addition, we estimated river turbidity during angler surveys. Survey clerks collected two samples daily, one during the morning and one during the evening count of angler effort. We used an electronic turbidimeter to measure turbidity of the samples.

Adults

Life History

We sampled returning adults by electrofishing in the lower river (RK 8-29) 1 day weekly from 1 December through 15 March, 1977-78 through 1980-81 run years. We used a 7 m aluminum sled with a 2,500 W generator, a 2,000 W transformer, and a array of 10 electrodes each for the anode and the cathode. We electrofished using pulsed DC at 200-300 V and 1.5-2.0 A, depending upon variations in water conditions. Hatchery fish were differentiated from wild fish at the time of capture, based on the presence of a deformed dorsal fin or fin clips. A deformed dorsal fin characterized almost all winter steelhead of hatchery origin in the Rogue River basin (personal communication dated 3 March 1989 from Michael Evenson, ODFW, Cole M. Rivers Hatchery, Trail, Oregon).

We investigated life history characteristics by scale analysis. We removed scale samples from a maximum of 35 fish within each 5 cm size interval. About 20 scales composed each sample. Scales were taken from the first four rows immediately above the lateral line and immediately posterior to the dorsal fin on both sides of the fish. Four of the larger, nonregenerated scales of regular shape were mounted on gummed cards and impressed on acetate strips at 100°C under 5,000 psi for 3 minutes. Scale measurements and circuli counts were averaged for two scales from each fish.

Scales were read at a magnification factor of 88. Measurements and circuli counts in the anterior region of the scale were made along the longer of two lines oriented at 20° from the longitudinal midline of the scale. Scales with a nucleus radius larger than 15 mm (at 88X) were considered regenerated and were excluded from further analysis. We measured magnified distances (to the nearest 0.5 mm) from the scale focus to the following points: each annulus, ocean entry, each spawning check, and the outer edge of the scale. Circuli were counted from the nucleus to points of annuli, ocean entry, spawning checks, false annuli, and the scale edge.

The subjective nature of the analysis resulted in an unknown number of errors in interpretation. In particular, we found it difficult to precisely differentiate the final portion of freshwater growth from the initial portion of ocean growth. Errors, if present, would be consistent among run years because only one reader interpreted scales of returning adults.

Abundance

Steelhead passage over Gold Ray Dam (RK 202) has been estimated by fishery agencies of the state of Oregon since 1942. Passing adults are counted 8 hours daily for 5 days weekly except when the counting facility is inoperable because of floods. Partial counts were designed to estimate biweekly passage with an average error of less than 10% (Li 1948). From 1942 to 1967, adults were counted as they passed above a white flashboard. Since 1968 adults have been counted as they pass an underwater viewing window. Beginning with the 1971 return, the counter recorded all fin clips. Beginning in 1977, steelhead smaller than 40.6 cm (16 inches) were classified as half-pounders based on findings reported by Everest (1973).

Steelhead passing Gold Ray Dam are classified into two races. Rivers (1964) found that 15 May was an appropriate date to differentiate "late run" winter steelhead from "early run" summer steelhead. However, no clear date is available by which to delineate late run summer steelhead and early run winter steelhead.

We chose 1 February as a demarcation date between these two races, based on three factors. First, based on biweekly estimates of steelhead passing

Gold Ray Dam, we usually found a nadir in migration during late January or early February. Second, Everest (1973) found that few known summer steelhead passed Gold Ray Dam after 1 February. During 1970, no summer steelhead tagged in the lower river passed the counting station after 1 February. During 1971, only 7% of the tagged summer steelhead passed the counting station after 1 February.

We found that few winter steelhead of hatchery origin passed Gold Ray Dam prior to February. Consequently, we concluded that 1 February was the most appropriate date for the delineation of summer and winter steelhead passing Gold Ray Dam. We recognize that some summer steelhead will pass after that date, and some winter steelhead will pass prior to that date.

At the counting station, hatchery and wild fish were differentiated on the basis of fin clips. During 1971-79, 100% of the returning winter steelhead of hatchery origin were marked. After 1979, passage estimates of hatchery and wild adults were made by expanding biweekly estimates of marked adults. To expand counts of marked adults that passed Gold Ray Dam, we used the proportion of marked fish among annual returns of hatchery fish to Cole M. Rivers Hatchery. Unmarked hatchery fish were differentiated from wild fish based on whether the dorsal fin was deformed.

A review of hatchery records indicated that winter steelhead predominated in the adult return at the hatchery from 13 March through 12 June. Estimated percentage of marked fish among hatchery winter steelhead that entered the hatchery is given in Table 2. Variations in the percentage of marked fish among adults that returned to the hatchery resulted from annual variations in mark rates of juvenile releases.

Table 2. Estimated percentage of marked fish among hatchery winter steelhead that entered Cole M. Rivers Hatchery during 13 March through 12 June, 1980-87.

Year	Hatchery fish	Marked (%)	Year	Hatchery fish	Marked (%)
1980	2,765	93.6	1984	4,145	27.0
1981	1,228	68.8	1985	1,655	30.4
1982	1,205	36.5	1986	1,038	79.5
1983	1,462	29.4	1987	2,213	26.2

We estimated the number of winter steelhead that returned to freshwater during the 3 run years of 1977-78 through 1979-80 based on calculations using counts of hatchery fish at Gold Ray Dam, catch estimates derived from salmon-steelhead cards, percentages of hatchery fish within samples from angler surveys and electrofishing, and a combined rate of prespawning mortality plus straying below Gold Ray Dam. Data used in the calculations are given in Table 3.

Table 3. Data used to estimate number of winter steelhead that returned to the Rogue River, 1977-78 through 1980-81 run years.

Run year	Hatchery fish that returned to Gold Ray Dam	Dec-Apr harvest in river	% hatchery in harvest downstream of Gold Ray Dam[a]	% hatchery at river entry[b]
1977-78	760	11,063	4.58	3.30
1978-79	2,818	13,688	9.80	9.90
1979-80	2,942	10,789	10.12	7.15
1980-81	1,743	7,616	12.00	(c)

[a] *Average from the two angler survey areas in the lower and middle river.*
[b] *Average from electrofishing and angler survey samples in the lower river.*
[c] *No reliable estimate from electrofishing to average with angler survey data.*

Before estimating the return of all fish (wild plus hatchery), we first had to estimate freshwater return of hatchery fish by the equation

$$E = (N/(1-c))+F \qquad (1)$$

where

E = estimated return of hatchery fish to freshwater,
N = estimated return of hatchery fish to Gold Ray Dam,
c = a constant representing the proportion of the freshwater return assumed to have died naturally or strayed to spawn downstream of Gold Ray Dam, and
F = estimated number of hatchery fish harvested downstream of Gold Ray Dam during December-April.

In this first equation we assumed a low rate of prespawning mortality plus straying downstream of Gold Ray Dam. We believe this assumption was reasonable because (1) we never observed or received reports of prespawning mortality during the period that winter steelhead migrated upstream, and (2) no unmarked juvenile winter steelhead of hatchery origin were released at sites other than the hatchery. All juveniles released into the Applegate River were marked and were excluded from the analyses.

Adults probably strayed to spawn near the hatchery, but we believe that few adults strayed to spawn in areas downstream of Gold Ray Dam. Cramer (1981) and Hiss et al. (1986) concluded that hatchery steelhead stray to spawn in areas upstream, rather than downstream, of the release site. Taft and Shapovalov (1938) estimated more than 95% of the summer steelhead in small tributaries of the Klamath River, California, homed to natal streams. Lister et al. (1981) summarized data from numerous studies that indicate straying is minimal when juvenile steelhead are released directly from the rearing facility. Therefore, to account for prespawning mortality plus straying, we assumed that only 5% of the hatchery adults that entered freshwater failed to pass Gold Ray Dam.

To estimate the number of hatchery fish harvested downstream of Gold Ray Dam for equation (1), we used data from salmon-steelhead cards returned by anglers in combination with percentage of hatchery fish within the catch sampled during angler surveys. We used the equation

$$F = 0.95T(P_1/100\%) \tag{2}$$

where

F = estimated number of hatchery fish harvested downstream of Gold Ray Dam during December-April,
T = estimated number of fish (wild plus hatchery) harvested throughout the river during December-April, and
P_1 = estimated percentage of hatchery fish within the harvest below Gold Ray Dam.

For equation (2) we assumed 95% of the total catch was taken below Gold Ray Dam during 1977-78 through 1980-81 based on data from the mid-1980s when estimates of angler catch were segregated by area. Data from angler returns of salmon-steelhead cards indicated that harvest above Gold Ray Dam was 9.9% of the total harvest during the 1984-85 run year. The harvest increased to 10.5% in 1985-86 and 13.5% in 1986-87. Because the area above Gold Ray Dam was not open to angling before 1975, we assumed that the increase in the mid-1980s reflected a steady increase from 0% in the 1973-74 run year.

The percentage of hatchery fish within the harvest below Gold Ray Dam was estimated each year for equation (2) by averaging the percentages of hatchery fish observed within the two angler survey areas in the lower and middle river (RK 8-21 and 139-156, respectively). Because the surveys were not designed to estimate total catch, and we had no indication that total catch differed markedly between the two areas, we chose to average the percentages from the two areas.

After we estimated return of hatchery fish to freshwater, we estimated return of all fish (wild plus hatchery) to freshwater using the equation

$$A = E/(P_2/100\%) \tag{3}$$

where

A = estimated return of all fish (wild plus hatchery) to freshwater,
E = estimated return of hatchery fish to freshwater, and
P_2 = estimated percentage of hatchery fish within the return of all fish to freshwater.

For equation (3) we estimated the percentage of hatchery fish within the return of all fish to freshwater each year by averaging the percentages of hatchery fish observed within the lower river angler survey and the electrofishing catch. We assumed that an average provided a better estimate than either source alone. Return of wild fish each year was estimated by subtracting equation (1) from equation (3).

Although we estimated the return of hatchery fish to freshwater in the 1980-81 run year using equation (2), we did not estimate return of all fish (wild plus hatchery) because of biased electrofishing data. Electrofishing in

1980-81 was done primarily during February-March when return of hatchery fish peaked. Gear problems minimized sampling during December-January when return of wild fish peaked, causing a biased estimate of the percentage of hatchery fish within the run.

Harvest

We assumed that catch estimates derived from salmon-steelhead cards were an unbiased estimate of the harvest of winter steelhead in the Rogue River. This assumption is probably erroneous because the adjustment factor for a nonresponse bias is only applicable on a statewide basis (Hicks and Calvin 1964). However, because the Rogue River is fished by a large number of anglers from throughout the region, we believe that catch estimates from salmon-steelhead cards provide a reasonable, but not necessarily precise, estimate of harvest.

We also assumed that catch estimates for December through April were entirely winter steelhead. This assumption is erroneous because anglers harvest summer steelhead during December through February. However, few summer steelhead are large enough to require entry on salmon-steelhead cards (Cramer et al. 1985). Use of catch estimates from salmon-steelhead cards for the period of December through April also excluded harvest of some winter steelhead. Anglers harvested some winter steelhead in the lower river during November. In addition, some winter steelhead do not exceed the 50.8 cm (20 inches) criteria necessitating entry on salmon-steelhead cards. Based on electrofishing samples, we estimated that an average of 6% of the adults that returned were smaller than 50.8 cm (20 inches). Because harvest estimates may be inflated by catches of summer steelhead, we chose not to adjust harvest estimates to include these small adults.

In equation (2) of the method for estimating adult abundance, we estimated the number of total fish and then the number of hatchery fish harvested downstream of Gold Ray Dam in the 1977-78 through 1980-81 run years. We then estimated the number of wild fish harvested below Gold Ray Dam by subtraction. This estimate of wild fish harvest was divided by the estimate of wild fish abundance at river entry to estimate harvest rate on wild fish in the mainstem below Gold Ray Dam.

We divided the hatchery fish catch below Gold Ray Dam into catch of Rogue River stock and catch of Applegate River stock based on observed fin clips. Harvest rate on hatchery fish of Rogue River stock in the mainstem below Gold Ray Dam was then estimated after excluding Applegate River stock from the estimate of hatchery fish abundance at river entry.

By derivation of equation (2), we also estimated the number of winter steelhead harvested above Gold Ray Dam during the 1977-78 through 1980-81 run years by assuming 5% of the river catch was taken above Gold Ray Dam. We then divided the estimated catch above the dam into wild and hatchery catches based on the percentage of hatchery fish within the run that passed Gold Ray Dam. Lacking data on catch composition above Gold Ray Dam, we assumed the percentage of hatchery fish within the catch was the same as the percentage within the run that crossed Gold Ray Dam. We assumed all hatchery fish above Gold Ray Dam were Rogue River stock. These separate catch estimates were divided by the separate counts of hatchery and wild fish passing the dam to estimate separate harvest rates for wild fish and for hatchery fish in the mainstem above Gold Ray Dam.

We conducted surveys of anglers fishing for winter steelhead in the lower and middle river. These surveys were designed to estimate catch rate and to index angler effort. In the lower river, we surveyed anglers fishing between Canfield Riffle (RK 8) and Dunkleburger Bar (RK 21) from 15 November through 28 February, 1977-78 through 1980-81 run years. In the middle river, we surveyed anglers fishing between Robertson Bridge (RK 139) and Lathrop Landing (RK 156) from 1 February though 31 March, 1978-81.

While interviewing anglers, survey clerks followed a circular route designed to encompass the entire area. Route direction and starting point were randomly selected. Anglers were asked how long they had fished and if they had landed fish. Data from bank and boat anglers were recorded separately. Fish retained by anglers were identified by species, examined for identifying marks, and classified by fork length. Steelhead smaller than 40.6 cm (16 inches) were classified as half-pounders. Larger steelhead were classified as adults. Hatchery fish were differentiated from wild fish based on the presence of fin clips or a deformed dorsal fin. When fish were landed but not retained, anglers were queried about the number landed, species, and size of fish released. Survey clerks assumed that anglers relayed accurate information about their catch. Within both surveys, clerks worked 8 hours daily, 5 days weekly. Survey days were randomly selected.

To index angler effort, clerks counted bank anglers, boats, and boat trailers daily at 0900, 1200, and 1600 hours. Counts were made only from the side of the river offering the best view of the fishery. The direction of each route varied daily on a random basis. Anglers were not interviewed during effort counts.

Juveniles

We did not sample any known juvenile winter steelhead during the study. Based on findings reported by Everest (1973), most of the juveniles we sampled in the Rogue River were probably juvenile summer steelhead. Samples of smolts probably contained higher proportions of winter steelhead because smolts migrating from tributaries must enter the mainstem prior to ocean entry. With the exception of data derived from scales of smolts, all of the juvenile data presented in this report were derived from scales of wild adults.

Use of juvenile scales to characterize the relationship between fish length and scale parameters can greatly aid interpretation of scales taken from returning adults (Carlander 1981). To establish relationships between fork length and scale radius, we sampled juveniles once weekly during 1976-80. In the middle river, we used a 50 X 8 ft floating seine with 3/8-inch square mesh. In the lower river, we used a seine similar to the one used in the middle river, except that the length was 100 ft. Juveniles destined to mature as summer steelhead composed an unknown proportion of the samples.

Steelhead that exhibited morphological changes associated with the parr-smolt transformation were segregated from other fishes. Low body condition, deciduous scales, absence of parr marks, a silvery appearance, and a black band on the distal portion of the caudal fin were visual characteristics used to classify juvenile steelhead as smolts (Ewing et al. 1984). Juveniles larger than subyearlings and not exhibiting smolt characteristics were classified as yearlings.

Prior to handling, we anesthetized juveniles with benzocaine or a mixture of tricaine methanesulfonate (MS-222) and quinaldine (Schoettger and Steucke 1970). We obtained scale samples and measured fork lengths to the nearest 0.1 cm from a maximum of 10 yearlings and 10 smolts weekly. We removed about 10 scales from each side of the body in the area 4 rows immediately above the lateral line and immediately posterior to the dorsal fin.

Scales taken from juveniles were mounted on glass slides with a solution of 5% glycerin and 95% sodium silicate. We mounted about 10 scales per juvenile and chose 2 of the larger, nonregenerated scales of regular shape for analysis. We analyzed juvenile scales with the same methods used to analyze adult scales. Scales from juveniles older than age 1 were excluded from samples classified in the field as yearlings.

From yearlings seined in the lower river, we found that scale radius correlated positively with fork length during each of the 5 years that we sampled (Table 4). We judged these relationships to be linear. Scale radius accounted for an average of 77% of the variability associated with fork length. Analysis of covariance revealed no significant differences ($P = 0.08$ for slopes and $P = 0.21$ for elevations) between regression equations, so we pooled annual regressions (Table 4).

Table 4. Regressions of fork length (cm) on scale radius (mm at 88X) for wild yearling steelhead seined at Agness, 1975-79. Scales with regenerated nuclei were excluded from the analyses.

Year(s)	Regression equation[a]	Standard error	*N*	r^2	*P*
1975	Y = 3.01 + 0.1827(X)	0.0103	102	0.76	<0.001
1976	Y = 4.02 + 0.1578(X)	0.0082	118	0.76	<0.001
1977	Y = 4.78 + 0.1438(X)	0.0078	101	0.78	<0.001
1978	Y = 4.38 + 0.1570(X)	0.0081	91	0.81	<0.001
1979	Y = 4.33 + 0.1532(X)	0.0093	102	0.73	<0.001
1975-79	Y = 4.18 + 0.1573(X)	0.0038	514	0.77	<0.001

[a] *Y = fork length; X = scale radius.*

For smolts sampled throughout the river, we found that the timing of annulus formation varied between individuals. Based on a narrowing and subsequent widening of circuli, we judged annulus formation was completed by May of each year. Consequently, we only used scales obtained from smolts seined after 1 May to estimate relationships between scale radius and body length. Most of the sampled smolts were 16-22 cm long.

Each year, we found that scale radius correlated positively with fork length of smolts (Table 5). Variability within the relationships was greater among smolts sampled in the middle river than among those sampled in the lower river. Coefficients of determination ranged from 0.21 to 0.80 for smolts sampled in the middle river, but only ranged from 0.42 to 0.62 for smolts sampled in the lower river.

Table 5. Regressions of fork length (cm) on scale radius (mm at 88X) for wild steelhead smolts sampled in the Rogue River, 1976-80. Scales with regenerated nuclei were excluded from the analyses.

Area, year	Regression equation[a]	Standard error	N	r^2	P
Lower river:					
1976	Y = 11.29 + 0.0908(X)	0.0136	62	0.42	<0.001
1977	Y = 8.05 + 0.1336(X)	0.0077	226	0.57	<0.001
1978	Y = 10.75 + 0.1023(X)	0.0136	47	0.56	<0.001
1979	Y = 7.75 + 0.1402(X)	0.0074	220	0.62	<0.001
1980	Y = 10.24 + 0.1068(X)	0.0126	87	0.46	<0.001
Middle river:					
1976	Y = 6.01 + 0.1624(X)	0.0107	61	0.80	<0.001
1977	Y = 6.01 + 0.1625(X)	0.0096	151	0.66	<0.001
1978	Y = 9.57 + 0.1138(X)	0.0119	137	0.40	<0.001
1979	Y = 12.50 + 0.0820(X)	0.0199	66	0.21	<0.001
1980	Y = 7.47 + 0.1458(X)	0.0100	165	0.57	<0.001

[a] *Y = fork length; X = scale radius.*

Within sampling areas, relationships between fork length and scale radius varied among years. Analysis of covariance revealed a significant difference ($P = 0.003$) among slopes of regressions developed annually from smolts seined in the lower river. Slopes of regressions developed for smolts sampled in the middle river also differed significantly ($P < 0.001$). Additional comparisons suggested that sampling area affected the estimate of the relationship between fork length and scale radius. An analysis of covariance revealed that, within years, regression slopes for samples from the lower river and from the middle river were consistently different ($P < 0.05$ in 5 of 6 cases).

These findings indicate that the relationship between fork length and scale radius varied for some unknown reason(s). Possible factors include variations in environmental conditions, sampling procedures, or genetic histories of the sampled fish. For example, the relative abundance of smolts that originated from distinct populations probably varied between years and between areas of sampling. Resultant uncertainty associated with the selection of appropriate regressions to be used for estimating smolt lengths from adult scales led us to select an alternative method.

We chose a more widely adopted alternative, the Lee method (Carlander 1981). We assumed an isometric relationship between body length and scale radius. Fork length at time of annulus formation and at ocean entry was estimated based on measurements of scales taken from returning adults using the equation

$$L_i = a + ((L_c - a)(S_i/S_c))$$

where

L_i = fork length of juvenile at time i,
a = a constant (we used 3.5 cm, a value used by Peterson (1978) for winter steelhead in the Alsea River, Oregon),
L_c = fork length of adult at time of capture,
S_i = scale radius of adult at time i, and
S_c = scale radius of adult at time of capture.

Analytical Procedures

Data we believed to exhibit a normal distribution were analyzed with parametric statistics, primarily using Microstat statistics software (Release 4.1). Because many of the data sets contained less than 10 observations, the assessment of normality was frequently subjective. Uncertainty about the normality of the data led us to defer testing for homogeneity of variances. In general, we used $P \leq 0.05$ as the criteria for statistical significance. However, if sample sizes were small, we used $P \leq 0.10$ as our level of significance. We referred to Snedecor and Cochran (1967) and Zar (1984) for analytical procedures.

Parametric methods most commonly used included analysis of variance, correlation analysis, and regression analysis. We used analysis of variance to test for differences between the means of preimpoundment and postimpoundment variables and to test for differences between means of life history parameters among age classes. Where no difference was noted, we calculated the minimum detectable difference (Zar 1984) to estimate how much the postimpoundment mean would have had to change in order to detect a change.

To identify relationships among variables, we used correlation analysis and assumed data were independent observations and errors were normally distributed. We also used correlation analysis primarily to evaluate potential multicollinearity among independent variables considered for inclusion in multiple regression analyses. Percentage or proportional data were logit transformed prior to analysis.

To quantify relationships between dependent and independent variables, we used regression and multiple regression analyses. Independent variables were assumed to be measured without error. This may be a reasonable assumption for measurements of physical factors (flow, upwelling, etc.), but is certainly erroneous for some biological data. Associated errors were probably smallest for life history parameters reported as means (length at ocean entry, scale measurements, etc.). Estimates or indexes of fish abundance probably contain some major sources of error, particularly where numerous assumptions and steps were required to derive the data. However, because abundance is of key importance to this evaluation, and other analytical procedures may be less robust, we used regression analysis to test for factors that affect abundance. Independent variables were included in regression analyses only when our previous findings (Cramer et al. 1985) or other literature identified variables as probable causal factors associated with the dependent variable in question.

Other potential problems associated with multiple regression analysis include autocorrelation, heteroscedasticity, and multicollinearity. We evaluated the potential for autocorrelation by the Durbin-Watson test. We evaluated the potential for heteroscedasticity by plotting residual values from a regression on the associated values of the dependent variable. Multicollinearity can occur when independent variables in the regression are not truly independent of each other. We attempted to minimize the potential for multicollinearity by (1) use of correlation analysis to identify significant relationships between independent variables and (2) limiting the number of independent variables included in regression analyses.

Finally, we used predictive regression analysis to estimate the relationship between values of the dependent variable and values of the independent variables. This procedure minimizes the sums of squares for the vertical distances of points from the regression line. Both Ricker (1973) and Jensen (1986) recommend use of predictive regression rather than functional regression if the objective is prediction rather than quantitative description of functional relationships. We do not propose any of the regressions as functional relationships. We chose to use predictive regression because our primary objective was to predict the response of dependent variables to variations in independent variables.

RESULTS AND DISCUSSION

Physical Factors

In 1988 USACE personnel simulated flow, water temperature, and turbidity for regulated (with dams) and unregulated (without dams) conditions during 1978-86. In this section of the report, we summarize some of the findings that are directly relevant to the production and harvest of winter steelhead in the Rogue River.

Flow

Operation of Lost Creek Dam affected flow in downstream areas. Storage of inflow occurred primarily during January through April and peaked during February (Figure 4). The reservoir reached full pool each year, usually by 1 June. Augmentation of natural flow usually began in the middle of June, peaked in July and August, and continued through the end of November (Figure 5).

On a proportional basis, effect decreased with distance downstream from Lost Creek Dam (Figure 5). At Raygold, regulated flow generally ranged between 3,000 and 5,000 cfs during January through April. Downstream at Agness, regulated flow usually ranged between 7,000 and 10,000 cfs during the same time period. As tributary flow declined during the late spring and early summer, flow in the lower river became similar to flow in the upper river.

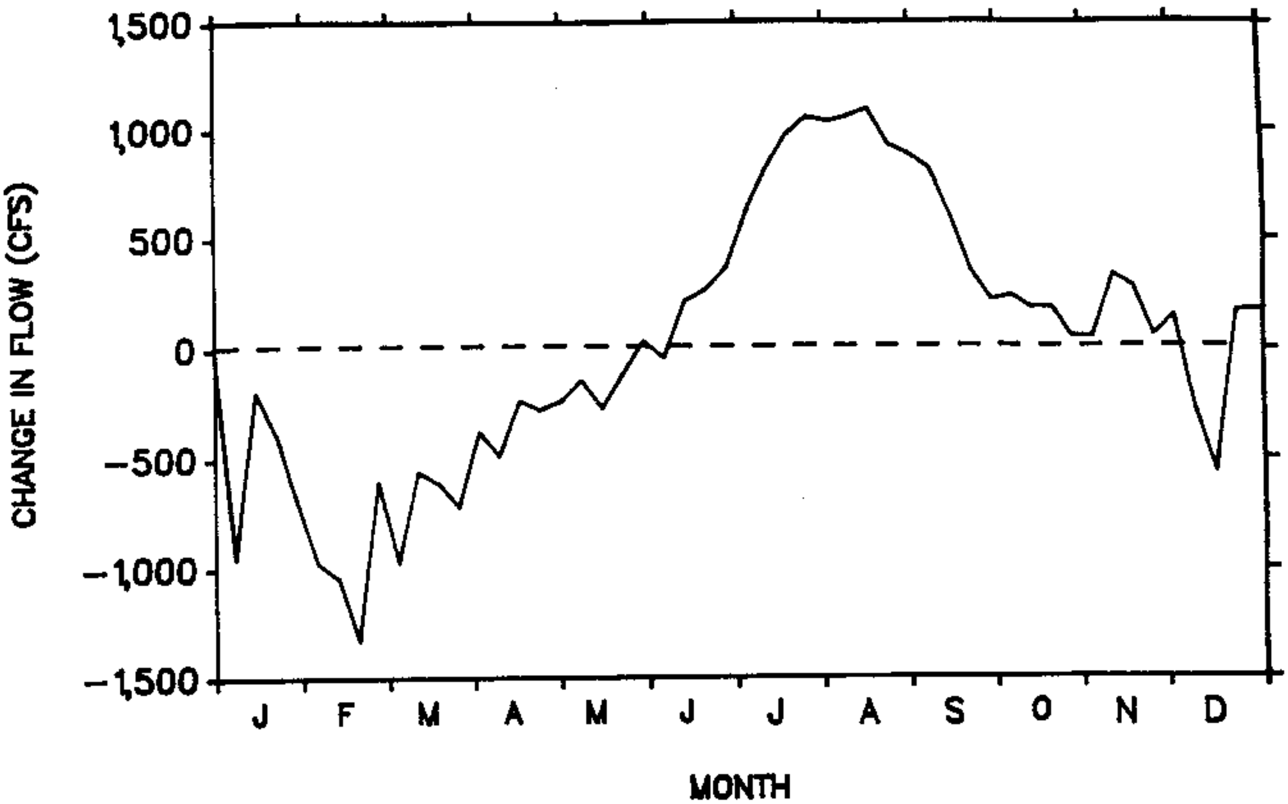

Figure 4. Change in mean weekly flow caused by the operation of Lost Creek Dam, 1978-86. The zero line represents unregulated flow.

Water Temperature

Throughout the river, water temperature increased during November-January, and decreased during June-September (Figure 6). Effects on water temperature diminished with distance downstream from Lost Creek Dam. Operation of the dam increased average water temperature at Raygold by about 1.5°C and at Marial by about 1.0°C during November-January. At the thermal peak during summer, operation of the dam reduced average water temperature at Raygold and Marial by 3.5°C and 3.2°C, respectively.

Turbidity

River turbidity varied greatly on a seasonal basis. We measured turbidity as high as 140 Jackson Turbidity Units (JTU) and as low as 1 JTU during angler surveys. Throughout the river, turbidity during the summer usually ranged between 2 and 4 JTU (Figure 7). During winter, turbidity increased with distance downstream from Lost Creek Dam, most noticeably during periods of high flow. Simulation models developed by USACE indicated mean weekly turbidity never exceeded 20 JTU in the upper river, but exceeded 50 JTU in the canyon (Figure 7). Tributary streams increased turbidity in the mainstem, particularly when flow increased during periods of high precipitation.

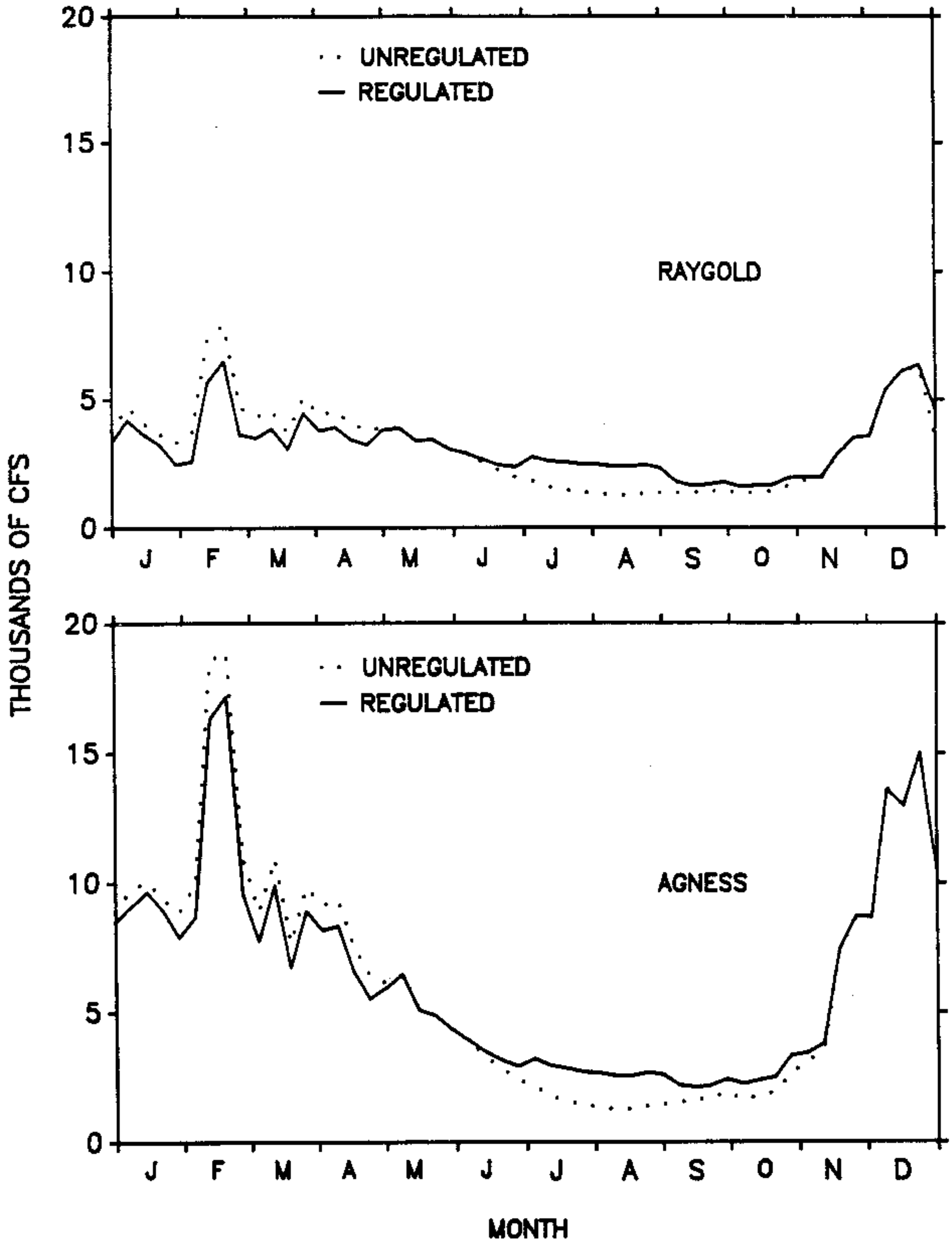

Figure 5. Mean weekly flow in the upper river at Raygold, and in the lower river at Agness, simulated for regulated and unregulated conditions, 1978-86.

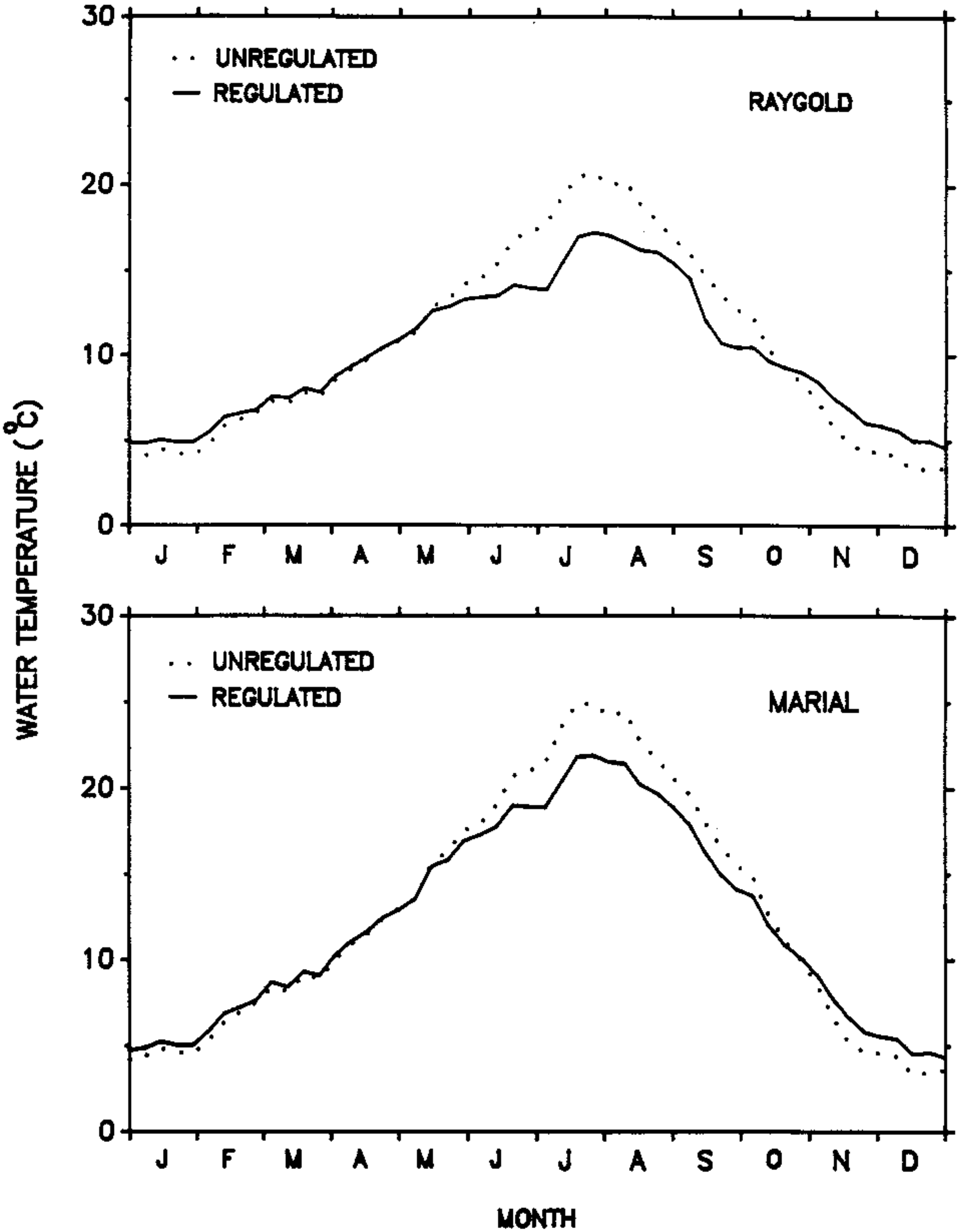

Figure 6. Mean weekly water temperature in the upper river at Raygold, and in the Rogue River canyon at Marial, simulated for regulated and unregulated conditions, 1978-86.

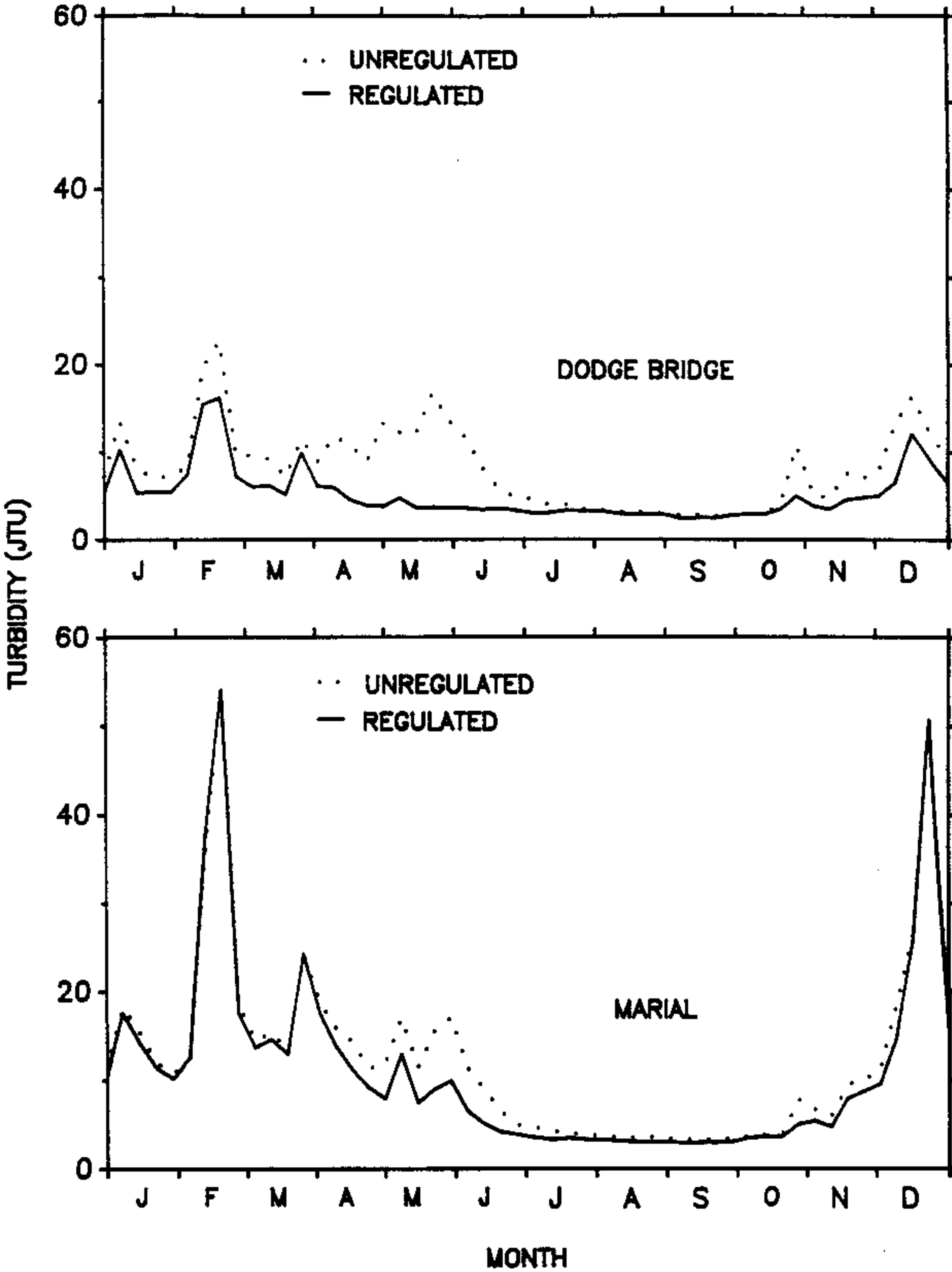

Figure 7. Mean weekly turbidity (Jackson Turbidity Units) in the upper river at Dodge Bridge, and in the Rogue River canyon at Marial, simulated for regulated and unregulated conditions, 1978-86.

Operation of the dam usually reduced turbidity in downstream areas. At Dodge Bridge, regulation reduced average turbidity by 6 JTU during April-June and 3 JTU during November-March (Figure 7). Downstream at Marial, regulation reduced average turbidity by 4 JTU during November-March and 1 JTU during April-June (Figure 7). In the canyon, as well as in the upper river, operation of the dam reduced average turbidity by less than 1 JTU during July-October.

Adults

Life History

We identified two distinctive life history strategies among wild winter steelhead that return to the Rogue River. One strategy, which produces what we termed "salt migrants", is to remain in the ocean until maturity as winter steelhead. The other strategy, which produces what we termed "spawning migrants", is to make a false spawning return to freshwater prior to maturity.

During the false spawning run, these immature steelhead are 30-38 cm (12-15 inches) long and are known as "half-pounders" (Kesner and Barnhart 1972). The distribution of this unusual life history pattern is limited to steelhead in only three river basins in northern California and southern Oregon. Half-pounders return to freshwater during the late summer or early fall after having spent 3-4 months in the ocean. Freshwater residence continues through the fall and winter, and return to the ocean occurs during the succeeding spring.

From analyses of scales taken from wild adults captured by electrofishing in the lower river, we estimated that spawning migrants averaged 31% of the adults that returned to the Rogue River basin during the 1977-78 through 1980-81 run years. Consequently, about 7 of every 10 wild winter steelhead were salt migrants that had not made a half-pounder run.

Winter steelhead exhibited a diversity of life history patterns. From scale samples, we identified nine life history patterns for salt migrants and five life history patterns for spawning migrants (Table 6). Such diversity is not uncommon among steelhead populations. In the Kalama River, Washington, wild winter steelhead exhibited 12 life history patterns (Leider et al. 1986a). Diverse life histories have also been found among runs of winter steelhead in California (Shapovalov and Taft 1954), Oregon (Kenaston and MacHugh 1986), Washington (Meigs and Pautzke 1941), and British Columbia (Hooton et al. 1987). Variations in life history patterns may be a means of minimizing the periodic effect of adverse environmental conditions by allocating production from a single brood year to a multitude of spawning years (Leider et al. 1986a).

Among winter steelhead in the Rogue River, we found that two-salts accounted for about half of the adults. The next most common life history pattern, first-spawning migrants, were only one-third as abundant as two-salts. No other life history pattern accounted for more than 10% of the adults that returned during the 1977-78 through 1979-80 run years (Table 7). Data from the 1980-81 run year were excluded because the sample of 92 fish was less than 50% of the sample of other years and included fewer life history patterns.

Table 6. Descriptions of adult life history types as interpreted from scales of wild winter steelhead collected by electrofishing in the lower river, 1977-78 through 1980-81 run years. Without exception, fish that made multiple spawning runs spent only one summer-autumn period in the ocean between spawning runs.

Life history occurrence, name	Description
Common:	
One-salt	First spawning run after one summer-autumn period in ocean.
Two-salt	First spawning run after two summer-autumn periods in ocean.
Two-salt, repeat spawner	Second spawning run for a two-salt adult.
First spawning migrant	First spawning run after one autumn-winter period in freshwater as a half-pounder, and one subsequent summer-autumn period in ocean.
Second spawning migrant	Second spawning run for a first spawning migrant.
Two-salt, first spawning migrant	First spawning run after one autumn-winter period in freshwater as a half-pounder, and two subsequent summer-autumn periods in ocean.
Uncommon:	
One-salt, repeat spawner	Second spawning run for a one-salt adult.
One-salt, second repeat spawner	Third spawning run for a one-salt adult.
Two-salt, second repeat spawner	Third spawning run for a two-salt adult.
Two-salt, third repeat spawner	Fourth spawning run for a two-salt adult.
Three-salt	First spawning run after three summer-autumn periods in ocean.
Three-salt, repeat spawner	Second spawning run for a three-salt adult.
Third spawning migrant	Third spawning run for a first spawning migrant.
Two-salt, second spawning migrant	Second spawning run for a two-salt, first spawning migrant.

Table 7. Life history composition of winter steelhead collected by electrofishing in the lower river, 1977-78 through 1979-80 run years. Sample size was 195 in 1977-78, 223 in 1978-79, and 204 in 1979-80.

Life history type	Percentage of sample			
	1977-78	1978-79	1979-80	All years
Two-salt	56.4	46.3	40.6	51.2
First spawning migrant	12.5	34.8	15.4	16.4
One-salt	14.0	6.3	7.4	8.2
Two-salt, first spawning migrant	0.8	0.1	18.5	7.6
Second spawning migrant	3.8	3.1	10.2	4.9
Two-salt, repeat spawner	4.2	5.9	0.5	4.2
Miscellaneous	8.3	3.5	7.4	7.5

Adults that returned to the Rogue River spent less time in the ocean compared with other populations of winter steelhead. We found ocean residence times of 1, 2, and 3 years averaged 32%, 66%, and 2%, respectively, among adults on their first spawning run. In comparison, only 1% of the adults that returned to streams on Vancouver Island, Canada, spent 1 year in the ocean (Hooton et al. 1987). Ocean residence times of 2 and 3 years accounted for 66% and 32%, respectively, of those returning adults. Studies of other populations of winter steelhead also showed longer times of ocean residence (Shapovalov and Taft 1954; Withler 1966; Peterson 1978; Ward and Slaney 1988). Winter steelhead that returned to the Rogue River basin also spent less time in the ocean, in part because 31% made a half-pounder run.

Repeat Spawning: Salt migrants were more susceptible to postspawning mortality than were spawning migrants. We found that repeat spawners averaged 10% of the salt migrants that entered the river and ranged from a low of 2% in the 1979-80 run year to a high of 13% in 1980-81 (Appendix Table A-1). In contrast, repeat spawners averaged 25% of the spawning migrants and ranged from a low of 10% in 1978-79 to a high of 34% in 1980-81. Among all wild winter steelhead that returned during the 1977-78 through 1980-81 run years, we estimated that 14.5% were repeat spawners.

Repeat spawners appeared to compose a higher percentage of the population in the Rogue River basin compared with populations in other coastal streams of Oregon (ODFW 1986). However, the percentage was comparable with that observed in other populations of winter steelhead on the Pacific Coast (Shapovalov and Taft 1954; Leider et al. 1986a; Hooton et al. 1987; Ward and Slaney 1988). Comparison of the rate of repeat spawning among stocks examined in these other studies and our study indicated that stocks at southern latitudes tend to have a greater rate of repeat spawning compared with stocks at northern latitudes.

Size at Return: Length at the time of freshwater entry was dependent on the amount of time spent in the ocean. One-salts, which reared in the ocean for about 9 months, were smaller than first-spawning migrants and two-salts (Table 8). First-spawning migrants and two-salts reared in the ocean an average of about 13 and 21 months, respectively. One-salts and two-salts that returned to the Rogue River were similar in size to adults of the same ages that returned to other coastal streams (Withler 1966; Leider et al. 1986a; Hooton et al. 1987; Ward and Slaney 1988). However, because of the younger age at return and the corresponding shorter period of residence in the ocean, winter steelhead that returned to the Rogue River were smaller than counterparts that returned to other coastal streams. Length frequency distributions of winter steelhead collected by electrofishing in the lower river can be found in Appendix Table A-2.

Table 8. Mean length (cm) ± 95% confidence interval of wild winter steelhead collected by electrofishing in the lower river, 1977-78 through 1980-81 run years.

Run year	One-salt	Two-salt	First spawning migrant[a]
1977-78	49.3 ± 2.7	69.4 ± 1.0	54.7 ± 1.2
1978-79	44.1 ± 1.2	65.0 ± 1.0	56.4 ± 1.0
1979-80	48.2 ± 1.6	63.0 ± 0.9	54.2 ± 1.4
1980-81	--	65.2 ± 1.3	--

[a] *Age 2 smolts only.*

Migration Timing

We found that winter steelhead entered the Rogue River from November through at least March. On the average, catches of wild adults increased rapidly during December and peaked during late January or early February. In contrast, catches of hatchery fish tended to increase in January and peak during late February (Figure 8). We concluded that hatchery fish entered the Rogue River later than wild fish during the 1977-78 through 1979-80 run years. Since that time, modifications in broodstock selection may have resulted in an earlier migration timing of hatchery adults.

Catch timing of wild winter steelhead varied between years. During the 3 run years when we were able to electrofish consistently throughout the run, catch rate peaked during late January in 1977-78, late December in 1978-79, and early February in 1979-80. Variations in estimates of run timing were probably affected by deviations in sampling efficiency and life history composition. Varying river conditions during electrofishing made it difficult to sample a consistent proportion of the population through time and thus introduced error into estimates of migration timing.

Life history composition of the run affected estimates of migration timing because individual life histories differed in the time of freshwater entry and varied between years in relative abundance. We found that adults with a two-salt life history tended to enter freshwater earlier than adults of other life histories (Figure 9). Length-frequency data also indicated that older adults entered freshwater earlier than younger adults. Winter steelhead

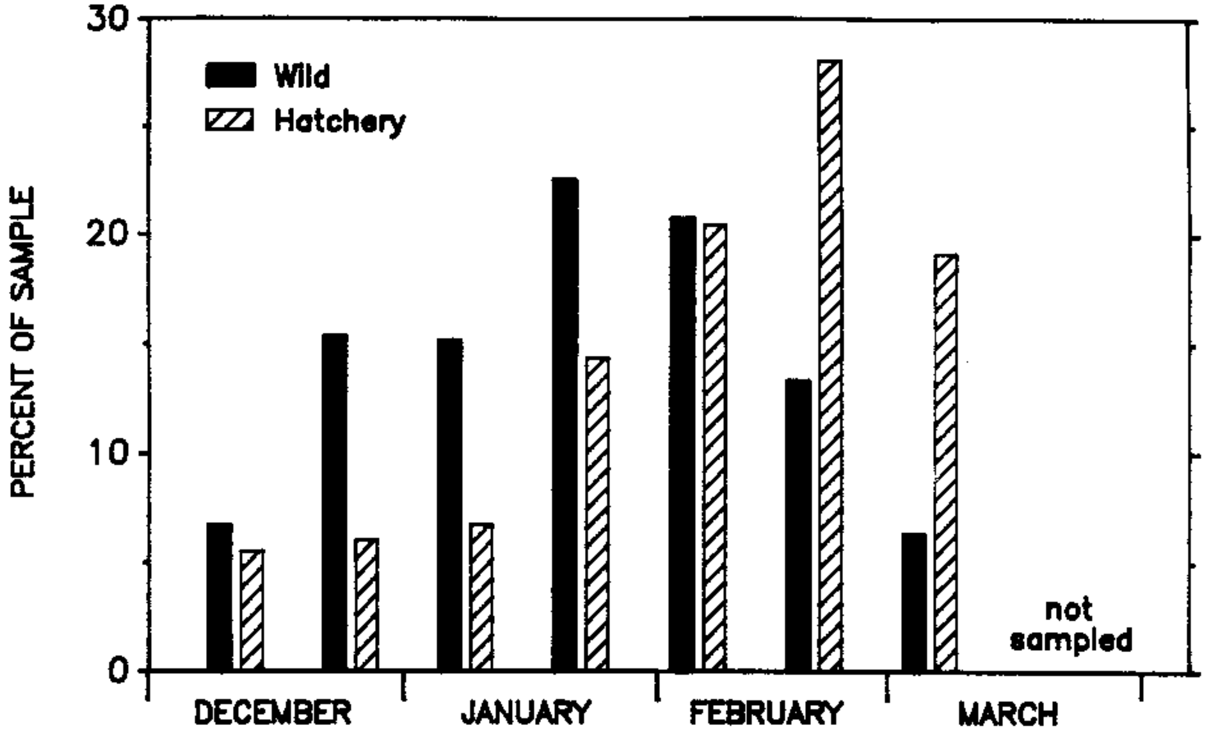

Figure 8. Mean timing of freshwater entry for winter steelhead collected by electrofishing in the lower river, 1977-78 through 1979-80 run years.

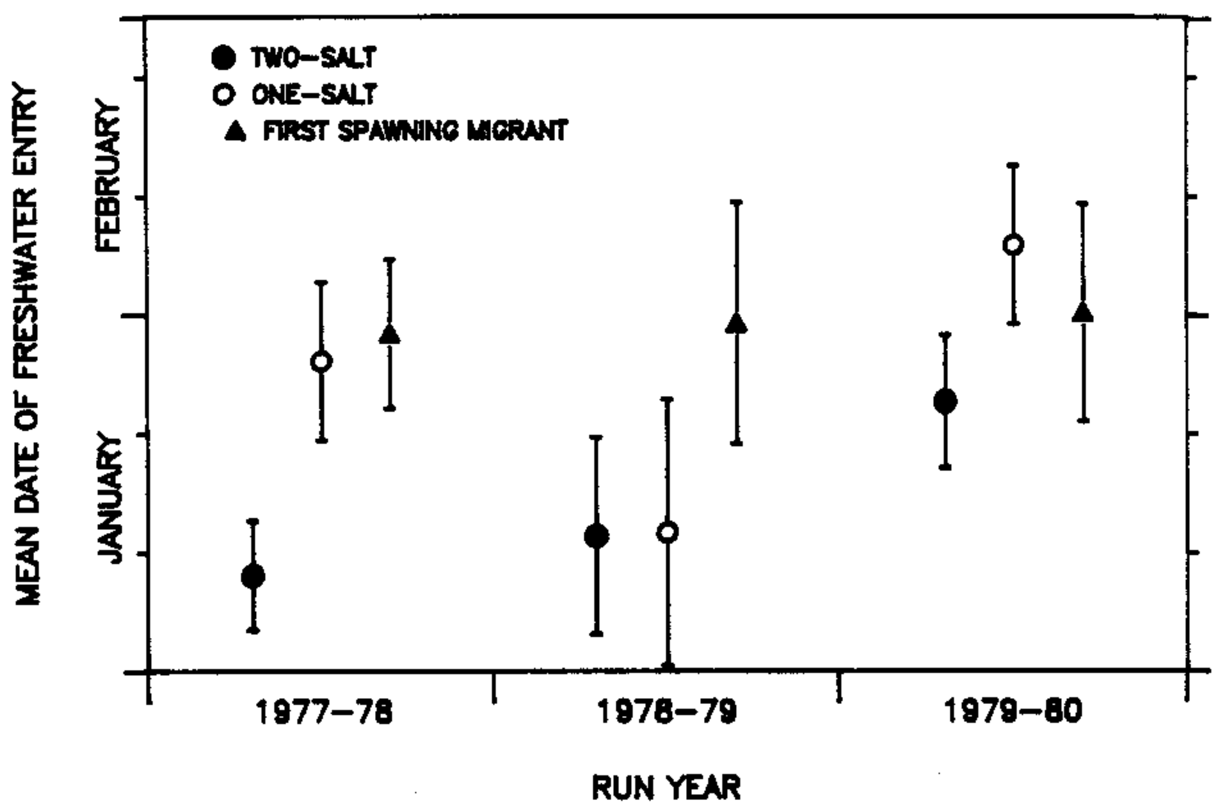

Figure 9. Mean date of freshwater entry for three life history types of adult winter steelhead collected by electrofishing in the lower river. Brackets represent 95% confidence intervals.

collected by electrofishing during December and January were larger than counterparts collected during February (McPherson and Cramer 1981). This finding led us to conclude that variations in age composition of the run affected the migration timing of adults through the lower river. Variations in the relative abundance of genetically distinct populations probably also affect migration timing. The migration timing of adult salmonids is greatly affected by heredity (Ricker 1972; Taylor 1980; Leider 1985).

Counts at Gold Ray Dam provided an accurate picture of the migration timing of adult winter steelhead into the upper river. On the average, counts increased during February, peaked during March, and declined during April and May. Hatchery fish migrated past Gold Ray Dam later than wild fish (Figure 10). During 1978-87, an average of 45% of the hatchery fish and 59% of the wild fish passed the counting station by 15 March. The difference between the means was significant ($P = 0.032$).

Water temperature affected the migration time of wild adults in the upper river. We found a positive correlation between water temperature and the proportion of adults that passed the counting station by 15 March (Figure 11). Adults migrated earlier when water temperature was higher during the spring.

We estimated the relationship between migration timing and water temperature, and used the regression (Table 9) to predict migration timing for regulated and unregulated conditions. After substituting water temperatures modeled by USACE, we found that operation of the dam had little effect on the migration timing of adults in the upper river during 1978-86. Predicted passage timing was the same for regulated and unregulated conditions in 4 of 9 years. Effect of the dam was greatest in 1985 when the estimated passage by 15 March differed by only 8% for regulated and unregulated conditions. Consequently, we concluded that operation of the dam had a negligible effect on the migration timing of adult winter steelhead in the upper river.

Run Composition

Wild fish accounted for almost all of the winter steelhead that returned to the Rogue River prior to the operation of Cole M. Rivers Hatchery. In the upper river, hatchery fish accounted for an average of only 7% of the winter steelhead that passed Gold Ray Dam between 1971 and 1978. Adults reared as juveniles at Cole M. Rivers Hatchery first returned in a large number during 1979. From 1979 through 1987, hatchery fish averaged 23% of the winter steelhead that passed Gold Ray Dam.

Because a large number of wild adults spawned in areas downstream of Gold Ray Dam, hatchery fish accounted for a smaller percentage of the run at the time of freshwater entry. We estimated that hatchery fish composed 3.3% of the adults that returned during 1977-78, 9.9% during 1978-79, and 7.2% during 1979-80. We did not estimate the percentage of hatchery fish within the 1980-81 run because we were not able to electrofish during December-January when return of wild adults usually peaked.

Among wild fish, we believe that fish collected by electrofishing in the lower river represented a conglomerate of distinct populations. Although we did not test for differences in life history parameters among adults that returned to specific areas of the basin, Rivers (1964) reported significant

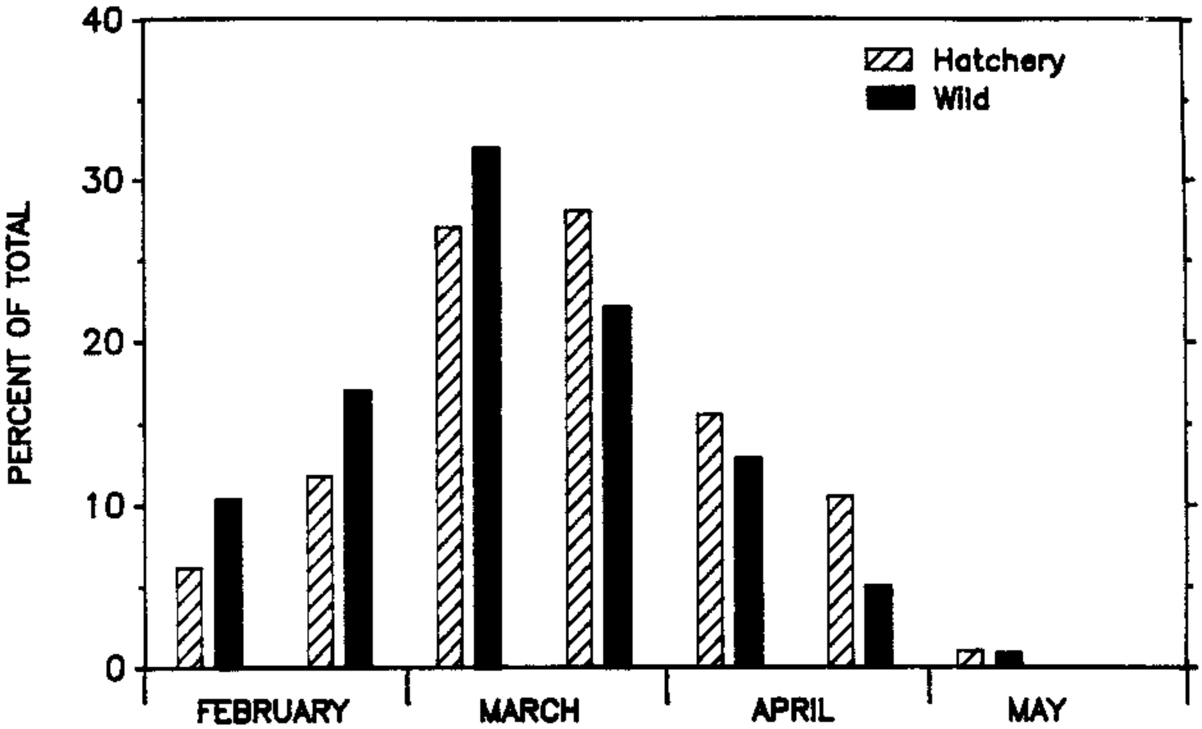

Figure 10. Mean timing of winter steelhead passage at Gold Ray Dam, 1978-87.

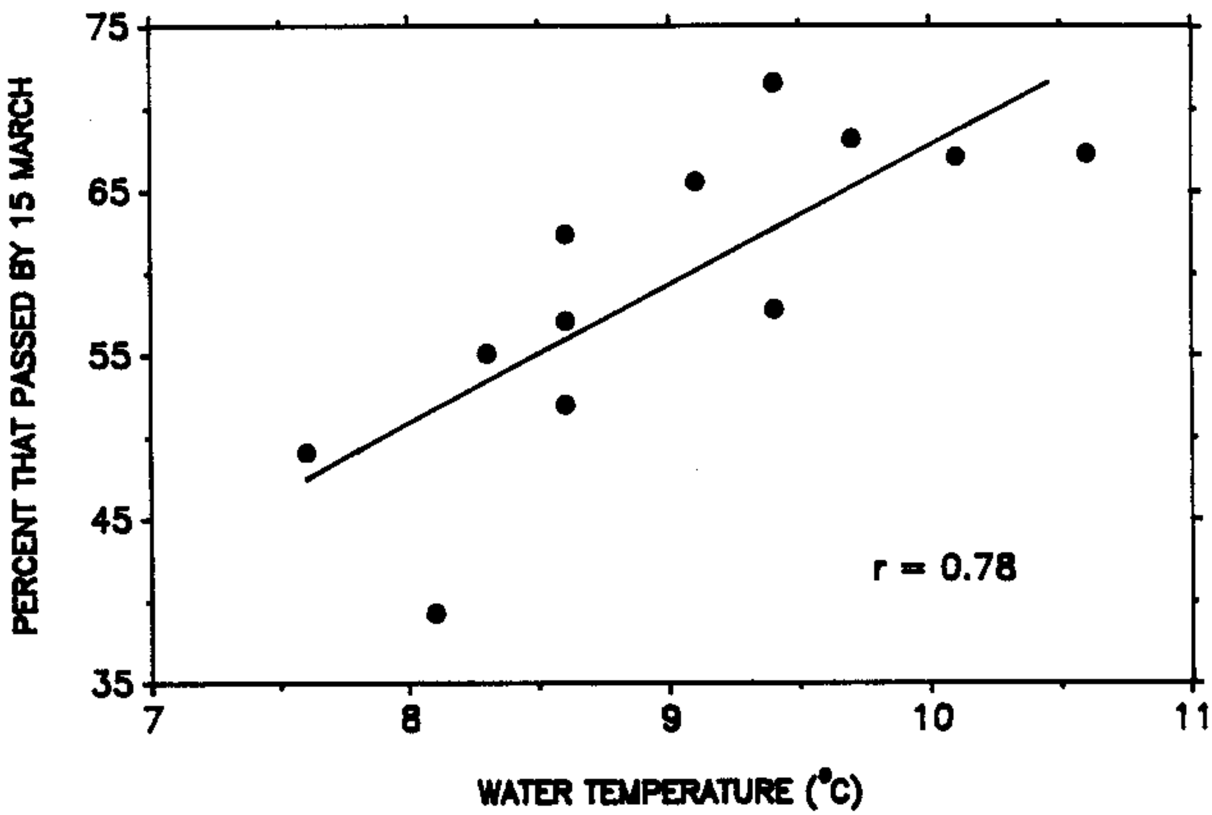

Figure 11. Relationship between migration timing of wild winter steelhead that passed Gold Ray Dam and mean maximum water temperature at Raygold during March, 1974-87. Data from 1975 and 1980 were not included because water temperature was not measured. Correlation coefficient was estimated from percentages transformed to logits.

Table 9. Regression analysis of the relationship between percentage of wild winter steelhead that passed Gold Ray Dam by 15 March and water temperature, 1974-87 (r^2 = 0.61). Data from 1975 and 1980 were not included because water temperature was not measured. Migration timing data were transformed into logits prior to analysis.

Independent variable	Regression coefficient	Standard error	*P*
Water temperature[a]	0.3538	0.091	0.003
Constant	-2.6193		

Source of variation	Sum of squares	df	Mean square	*F*	*P*
Regression	1.0423	1	1.042	15.18	0.003
Residual	0.6868	10	0.069		

[a] *Mean maximum water temperature (°C) at Raygold during March.*

differences between populations. At the time of first spawning, winter steelhead in the Illinois River were older and were heavier at a given length than counterparts captured in the middle Rogue and in the Applegate River.

Differences in life history parameters among other populations in the basin can also be expected. We hypothesize that populations that spawn in areas of the basin where summer steelhead also spawn, produce some progeny with half-pounder life histories because of interbreeding or comparable selective factors in their environment. In contrast, we believe that populations that spawn in areas producing few or no summer steelhead will exhibit life history patterns more similar to winter steelhead in other coastal areas. Based on the findings of Leider et al. (1984), we suspect that summer and winter races of steelhead in the Rogue River basin are not reproductively isolated by spatial or temporal differences during spawning. However, tagging studies by Everest (1973) suggested that summer and winter steelhead in the Rogue River basin do not interbreed because of spatial and temporal differences in spawning.

Even among "pure" populations of winter steelhead, differences in life history patterns may be evident. Adaptations to survive warm water in the Illinois River basin may be quite different than adaptations to survive in small tributaries of the Rogue River close to the coast. Variation in environmental factors such as water temperature, flow, forage resources, and habitat complexity in tributaries is probably expressed in adult life history patterns. Parkinson (1984) found differences in genetic attributes of steelhead within adjacent streams in British Columbia. Heggberget et al. (1986) identified three genetically distinct populations of Atlantic salmon *Salmo salar* in the Alta River, Norway.

Abundance

We estimated that freshwater return averaged 43,300 wild and 3,200 hatchery winter steelhead during the 1977-78 through 1979-80 run years (Table 10). With the extra year (1980-81) of data on hatchery fish, the 4 year average for freshwater return was 3,100 fish. Using the estimate of freshwater return and the estimate of passage at Gold Ray Dam, we estimated that 13% of the wild adults that entered the Rogue River during the 1977-78 run year passed the counting station. We also estimated that the upper river component accounted for 25% of the 1978-79 return to the Rogue River and 17% of the 1979-80 return.

Assuming that the upper river component accounted for an average of 18% of the freshwater returns for other years, we estimated that an average of 44,000 wild adults entered the Rogue River annually during the 1970-71 through 1986-87 run years. This estimate should be considered a rough average, because the number of wild adults that passed Gold Ray Dam may not have varied directly with the number of wild adults that returned to other areas of the basin. An average return of 44,000 adults would make the run of wild winter steelhead in the Rogue River larger than any other run (wild plus hatchery) on the coast of Oregon (Kenaston 1989).

Total return of winter steelhead (wild plus hatchery) to the upper river increased after full operation began at Lost Creek Dam. Counts at Gold Ray Dam averaged 8,119 and 10,651 adults during 1960-78 and 1982-87, respectively. The difference in mean return was significant ($P = 0.097$). We chose these years to represent preimpoundment and postimpoundment conditions for three reasons.

First, passage estimates of winter steelhead at Gold Ray Dam decreased significantly ($P < 0.01$) between 1943 and 1959 for some unknown reason (Figure 12). Second, winter steelhead that originated from smolts released at Cole M. Rivers Hatchery began to account for a large number of adults that returned after 1978. Finally, juveniles produced during postimpoundment years did not predominate the return of wild adults until 1982. Data used in the analysis are included in Appendix Table A-3.

Table 10. Estimated number of wild and hatchery winter steelhead that returned to the Rogue River, 1977-78 through 1980-81 run years. Wild return not estimated for 1980-81 because of a late timing of the electrofishing sample.

Run year	Hatchery	Wild
1977-78	1,281	37,537
1978-79	4,240	38,588
1979-80	4,134	53,684
1980-81	2,703	--

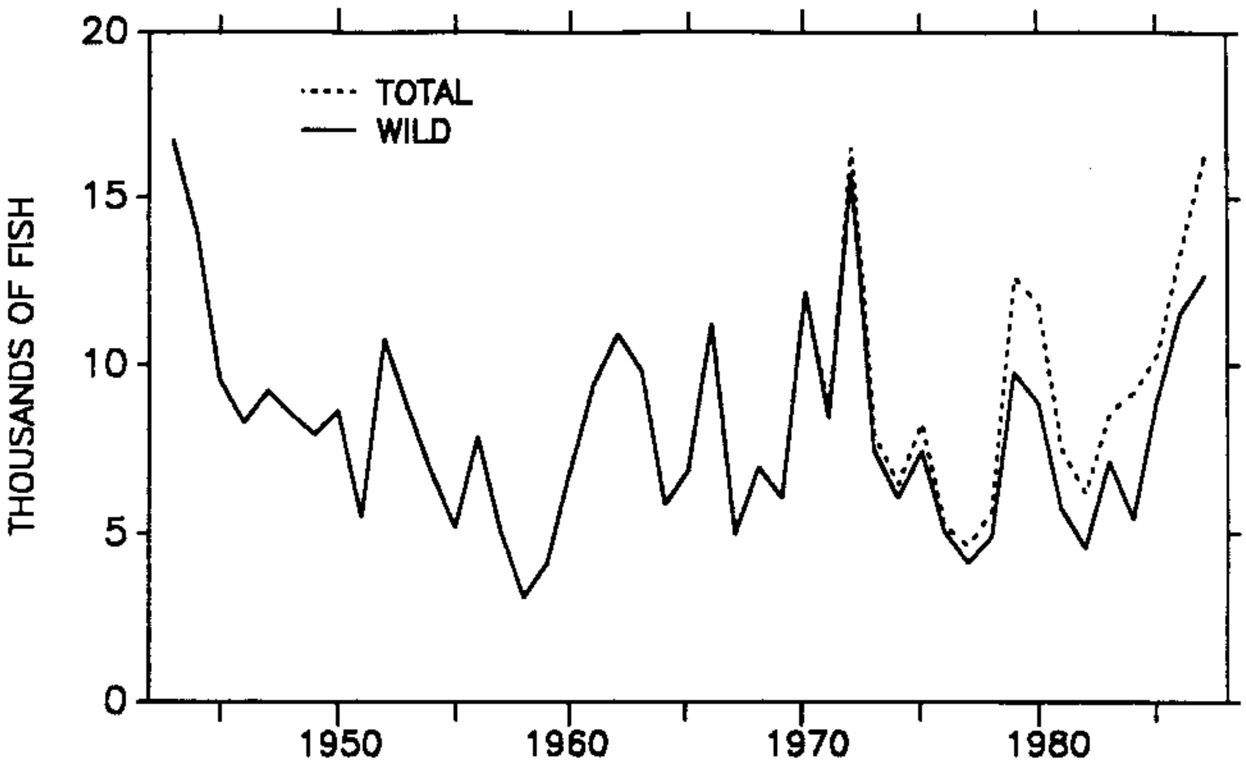

Figure 12. Estimated number of winter steelhead that passed Gold Ray Dam, 1943-87.

Increased return of hatchery fish accounted for the increase in total return of adults. Estimates of hatchery fish passing Gold Ray Dam averaged 528 and 2,336 adults during 1971-78 and 1979-87, respectively. The difference in means was significant ($P < 0.001$). We chose these time periods because hatchery fish were not differentiated from wild fish that passed Gold Ray Dam prior to 1971, and releases from Cole M. Rivers Hatchery began to predominate the return after 1978. Increased return of hatchery adults during 1979-87 was a result of hatchery releases funded by USACE. Data used in the analysis are listed in Appendix Table A-4. Annual releases of juvenile winter steelhead from Cole M. Rivers Hatchery are listed in Appendix Table A-5.

Two analyses indicated that the operation of Lost Creek Dam did not affect the number of wild adults that returned to the upper river. First, we found no change in the average number of wild adults that returned from broods produced during the preimpoundment and postimpoundment periods. Second, we found no significant change in the return of adults to the upper river in comparison with return of adults to the North Umpqua River. Because age composition data were not available for either run, we assumed all adults returned during their fourth year of life.

We estimated that return to Gold Ray Dam averaged 7,927 and 8,984 wild adults during 1960-81 and 1982-87, respectively. The difference in means was not significant ($P = 0.728$). A sensitivity analysis indicated that the average return for broods produced during the postimpoundment years needed to increase to more than 11,800, or decrease to less than 4,000 wild adults to have an 80% chance of detecting a change significant at the 95% confidence level. The large variability within returns of preimpoundment broods reduced the chance of detecting a change. Data used to evaluate return of wild adults to the upper river are included in Appendix Table A-6.

A comparison that used return to the North Umpqua River (Appendix Table A-6) as a control was a more sensitive analysis. Between 1946 and 1987, wild adults that passed Gold Ray Dam accounted for 33% to 71% of the wild adults that passed counting stations on the Rogue and North Umpqua rivers. Again we noted a trend of decreasing return in the upper Rogue River during the 1950s (Figure 13). Concern that change in freshwater habitat caused the decrease led us to exclude years prior to 1960 from further analysis.

Return of wild adults to the upper Rogue River averaged 52% of the total return to both rivers during 1960-81 and 54% during 1982-87. Returns from 1960-81 represent juveniles produced before and returns from 1982-87 represent juveniles produced after full operation began at Lost Creek Dam. An analysis of variance indicated that the means were not significantly different ($P = 0.527$). The lack of a significant difference was not attributable to highly variable data. With this analysis, we had a good chance of detecting a change in the abundance of wild winter steelhead in the upper Rogue River. A sensitivity analysis indicated that to have an 80% chance of detecting a change significant at the 95% confidence level, Rogue River fish needed to increase to 63% or decrease to 41% of the total return to both rivers during postimpoundment years. As we did not detect a change, we concluded that the operation of Lost Creek Dam had little effect on the abundance of wild winter steelhead that returned to areas upstream of Gold Ray Dam.

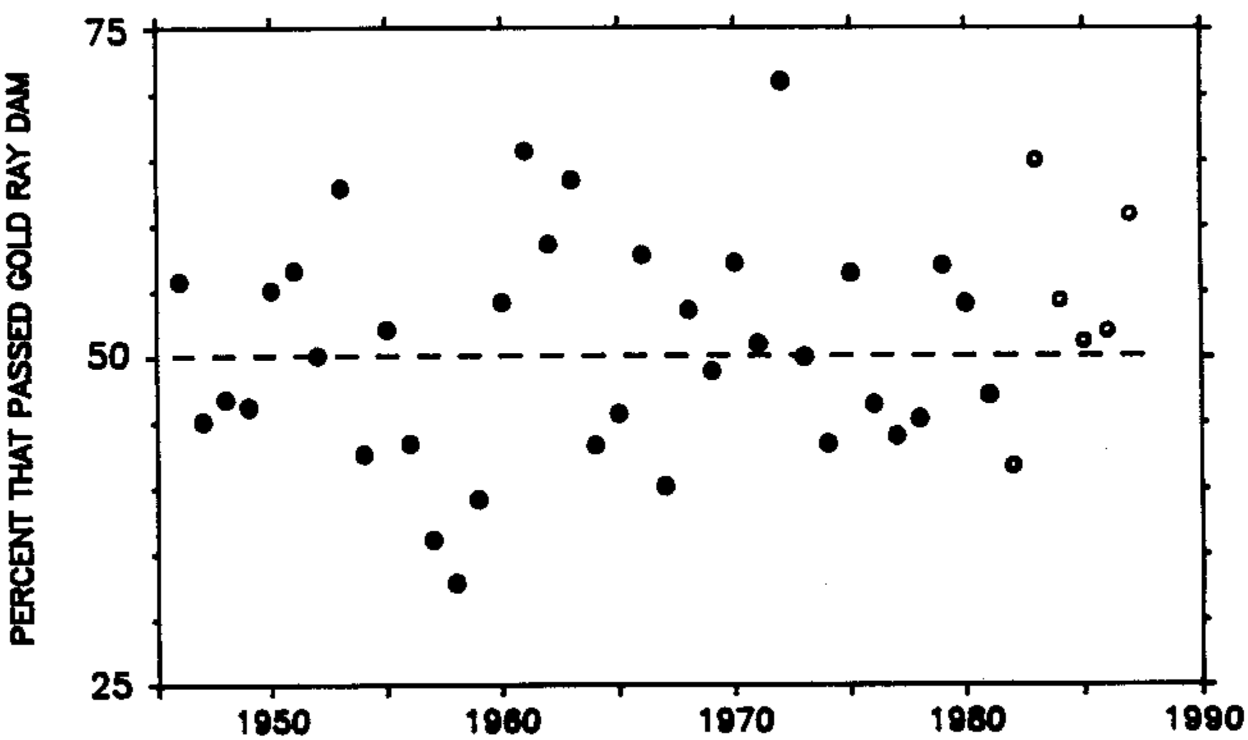

Figure 13. Percentage of fish that returned to Gold Ray Dam among wild winter steelhead that returned to Gold Ray Dam on the Rogue River and Winchester Dam on the North Umpqua River. Dashed line represents equal return to both rivers. Data points represent brood years produced before (closed circles) and after (open circles) full operation began at Lost Creek Dam.

Because return of wild adults to the upper Rogue River varied between years, we attempted to identify causative environmental factors. We hypothesized that tributary flow during parental spawning, mainstem flow during the first year of life, and upwelling at the time of ocean entry were factors that might affect return of wild adults to Gold Ray Dam. Exploratory correlations of those environmental factors and adult return did not produce any significant results. Again, without estimates of age composition, we assumed that all adults returned to freshwater during their fourth year of life.

The lack of significant correlations between return of wild adults and other variables should not be construed as meaning that those factors do not affect production. Rather, our findings indicate that the age composition of the run must be estimated to identify factors that affect the production of wild winter steelhead in the upper river. Collection of adult scales would be particularly valuable for long-term management of the population. With age composition data, stock-recruitment analyses could be developed. In this study, we chose to not estimate production parameters of the population because we were unable to specifically relate progeny to their parents.

A review of the literature indicated that few studies have evaluated factors that affect the production of wild winter steelhead. Ward and Slaney (1988) found that adult return to the Keogh River, British Columbia, was directly related to smolt production ($r^2 = 0.86$), and smolt size accounted for much of the residual variation. Beecher (1980) concluded that a positive relationship existed between flow during the first summer of life and the subsequent abundance of adults that returned to streams in western Washington. Gibbons et al. (1985) developed a spawner-recruit model for steelhead inhabiting Washington streams. Difference in adult production between basins was accounted for by the amount of habitat available to rear yearlings. Errors in predictions associated with winter steelhead returns to 6 rivers averaged 12% and 16% for adults that returned during the 1986-87 and 1987-88 run years, respectively (Gibbons 1988a, 1988b). Although this does not necessarily validate the model, the relatively small amount of error in predictions may indicate that the habitat capability for yearling production is an important determinant of adult production. Because we judged that the operation of Lost Creek Dam had a minimal effect on juvenile production (*see* **Abundance**, page 54), we also believe the effects on adult production were minimal.

Harvest

We found that winter steelhead supported extensive sport fisheries in the Rogue River. Anglers fished throughout the river, with effort concentrated near the population centers of Gold Beach, Grants Pass, and Shady Cove. The timing of each fishery coincided with the migration timing of adults through the respective area.

Total Harvest: From salmon-steelhead cards we estimated that anglers harvested an average of about 7,900 winter steelhead annually during the 1966-67 through 1986-87 run years. We chose not to work with harvest estimates prior to 1966-67 because the upper river, and much of the middle river, was closed to angling. Harvest regulations for the sport fisheries have varied little since 1967, with the exception of the opening of the area upstream of Gold Ray Dam (Appendix Table A-7). Angler harvest during December, January, and February averaged about 1,900 fish monthly. Harvest decreased during March and April, averaging about 1,600 and 700 adults, respectively. Data composing these analyses can be found in Appendix Table A-8.

Angler harvest of winter steelhead did not change after full operation began at Lost Creek Dam. We found no significant differences between mean harvest before and after the operation of the dam for any of the 5 months we examined (Table 11). Also, we found no difference between mean annual catch before and after the operation of the dam. However, our ability to detect a change was limited by high variability within the data. A sensitivity analysis indicated that the mean annual harvest in postimpoundment years needed to increase to 11,833 or decrease to 3,485 in order to have an 80% chance of detecting a change significant at the 95% confidence level.

However, releases of Rogue River stock from Cole M. Rivers Hatchery returned an average of 2,300 adults annually to Gold Ray Dam during 1979-87 (*see* **Abundance**, page 35). We estimated that release of these hatchery fish increased harvest an average of about 1,200 adults annually in the Rogue River (equaling about 16% of the annual harvest of winter steelhead) during the 1978-79 through 1986-87 run years. This estimate assumed a 5% loss from straying and natural mortality below Gold Ray Dam (*see* **Abundance**, page 13), a harvest rate of 30% on hatchery fish below the dam, and a harvest rate of 34% on hatchery fish throughout the river (*see* **Harvest Rate:**, page 27).

Table 11. Comparisons of estimates of mean monthly, and mean annual harvest, of winter steelhead before and after full operation began at Lost Creek Dam, 1966-67 through 1986-87 run years. Harvest estimates developed from salmon-steelhead cards returned by anglers to ODFW and include some summer steelhead.

Time period	1966-67 through 1976-77	1977-78 through 1986-87	*P* (for difference)
December	2,104	1,606	0.244
January	2,030	1,739	0.542
February	2,034	1,972	0.891
March	1,490	1,963	0.224
April[a]	619	735	0.495
December-March	7,659	7,279	0.791

[a] *Preimpoundment years include only 1974-75 through 1976-77. Fishery closed during April in earlier years.*

In addition, we estimated that releases of winter steelhead increased harvest by an average of about 3,600 half-pounders annually during 1978-86. This estimate was derived by assuming (1) that 75% of the hatchery adults made a half-pounder run (personal communication dated 3 March 1989 from Mike

Evenson, ODFW, Cole M. Rivers Hatchery, Trail, Oregon), (2) a smolt-to-half-pounder survival rate of 20% (ODFW, unpublished data), and (3) a 20% harvest rate on half-pounders (ODFW, unpublished data). Survival rate and harvest rate of half-pounders were developed from data for summer steelhead. Angler surveys indicated that half-pounders derived from winter and summer steelhead broodstock contributed to the fisheries at the same rate.

We hypothesized that adult abundance and flow were important determinants of angler harvest of winter steelhead in the Rogue River. Further, based on the findings of Mathews and Hinton (1981), we hypothesized that harvest was directly related to fish abundance and flow during the fishery. To evaluate these hypotheses, we used regression analysis to examine the relationship between fish abundance and angler harvest during February-March, and then we plotted residual variation on mean flow during the fishery. Data included in this analysis are listed in Appendix Table A-9.

Results indicate that harvest correlated positively with fish abundance. In addition, the residuals from this relationship correlated negatively with flow (Figure 14). Regression analysis indicated that fish abundance and flow accounted for 45% of the variation within annual harvest of winter steelhead. Regression coefficients suggested that harvest during February-March increased by about 290 adults for each 1,000 fish that passed Gold Ray Dam (Table 12).

Also, harvest appeared to increase by about 400 adults for each 1,000 cfs decrease in flow. We believe these estimates to be reasonable because we found no relationship between the passage count and flow (r = 0.27, P = 0.241). The regression constant was not 0 (Table 12) because winter steelhead that do not pass Gold Ray Dam also contribute to angler harvest during February-March. We used passage estimates from the counting station only as an index of adult abundance.

Flow simulations developed by USACE indicated that operation of Lost Creek Dam decreased February-March flow by an average of 1,021 cfs annually during 1978-86. Substitution of values for (1) simulated flow for regulated and unregulated conditions and (2) adult return to Gold Ray Dam into the regression suggested that decreased flow increased harvest during February-March by an average of 405 adults annually. However, we do not know if the relationship between flow and harvest is causal. Other physical factors, particularly turbidity, are highly correlated with flow. As we will show later, fishing effort decreased when flow was high and the river was turbid.

Harvest Rate: Based on annual estimates of run size and angler harvest, we estimated harvest rate on all stocks in the river averaged 26% for the 1977-78 through 1979-80 run years (Table 13). Estimated harvest rate averaged 34% on hatchery fish and 26% on wild fish (Table 13). We believe that angler harvest is not currently an important factor limiting recruitment of wild winter steelhead in the Rogue River basin. Chapman (1986) estimated a maximum sustainable harvest rate of 69% for wild steelhead populations inhabiting unaltered areas of the Columbia River basin.

We estimated that anglers that fished downstream of Gold Ray Dam harvested an average of 25% of the wild winter steelhead that entered the Rogue River during the 1977-78 through 1979-80 run years (Table 13). Harvest rate among individual populations must have varied widely. Anglers probably harvested few wild fish from populations that spawned in tributaries of the

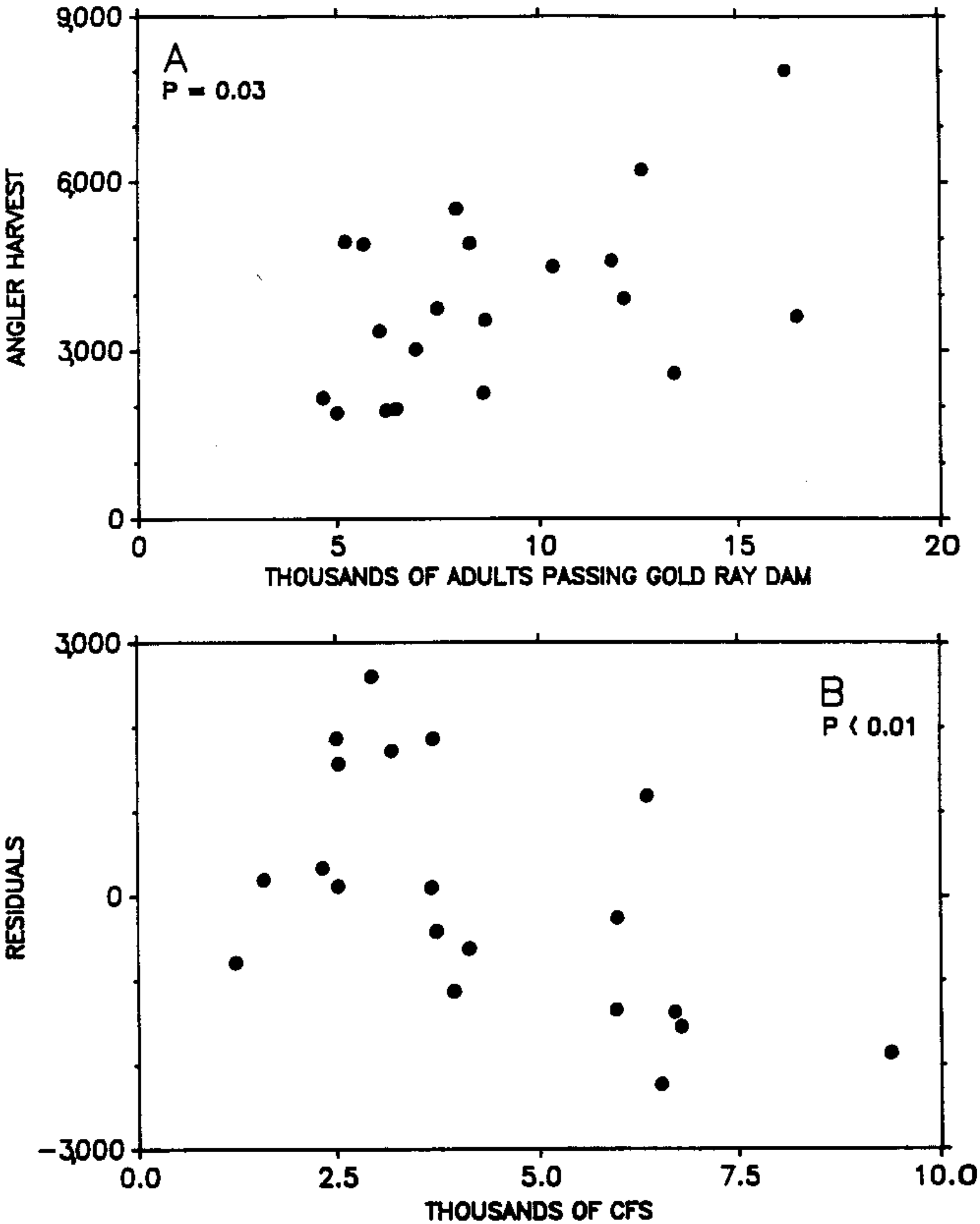

Figure 14. Relationship between the February-March harvest of winter steelhead (from salmon-steelhead cards) and the estimated number of adults that passed Gold Ray Dam (A); and residual variation plotted on mean flow at Raygold during February-March (B), 1967-87. Data from 1984 were excluded as an outlier.

Table 12. Regression analysis of factors that affected the harvest of winter steelhead in the Rogue River during February-March, 1967-87 (r^2 = 0.45). Data from 1984 were excluded as an outlier.

Independent variable	Regression coefficient	Standard error	*P*
Adult Abundance[a]	0.2788	0.0787	0.003
Flow[b]	-0.4056	0.1336	0.007
Constant	3,100		

Source of variation	Sum of squares	df	Mean square	*F*	*P*
Regression	24,925,293	2	12,462,647	8.62	0.003
Residual	24,567,992	17	1,445,176		

Variables tested	Partial r^2	
	Step 1	Step 2
Adult abundance[a]	0.23	--
Flow[b]	0.14	0.35

[a] *Estimated passage at Gold Ray Dam, 1 February through 15 May.*
[b] *Mean flow (cfs) at Raygold during February-March.*

lower river because adults contributed only to the fishery near Gold Beach. In contrast, adults returning to spawning areas in the upper river were probably harvested at a higher rate because they contributed to multiple fisheries. Attempts to improve estimates of harvest rate on individual populations of wild winter steelhead would require more accurate estimates of abundance and harvest of winter steelhead in the Rogue River and in tributary streams.

Hatchery fish of Rogue River stock were harvested at a higher rate than wild fish because they contributed to fisheries throughout the river (Table 13). Harvest rate of hatchery fish was higher below Gold Ray Dam than above the dam (Table 13). Higher rate of harvest below Gold Ray Dam was probably the result of (1) greater angler effort in the 202 kilometers downstream of the dam compared with the 50 kilometers upstream of the dam and (2) the fishery above Gold Ray Dam was relatively new after this area was opened in 1975 for the harvest of winter steelhead.

Table 13. Estimated harvest rate (%) on winter steelhead adults in the Rogue River by stock and by area in relation to Gold Ray Dam, 1977-78 through 1980-81 run years. Harvest rates above Gold Ray Dam on wild fish and on hatchery fish of Rogue River stock were assumed to be the same as for all stocks combined.

Run year	All stocks			Wild		Hatchery[a]	
	Below dam[b]	Above dam	Both areas[b]	Below dam	Both areas	Below dam	Both areas
1977-78	27	10	28	27	28	38	43
1978-79	30	5	32	30	32	28	32
1979-80	18	5	19	17	18	23	26
1980-81	--	5	--	--	--	30	33

[a] *Rogue River stock only.*
[b] *Includes hatchery fish of Applegate River origin caught downstream of Gold Ray Dam.*

Catch Rate: During the 4 years of angler surveys, annual catch rate varied little in the lower river, but varied considerably in the middle river (Table 14). Bank anglers in the middle river caught winter steelhead at a higher rate than bank anglers fishing the lower river. Catch rate of boat anglers averaged about three times higher than catch rate of bank anglers. We chose to not evaluate potential factors that may affect catch rate in either fishery, because of the difficulty in estimating fish abundance within the survey areas.

Table 14. Mean annual catch rate of winter steelhead harvested by anglers that fished in the Rogue River, 1977-78 through 1980-81 run years. Catch of half-pounders was excluded.

Run year	Bank anglers				Boat anglers in middle river	
	Lower river		Middle river			
	Fish/hour	hours	Fish/hour	hours	Fish/hour	hours
1977-78	0.037	8,547	0.044	1,212	0.176	459
1978-79	0.042	8,332	0.045	1,859	0.112	2,547
1979-80	0.039	9,906	0.039	1,274	0.103	2,302
1980-81	0.034	7,983	0.026	1,042	0.061	1,879

In the Rogue River, anglers caught winter steelhead at a rate similar to rates for fisheries in other rivers. Hiss et al. (1986) reported catch rates of 0.04-0.08 steelhead per hour for the Hoh River, Washington. Kenaston (1987) reported an average annual catch rate of 0.05 winter steelhead per hour for the Alsea River, Oregon. Annual catch rate of summer steelhead in four tributaries of the Snake River ranged between 0.06 and 0.10 fish per hour during 1986 (Carmichael et al. 1987).

We also found that catch rate on winter steelhead in the Rogue River did not differ from the historic rate. Rivers (1964) reported catch rates of 0.5-1.0 winter steelhead per day in the middle river during 1952-54. Assuming anglers fished an average of 6 hours daily, these catch rates would equate to 0.08-0.17 fish per hour. Thus, catch rates in the early 1950s were intermediate to catch rates by bank and boat anglers in the late 1970s and early 1980s.

Catch Composition: Winter steelhead accounted for almost all the harvest in the lower river between late November and mid March. Half-pounders and spawned summer steelhead, on their return migration to the ocean, accounted for less than 3% of the harvest. In contrast, half-pounders accounted for an average of 18% of the harvest in the middle river. The percentage of half-pounders within the catch ranged from a low of 9% during the 1978-79 run year to a high of 26% during 1977-78. Some half-pounders reside in the middle river throughout the winter (Everest 1973).

Contribution rates to fisheries in the Rogue River also varied between life history types of wild winter steelhead. In each of the 2 years we sampled scales from the catch in the lower river, salt migrants composed a higher percentage of the catch compared with the run (Table 15). Salt migrants contributed at a disproportionately high rate because of decreased angler effort late in the season, when spawning migrants were relatively more numerous among the returns.

Salt migrants contributed to the fishery in the middle river at a much lower rate. Salts migrants accounted for 50%-60% of the run in the lower river, but only accounted for 20%-40% of the fish harvested in the middle river (Table 15). We believe that many winter steelhead that are salt migrants enter tributary streams in downstream areas (i.e., the Illinois River) while spawning migrants continue up the Rogue River. If this hypothesis is correct, as the run of winter steelhead moves upstream, salt migrants would represent a smaller percentage of the run and a smaller percentage of the angler catch.

Table 15. Comparisons of life history composition of wild winter steelhead caught by anglers and by electrofishing, 1978-79 through 1979-80 run years.

	Angler catch				Electrofishing	
	Lower river		Middle river		in lower river	
Run year	% salt migrants	*N*	% salt migrants	*N*	% salt migrants	*N*
1978-79	72.9	170	35.8	173	61.4	223
1979-80	61.3	194	23.3	150	52.9	204

Changes in run composition during the upstream migration were also evident from changes in the percentage of hatchery fish within the angler catch. Hatchery fish composed a larger percentage of the catch in the middle river than they composed of the catch in the lower river (Table 16). Hatchery fish generally composed less of the middle river harvest than they composed of the run observed 50 km upstream at Gold Ray Dam (Table 16). The change in composition was probably attributable to the migration of wild adults into spawning tributaries downstream of Gold Ray Dam.

We also noted that hatchery fish contributed poorly, per returning adult, to the fisheries in the lower river during the 1977-78 through 1980-81 run years (Table 16). During these years, winter steelhead of hatchery origin entered the river late when angler effort was low. Modifications in broodstock selection procedures were implemented to produce a run that would return earlier. We did not evaluate the effects of modified spawning practices because adults did not return until after we terminated angler surveys.

Table 16. Percentage of hatchery fish among winter steelhead within the catch retained by anglers, within the sample captured by electrofishing, and within the count at Gold Ray Dam, 1977-78 through 1980-81 run years.

	Lower river		Middle river		Counted at
Run year	Retained by bank anglers	Captured by electrofishing	Retained by bank anglers	Retained by boat anglers	Gold Ray Dam
1977-78	1.1	5.5	5.9	10.2	13.4
1978-79	6.3	13.5	13.9	12.7	22.4
1979-80	3.3	11.0	19.9	14.0	24.9
1980-81	11.0	--	11.1	14.9	23.3

Angler Effort: In the lower river, we found angling began during the middle of November and continued into March. Survey data indicated that, on the average, effort increased through December and peaked in either January or February (Figure 15). However, the timing of angler effort varied between years. For example, effort during the first 2 weeks of January averaged 16% of the annual total from the 4 years of surveys, but ranged from a low of 7% in the 1978-79 run year to a high of 23% in 1977-78.

Variations in fish abundance and river condition were likely factors that affected angler effort in the lower river. We believe that economic and social factors affected effort to a lesser degree. Local residents predominated among anglers that participated in the fishery. Few guides worked the fishery, and few anglers used boats. We estimated that boat anglers accounted for less than 5% of the effort during most years. During the 4 years of surveys, the average daily count of bank anglers was more than 70 and the average daily count of boats was less than 2. We observed that easy access to preferred fishing sites, which allowed anglers to remain within their vehicles while "plunking," reduced concerns about adverse weather. These factors led us to hypothesize that rate of angler success and river

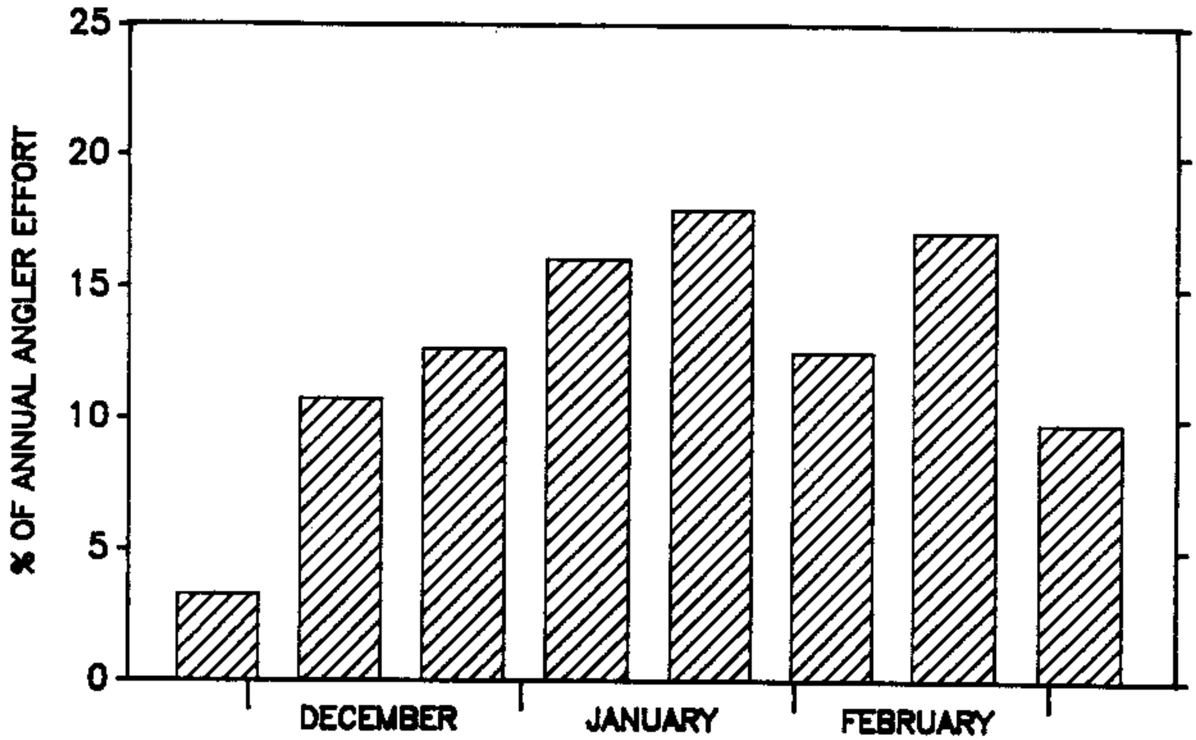

Figure 15. Timing of effort by bank anglers that fished for winter steelhead in the lower river, averaged for the 1977-78 through 1980-81 run years.

condition were the primary determinants of angler effort. We were unable to evaluate the effect of fish abundance on angler effort because we had no way to estimate weekly passage of winter steelhead through the fishery.

We found no correlation between weekly index of angler effort and angler catch rate or river physical factors. Data included in these analyses can be found in Appendix Table A-10. A correlation matrix outlining relationships between all variables can be found in Appendix Table A-11.

A plot of angler effort and turbidity suggested a curvilinear relationship between these two variables (Figure 16). When turbidity exceeded 10 JTU, effort decreased as turbidity increased. Few anglers fished for winter steelhead in the lower river when turbidity was less than 3 JTU. Angler effort generally peaked at an intermediate level of turbidity (5-20 JTU). Surveys of fishermen farther upstream produced comparable results.

In the middle river, angler effort for winter steelhead increased during February and peaked in either late February or early March. Timing of effort was similar for bank and boat fishermen (Figure 17). Use of boats is much more popular in this fishery compared with the fishery in the lower river. On the average, survey personnel counted 0.6 boat trailers for every bank angler observed during effort counts. Taking into account areas inaccessible to the survey clerk, we believe that effort in the middle river fishery was evenly distributed between bank and boat anglers.

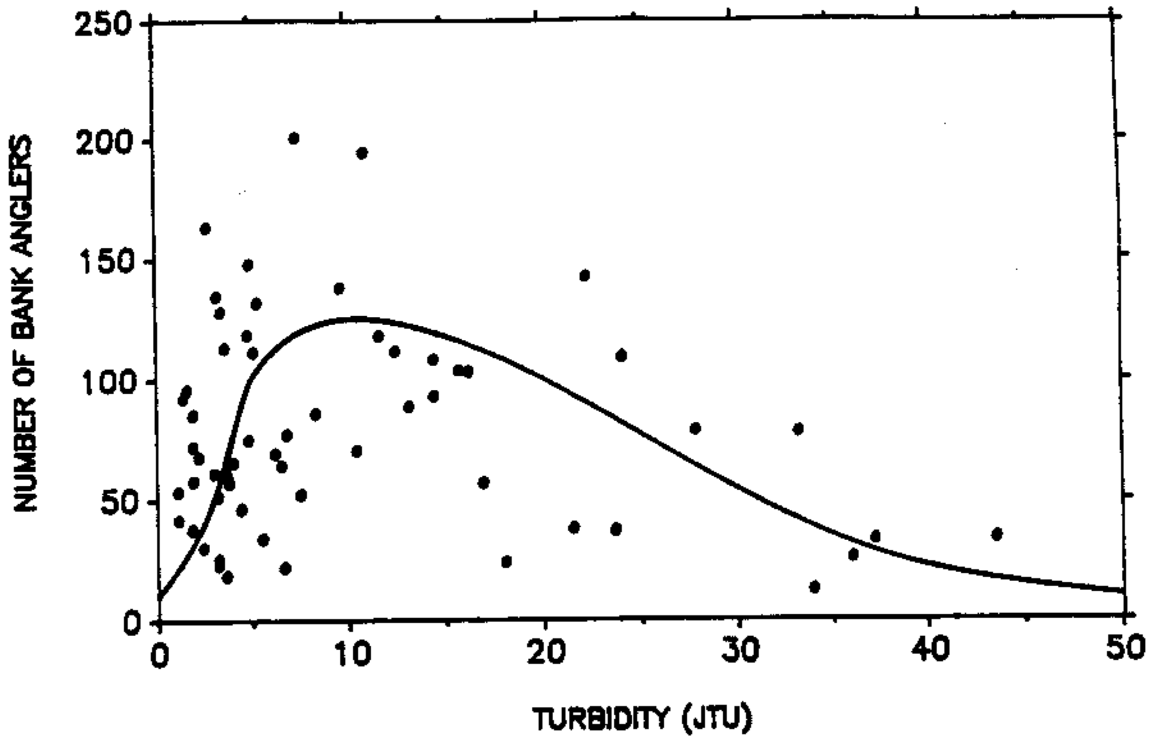

Figure 16. Postulated relationship between mean weekly count of bank anglers and mean weekly turbidity in the lower river, 1977-78 through 1980-81 run years. Curve fitted by eye.

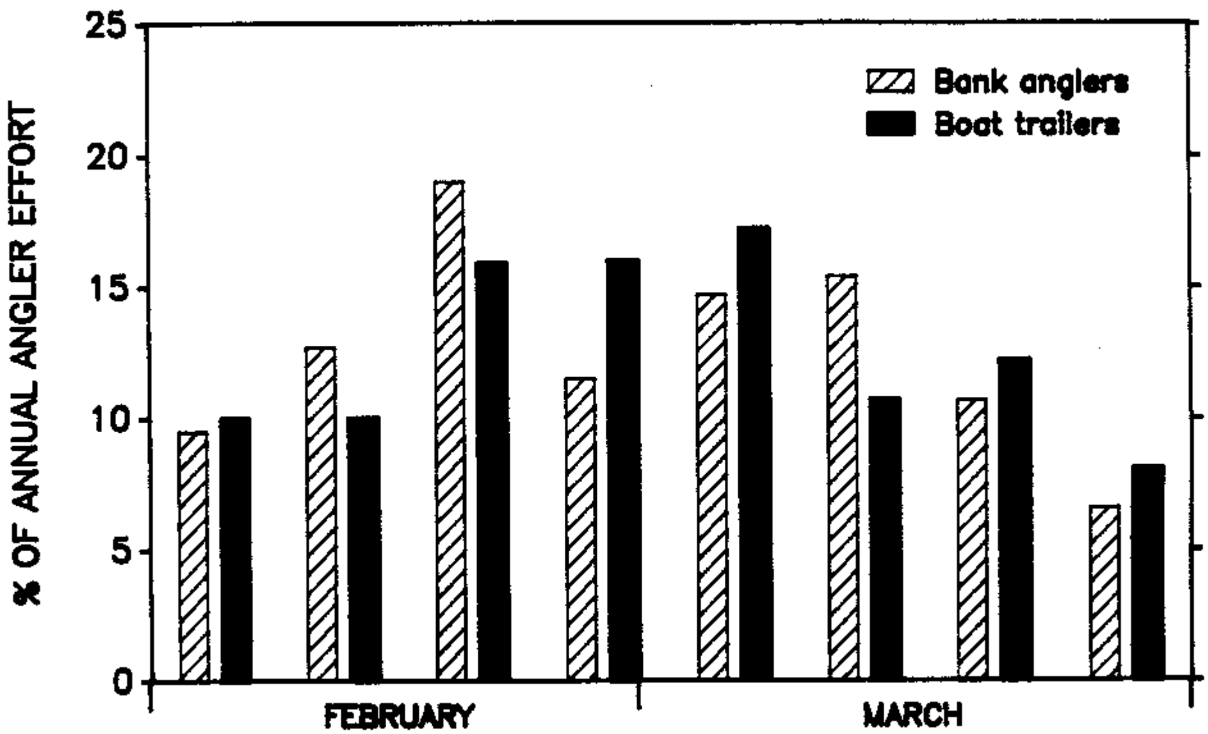

Figure 17. Timing of effort by anglers that fished for winter steelhead in the middle river, averaged for 1978-81.

For bank anglers, we found a positive correlation ($P \leq 0.05$ for a one-tailed test) between effort and mean weekly catch rate. As expected, angler effort increased as fishing success increased. Angler effort also correlated significantly with mean weekly turbidity but was not correlated with any of the other physical factors. However, the relationship between angler effort and turbidity may have been curvilinear (Figure 18). When turbidity exceeded 10 JTU, bank angler effort decreased as turbidity increased. Effort was also low when turbidity decreased below 3 JTU. Angler effort from the bank peaked at turbidity of 5-15 JTU.

Analyses of boat trailer counts produced similar results. The mean weekly count of boat trailers correlated positively ($P \leq 0.05$ for a one-tailed test) with the mean weekly catch rate by boat anglers. Effort by boat anglers was not correlated with any of the physical factors. However, the relationship between angler effort and turbidity again appeared to be curvilinear (Figure 18). When turbidity exceeded 10 JTU, trailer counts decreased as turbidity increased. Low counts of boat trailers indicated that few boats fished when turbidity decreased below 4 JTU. Counts of boat trailers peaked at a turbidity of 5-15 JTU. Data included in these analyses are listed in Appendix Table A-12. A correlation matrix outlining the relationships between all of the variables in the analysis can be found in Appendix Table A-13.

Other workers have commented on the effects of turbidity on angling. Lloyd et al. (1987) stated that anglers avoid turbid streams in Alaska. Rivers (1964) stated that catch of winter steelhead in the Rogue River was negligible when turbidity increased during mining and road building activities. Meigs and Pautzke (1941) claimed that angler success in the Green River, Washington, was lowest "when the river was high and off-color." These comments suggest high levels of turbidity result in decreased angling effort and success.

Our findings suggest that the operation of Lost Creek Dam affected angler effort in downstream areas. Operation of the dam decreased turbidity during periods of high flow and turbidity, and thus increased angling opportunity for winter steelhead. This situation commonly occurred in the lower river and middle river fisheries. Model simulations by USACE indicated that turbidity rarely dropped below 5 JTU during November-March in these areas.

Operation of the dam also decreased turbidity during periods of low flow and turbidity in the upper river during March-April. Under these conditions, decreased turbidity may have decreased angler effort in the fishery upstream of Gold Ray Dam. Operation of Lost Creek Dam to increase turbidity in the upper river during the spring is probably desirable but is not possible to attain. Differing levels of turbidity are not available for selective release from the reservoir, except after periods of highly turbid inflow (USACE 1983).

Juveniles

Life History

In this section we present data developed from analyses of scales taken from adult winter steelhead collected by electrofishing in the lower river. These data represent only those juveniles that survived to return as adults

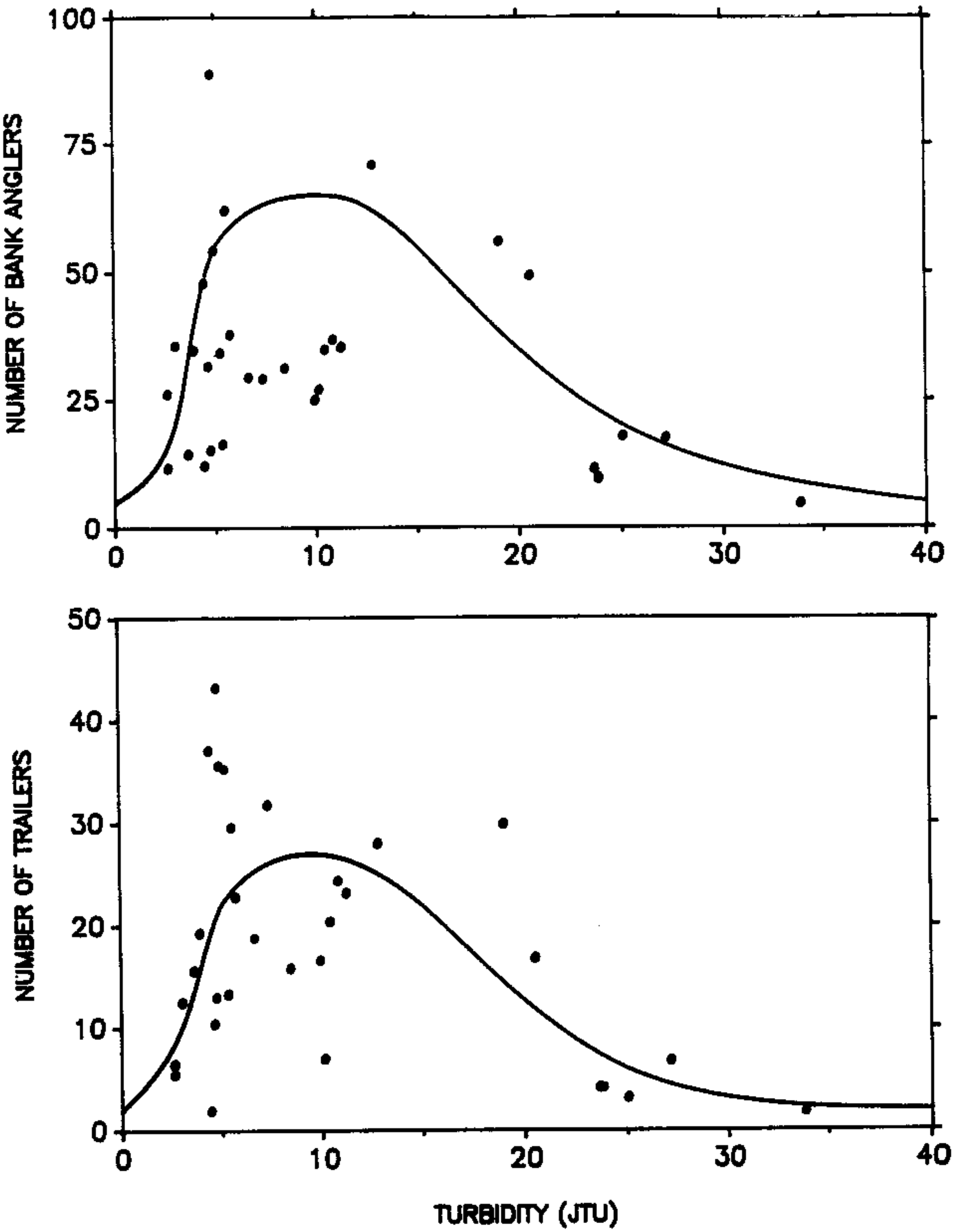

Figure 18. Postulated relationships between mean weekly indexes of angler effort and mean weekly turbidity in the middle river, 1977-78 through 1980-81 run years. Curves fitted by eye.

during the 1977-78 through 1980-81 run years. Because we did not sample later runs, there was almost no data for fish that reared as juveniles during postimpoundment years. Consequently, we were unable to make comparisons of biological data from juveniles that reared before and after the operation of Lost Creek Dam. This type of comparison would have been comprised anyway because data was generated from scales of adults, many of which reared as juveniles in tributary streams rather than the Rogue River (Rivers 1964).

Findings from field work with juveniles will be presented later in a completion report for our work with summer steelhead. Based on the findings of Everest (1973), we believe that most juvenile steelhead that reared in the mainstem were progeny of the summer steelhead. However, we observed as many as 200 winter steelhead spawning in the mainstem between Shady Cove and Dodge Bridge during April. Consequently, we believe at least some juvenile winter steelhead rear in the upper river.

Emergence Timing: Spawning time and water temperature are important determinants of the emergence timing of steelhead fry (Rombough 1988). Modified water temperature in areas downstream of Lost Creek Dam had little effect on the time that winter steelhead fry emerged from gravel redds in the upper river. Results of simulation models developed by USACE indicate that water temperature at Raygold during the middle of April through May averaged 11.6°C for regulated and 11.8°C for unregulated conditions.

Decreased water temperature resulted in only a minor delay in emergence timing. We assumed that spawning peaked on 15 April and estimated that peak emergence averaged 4 June for regulated and 6 June for unregulated conditions. We developed these estimates based on a guideline of 1,047 temperature units for winter steelhead of Rogue River origin to reach the "swim-up" stage (telephone conversation on 30 June 1989 with Michael Evenson, ODFW, Cole M. Rivers Hatchery, Trail, Oregon). We judged that a 2 day delay in emergence timing to have an insignificant effect on the production of winter steelhead fry in the upper river. Chandler and Bjornn (1988) noted the duration of emergence encompassed two to three weeks for steelhead eggs and fry incubated at 10°-12°C.

Growth Rate: Analyses of adult scales indicated that most subyearlings reached 8-10 cm by the time of formation of the first annulus (Appendix Table B-1). Most yearlings grew to a length of 12-16 cm by the time of formation of the second annulus (Appendix Table B-1). Comparable data for winter steelhead from other streams is scarce, with one exception. Hooton et al. (1987) estimated juvenile lengths from scales of adults that returned to streams on Vancouver Island. Their findings indicated that juvenile steelhead produced in Vancouver Island streams grew slower than juveniles produced in streams within the Rogue River basin. Among all life history types, mean length at annulus 1 ranged from 5-9 cm and mean length at annulus 2 ranged from 11-16 cm.

We noted significant differences in growth rate between life history patterns of juveniles ($P \leq 0.05$). Younger smolts grew faster than older smolts (Appendix Tables B-2 through B-4). At the time the first annulus formed, juveniles destined to migrate as age 1 smolts were 10-12 cm, while cohorts destined to migrate as age 2 or age 3 smolts were 8-10 cm. During the period between the formation of the first and second annuli, juveniles destined to migrate as age 2 smolts grew 5-7 cm, while cohorts destined to migrate as age 3 smolts grew 3-6 cm. Hooton et al. (1987) reported similar rates of growth for age 2 and age 3 smolts from Vancouver Island streams based on analysis of scales taken from adult winter steelhead.

Growth rate between the time of formation of the last freshwater annulus and the time of ocean entry ("plus-growth") also varied between adults of different life histories. Smolts of younger ages exhibited greater plus-growth compared with older smolts (Appendix Tables B-2 through B-4). Plus-growth averaged 9-11 cm for age 1 smolts, 5-7 cm for age 2 smolts, and 3-6 cm for age 3 smolts. Hooton et al. (1987) also noted greater plus-growth for winter steelhead that smolted at younger ages in Vancouver Island streams. Plus-growth was generally less among migrants from these streams compared with migrants leaving the Rogue River. We believe that variations in genetic complements of populations (McKay et al. 1986; Wangila and Dick 1988), environmental factors during freshwater rearing, and juvenile density probably accounted for the variation in growth rate for smolts of different ages.

Competition can affect the growth rate of juvenile salmonids in freshwater. Reeves et al. (1987) found that the presence of redside shiners did not affect biomass production of juvenile steelhead when water temperature was 12°-15°C, but reduced production when water temperature was 19°-22°C. Competition between cohorts can also affect growth rate. Bjornn (1978) concluded that high density reduced the growth rate of juvenile steelhead in Big Springs Creek, Idaho. Density also affected the size of subyearling and yearling steelhead in Lynn Creek, British Columbia (Hume and Parkinson 1987).

Water temperature also directly affects growth rate. Hokanson et al. (1977) found a positive relationship between water temperature and the growth rate of rainbow trout reared at 8-17°C. This finding was similar to that of Wurtsbaugh and Davis (1977). These studies confirm that modifications in river temperature affected growth rate of juvenile winter steelhead that reared in the Rogue River. Effect on growth rate was probably greatest in the area just downstream of Lost Creek Dam.

Results of model simulations by USACE indicated that water temperature near McLeod during June-August averaged 11.6°C for regulated and 13.7°C for unregulated conditions. Decreased water temperature must have reduced the growth rate of juveniles that reared in the mainstem for some distance below the dam. Effect must have diminished with distance downstream from the dam. At Raygold, model simulation indicated water temperature averaged 15.4°C for regulated and 18.1°C for unregulated conditions. However, without estimates of growth rate specific to juveniles rearing in the upper river, we were unable to quantify the effect of operation of the dam.

Age at Ocean Entry: Juvenile winter steelhead entered the ocean after one to four years of residence in freshwater. From analysis of scales taken from adults that returned during the 1977-78 through 1980-81 run years, we estimated that the age composition of smolts averaged 12% age 1, 66% age 2, 21% age 3, and 1% age 4 (Appendix Table B-5). This estimate represented a composite of distinct populations produced in various areas of the basin. Rivers (1964) documented that smolt ages varied among populations of winter steelhead in the Rogue River basin. He found that scale samples from adults indicated that juveniles that reared in the Applegate River were youngest at ocean entry and those that reared in the Illinois River were oldest at ocean entry.

Age at ocean entry has been reported for numerous populations of winter steelhead. In general, smolt age increased with increased latitude (Table 17). Age 1 smolts accounted for 30% of the adults that returned to a stream in central California. In other populations, age 1 smolts averaged less than 10% of adults that returned (Table 17) and of migrating juveniles (Loch et al. 1988). Similarly, age 3 smolts averaged more than 30% of adults that returned to British Columbia streams, but averaged less than 15% of adults that returned to streams in California and Oregon.

Table 17. Age at ocean entry of winter steelhead returning to streams on the Pacific coast of North America. Age was estimated from scales of returning adults, and annual values were averaged for multiple year studies.

Reference	Locality	Smolt age composition			
		Age 1	Age 2	Age 3	Age 4
Shapovalov and Taft (1954)	California	30%	58%	12%	0%
Chapman (1958)	Oregon	1%	80%	18%	1%
Wagner et al. (1963)	Oregon	5%	82%	13%	0%
Meigs and Pautzke (1941)	Washington	18%	72%	9%	1%
Maher and Larkin (1954)	British Columbia	2%	62%	35%	1%
Withler (1966)	British Columbia	6%	59%	33%	2%
Narver and Withler (1974)	British Columbia	0%	65%	33%	2%
Ward and Slaney (1988)	British Columbia	2%	60%	38%	0%
This study	Rogue River	12%	66%	21%	1%

Although age 2 smolts were the predominant life history pattern, we found that age at ocean entry varied among adult life history types (Figure 19). Age 1 smolts accounted for about 25% of the first spawning migrants, but composed less than 5% of the salt migrants. Salt migrants entered the ocean at older ages. Almost all two-salts entered the ocean as age 2 or age 3 smolts. Age 4 smolts that returned as adults returned mostly as one-salts. Data relating to smolt age composition can be found in Appendix Table B-5.

Smolt age appears primarily affected by genetic history (Ricker 1972) and body size (Wagner 1974; Johnsson and Clarke 1988). We found that faster growing juveniles entered the ocean at a younger age compared with slower growing juveniles (see **Growth Rate:**, page 50). Other studies of winter steelhead have also found a negative relationship between growth rate and smolt age (Wagner et al. 1963; Narver and Withler 1974; Hooton et al. 1987). Change in freshwater growth rate could have affected the age of ocean entry for juvenile winter steelhead that reared in the upper river.

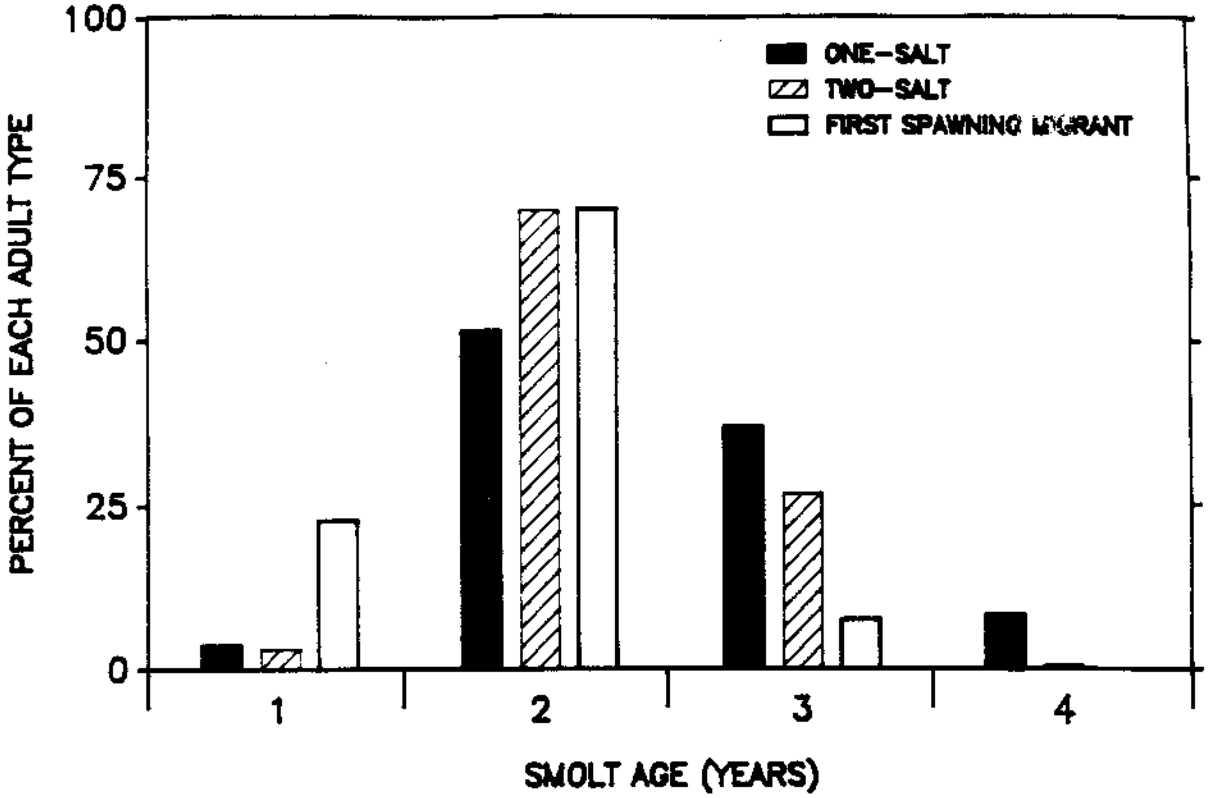

Figure 19. Smolt age composition for three life history types of wild adult winter steelhead collected by electrofishing in the lower river, averaged for the 1977-78 through 1980-81 run years.

The operation of Lost Creek Dam may have affected the smolt age of juvenile winter steelhead that reared in the upper river. Decreased water temperature during the summer probably decreased growth rate, which may have caused smolts to migrate at an older age. However, we were unable to evaluate this possibility because we were unable to estimate the effect of reservoir operation on growth rate of juveniles that reared in the upper river.

Length at Ocean Entry: We estimated that juvenile winter steelhead entered the ocean at a length ranging between 17 and 28 cm (7-11 inches). Most migrants were 20-24 cm (8-10 inches) long. Size at ocean entry differed among life history types of adults. Smolts destined to mature as one-salts were larger than smolts destined to mature as two-salts or as first spawning migrants. One-salts were larger at the time of ocean entry because they entered the ocean at an older age (Appendix Table B-6). Older smolts were also the largest smolts within other populations of winter steelhead on the Pacific coast (Maher and Larkin 1954; Narver and Withler 1974; Hooton et al. 1987).

Our data suggested that winter steelhead from the Rogue River basin entered the ocean at a larger size compared with smolts from other rivers. From adult winter steelhead that returned to the Nanaimo River, British Columbia, Narver and Withler (1974) estimated that length at ocean entry averaged 13.2 cm for age 2 smolts, 14.0 cm for age 3 smolts, and 16.0 cm for age 4 smolts. Mean length at ocean entry was less than 20 cm for almost all winter steelhead that returned to other streams on Vancouver Island (Hooton et al. 1987). Peterson (1978) estimated that winter steelhead that returned to the Alsea River, Oregon, entered the ocean at a mean length of 16.0-18.4 cm.

We found that most juvenile winter steelhead migrated from the Rogue River at a length of 20-24 cm. Other studies have found that steelhead smolt at a length greater than 20 cm (Meigs and Pautzke 1941; Maher and Larkin 1954; Narver 1969; Bjornn 1978). Juvenile steelhead as large as 28 cm have been trapped in streams of California (Shapovalov and Taft 1954) and British Columbia (Ward and Slaney 1988).

We also found that plus-growth accounted for a substantial portion of the growth in freshwater. Identification of the point of ocean entry was difficult because no clear check separated plus-growth and ocean growth. Because one person interpreted all scales collected from winter steelhead, any errors would be consistent among life history types of juveniles and adults. However, variations in interpretation of plus-growth among researchers may partially account for reported differences in smolt length. We may have been liberal in our estimate of plus-growth, which would have resulted in inflated estimates of smolt length at time of ocean entry.

Among smolts of the same age, we also noted differences in the size at ocean entry between adults of different life histories. Age 2 smolts destined to mature as one-salts were larger at ocean entry compared with the length of age 2 smolts destined to mature as two-salts or as first spawning migrants (Figure 20). This finding suggested that, among smolts of the same age, larger individuals were more likely to mature at a younger age than smaller cohorts. Negative relationships between smolt size and age at maturity have been documented for Atlantic salmon (Saunders 1986), coho salmon (Hager and Noble 1976), and sockeye salmon *Oncorhynchus nerka* (Hyatt and Stockner 1985). Changes in freshwater growth rate could have affected the size at ocean entry for juvenile winter steelhead that reared in the upper river. However, we were not able to estimate the effect of the operation of the dam on the growth rate of the segment of the population that reared in the upper river.

We were unable to estimate the effect of reservoir operation on the length of winter steelhead smolts that migrated from the Rogue River. Decreased water temperature in the upper river probably decreased growth rate (*see* **Growth Rate:**, page 50) and may have increased age at smolting (*see* **Age at Ocean Entry:**, page 51). Smolts produced in the upper river may have been smaller because of reduced growth rate. Conversely, they may have been larger because of an older age at migration (also a possible result of reduced growth rate). Without estimates of the effect of reservoir operation on the growth rate and smolt age of juveniles that inhabited the upper river, we could not estimate the effect of reservoir operation on smolt length.

Abundance

Based on our observations of adults spawning upstream of Gold Ray Dam and on the findings of Leider et al. (1986b), we concluded that the mainstem produced at least some juvenile winter steelhead. We did not observe any adults spawning in the mainstem downstream of Gold Ray Dam except during some drought years when adults were unable to enter small tributaries of the middle

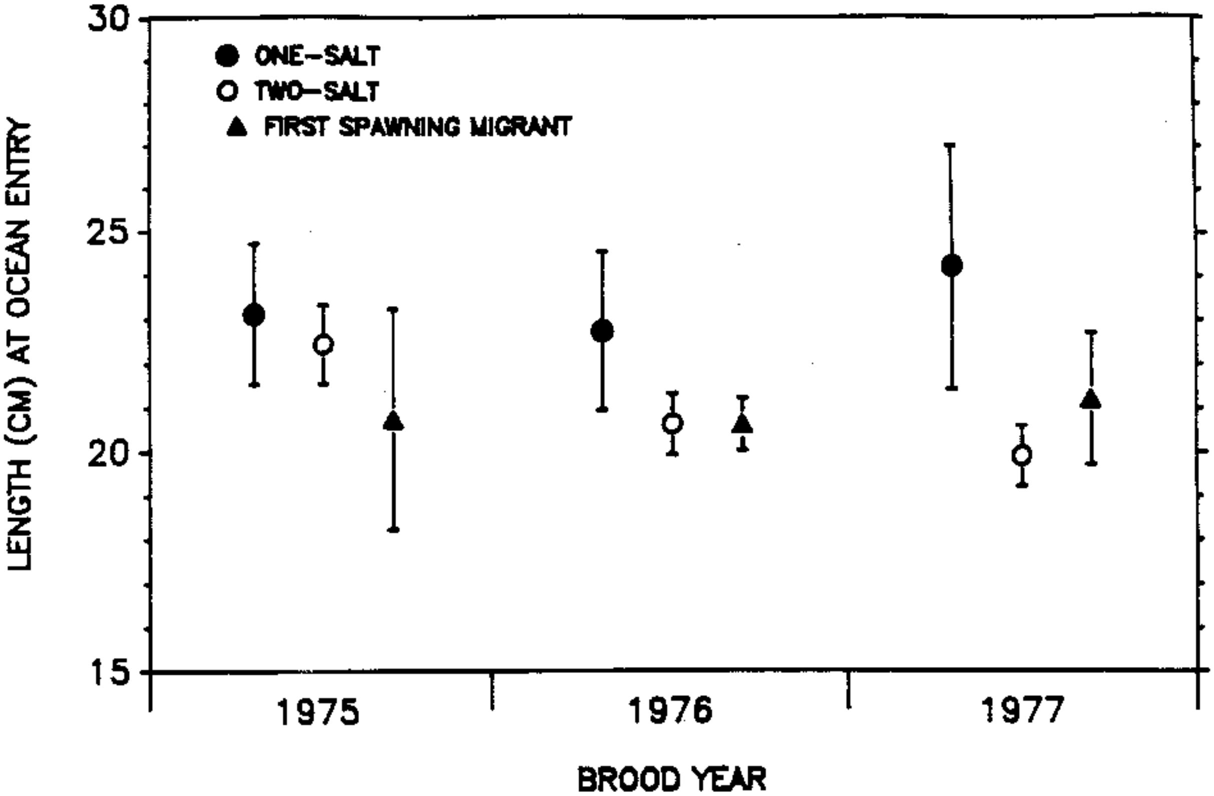

Figure 20. Estimated mean length of wild age 2 smolts at the time of ocean entry for three life history types of adults collected by electrofishing in the lower river, 1977-78 through 1979-80 run years. Brackets represent 95% confidence intervals.

river. Because we lacked data on juvenile abundance, we reviewed the literature for information relating to environmental determinants of the production of juvenile steelhead.

Estimates of survival rate of juvenile steelhead rearing in freshwater have been developed during numerous studies (reviewed by ODFW (1986) and Bley and Moring (1988)). However, information relating survival rate to the effect of environmental factors is lacking. Consequently, we can only make a qualitative assessment of the effect of the dam on the abundance of juvenile winter steelhead. The literature did indicate that modifications in river physical factors result in changes in juvenile habitat. Key freshwater habitat for juvenile steelhead encompasses three types (1) gravel redds inhabited by incubating eggs and alevins, (2) rearing habitat for free swimming fry and parr, and (3) winter habitat for hiding juveniles. In the following text, we discuss how operation of the dam affected each of these habitat types.

Female winter steelhead construct redds in areas of gravel. Smith (1973) reported that winter steelhead in Oregon spawned at a mean water depth of 0.42 m (SD = 0.55 m). The depth of the most shallow redd was 0.24 m. Consequently, we believe that operation of Lost Creek Dam can cause redds of winter steelhead to be dewatered in the upper river.

On 17 April 1985, outflow from Lost Creek Dam decreased from 4,300 cfs at 1100 hours to 2,000 cfs at 2200 hours. Decreased outflow decreased water level at Dodge Bridge by 0.4 m. Because we observed adults spawning during April, we believe that some redds were dewatered and that some adults were forced to vacate partially constructed redds. The resultant effect on juvenile production is unknown.

During spring, after the potential for flooding has passed, the need diminishes for large, immediate changes in reservoir outflow. Strategies can be implemented to minimize the potential for disruption of spawning, dewatering of incubating eggs and alevins, and dewatering of newly emergent fry. We recommend that during April-July, outflow from Lost Creek Dam be managed so that short-term decreases in outflow (i.e., less than 3 days) do not reduce the water level at Dodge Bridge by more than 0.3 m. For a flow of 3,000 cfs at Dodge Bridge, the proposed criteria would limit the allowable decrease in outflow to 1,340 cfs. Efforts should be made to minimize the duration of any short-term decreases in flow during the spring to limit mortality of eggs incubating in the gravel (Becker et al. 1986).

After short-term reductions in outflow, subsequent outflow should not exceed the outflow that preceded the short-term decrease. Instead, managers should plan far enough ahead to allow for gradual changes in river flow during periods other than flood control. Implementation of this recommendation would minimize the potential that (1) adults would spawn at a flow augmented to discharge excess storage from the reservoir and (2) newly emergent fry would colonize areas soon to be dewatered when outflow decreases to keep reservoir level within guidelines set by the authorizing document.

Free swimming steelhead fry are susceptible to dewatering because they generally inhabit areas less than 15 cm in depth (Everest and Chapman 1972; Bustard and Narver 1975; Sheppard and Johnson 1985). Because fry inhabit shallow water, augmented flow during the summer probably increased the amount of rearing habitat for steelhead fry. Increased habitat may have resulted in increased survival, particularly if density was high (Hume and Parkinson 1987).

Decreased water temperature during summer probably did not increase production of juvenile winter steelhead. Water temperature was near optimum in the upper river prior to the construction of Lost Creek Dam (*see* **Growth Rate:**, page 50). Lower water temperature in summer possibly decreased production of smolts. If smolts migrated at older ages because of a slower rate of growth, then total mortality among presmolts would increase because of additional residence time in freshwater. However, decreased water temperature may have increased the ability of juvenile steelhead to compete with sympatric redside shiners (Reeves et al. 1987).

Alternatively, changes in river physical parameters during summer may have had little effect on production of smolts. Some biologists have postulated that the quantity and quality of hiding cover during the winter is a more important determinant of smolt production. Bustard and Narver (1975) found juvenile steelhead in Carnation Creek, British Columbia, increased habitation of areas with hiding cover as water temperature decreased from 9°C to 2°C. Yearlings most commonly used logs and exposed tree roots for cover. Subyearlings primarily used interstices between large rocks for cover. The authors theorized that the availability of stable cover may be an important factor that effects survival rate of juveniles during the winter, particularly during periods of peak flow. Bjornn (1971) and Swales et al. (1986) also reported extensive use of hiding cover by juvenile steelhead when water temperature decreased below 5°C.

Construction of Lost Creek Dam may result in a decreased amount of winter cover for juvenile steelhead inhabiting the upper river. The dam blocks recruitment of large woody debris and large gravel into downstream areas. Significant changes in availability of winter habitat may not manifest for many years, or may be ameliorated by recruitment of large woody debris and large gravel from tributary streams. Because we do not know if a significant number of juvenile winter steelhead rears in the mainstem, we cannot adequately assess the need for winter habitat.

To better assess the status of juvenile steelhead, we recommend surveys to estimate the density of subyearlings rearing in the upper river. Surveys should encompass a time span of at least 3 years to assess variability in annual production. If juveniles are judged to be numerous, surveys to quantify the amount of winter habitat should follow.

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APPENDIX A

Tables of Data Relating to Studies of
Adult Winter Steelhead

Appendix Table A-1. Percentage that repeat spawners composed of salt migrant and spawning migrant life histories of wild winter steelhead collected by electrofishing in the lower river, 1977-78 through 1980-81 run years.

Run year	Salt migrants *N*	Salt migrants % Repeat spawners	Spawning migrants *N*	Spawning migrants % Repeat spawners
1977-78	159	12.4	36	28.3
1978-79	119	12.8	104	9.6
1979-80	161	1.9	43	27.3
1980-81	73	12.8	19	34.3

Appendix Table A-2. Length frequency distributions of winter steelhead electrofished in the lower river (RK 8-29), 1977-78 through 1979-80 run years. Data for the 1980-81 run year not reported because sampling was not consistent throughout the run. Lengths represent mid-points of the size intervals.

Fish type, run year	Fork length (5 cm size interval) 45	50	55	60	65	70	75	80	85	90
Wild:										
1977-78	8	34	46	30	94	116	39	9	0	0
1978-79	19	32	96	142	140	76	24	6	0	1
1979-80	6	23	36	69	94	36	16	3	0	0
Hatchery:										
1977-78	0	0	5	4	5	4	2	0	0	0
1978-79	14	6	30	22	12	3	0	0	0	0
1979-80	0	0	18	6	6	2	0	0	0	0

Appendix Table A-3. Estimated number of winter steelhead that returned to Gold Ray Dam, 1943-87.

Year	Number[a]	Year	Number[a]	Year	Number[a]
1943	16,708	1958	3,101	1973	7,935
1944	14,122	1959	4,111	1974	6,464
1945	9,552	1960	6,894	1975	8,267
1946	8,284	1961	9,418	1976	5,202
1947	9,219	1962	10,891	1977	4,633
1948	8,519	1963	9,794	1978	5,664
1949	7,913	1964	5,855	1979	12,579
1950	8,593	1965	6,841	1980	11,807
1951	5,464	1966	11,170	1981	7,472
1952	10,683	1967	4,989	1982	6,213
1953	8,627	1968	6,949	1983	8,596
1954	6,763	1969	6,056	1984	9,184
1955	5,173	1970	12,126	1985	10,318
1956	7,830	1971	8,647	1986	13,382
1957	5,033	1972	16,463	1987	16,213

[a] *Includes wild and hatchery fish, 1 February through 15 May.*

Appendix Table A-4. Estimated number of hatchery winter steelhead that returned to Gold Ray Dam, 1971-87, and to Cole M. Rivers Hatchery, 1979-87.

Year	Number of adults		Year	Number of adults	
	Gold Ray Dam[a]	Hatchery[b]		Gold Ray Dam[a]	Hatchery[b]
1971	209	--	1979	2,818	2,129
1972	812	--	1980	2,942	2,765
1973	512	--	1981	1,743	1,228
1974	410	--	1982	1,634	1,205
1975	829	--	1983	1,451	1,462
1976	187	--	1984	3,739	4,145
1977	503	--	1985	1,345	1,655
1978	760	--	1986	1,813	1,038
			1987	3,536	2,213

[a] *Count period 1 February through 15 May.*
[b] *Count period 13 March through 12 June. Hatchery estimate exceeds passage count during some years because counting station was inoperable at high flow.*

Appendix Table A-5. Juvenile winter steelhead of hatchery origin released in the Rogue River basin, 1976-86. All were mitigation fish reared at Cole M. Rivers Hatchery (data received from Michael Evenson, Oregon Department of Fish and Wildlife, Cole M. Rivers Hatchery, Trail, Oregon).

Month, year of release	Stream of release	Brood year	Number released	Number per pound	Broodstock
04/76	Rogue	1974	59,908	5.0	Rogue
04/77	Rogue	1975	179,004	5.2	Rogue
04/78	Rogue	1976	131,189	4.5	Rogue
04/78	Applegate	1976	45,639	4.2	Rogue
04/79	Rogue	1977	138,733	3.6-5.0	Rogue
04/80	Rogue	1978	94,088	4.1-4.6	Rogue
04/81	Rogue	1979	81,281	3.8-4.4	Rogue
04/81	Applegate	1979	83,536	3.3	Applegate
04/82	Rogue	1980	125,341	4.0-4.5	Rogue
05/82	Rogue	1981	123,852	6.4	Rogue
05/82	Applegate	1980	112,589	5.1	Applegate
04/83	Rogue	1982	58,180	6.3	Rogue
04/83	Applegate	1981	82,482	4.5	Applegate
04/84	Rogue	1982	60,548	4.5	Rogue
04/84	Applegate	1982	19,453	4.9	Applegate
04/85	Rogue	1983	117,591	4.8	Rogue
05/85	Rogue	1984	62,498	6.4	Rogue
04/85	Applegate	1983	108,087	4.6	Applegate
05/86	Rogue	1984	30,024	4.6	Rogue
05/86	Rogue	1985	69,709	5.4	Rogue
05/86	Applegate	1984	54,643	4.7	Applegate

Appendix Table A-6. Estimated number of wild winter steelhead that returned to Gold Ray Dam on the Rogue River and to Winchester Dam on the North Umpqua River, 1946-87.

Year	Estimated number[a]		Year	Estimated number[a]	
	Gold Ray Dam	Winchester Dam		Gold Ray Dam	Winchester Dam
1946	8,284	6,563	1967	4,989	7,659
1947	9,219	11,220	1968	6,949	6,258
1948	8,519	9,700	1969	6,056	6,865
1949	7,913	9,225	1970	12,126	10,332
1950	8,593	7,008	1971	8,438	8,083
1951	5,464	4,188	1972	15,651	6,352
1952	10,683	10,635	1973	7,423	7,415
1953	8,627	5,094	1974	6,054	7,894
1954	6,763	9,124	1975	7,438	5,744
1955	5,173	4,755	1976	5,015	5,789
1956	7,830	10,211	1977	4,130	5,264
1957	5,033	8,923	1978	4,904	5,949
1958	3,101	6,350	1979	9,761	7,359
1959	4,111	6,372	1980	8,865	7,532
1960	6,894	5,815	1981	5,729	6,580
1961	9,418	4,906	1982	4,579	6,405
1962	10,891	7,688	1983	7,145	3,853
1963	9,794	5,639	1984	5,445	4,588
1964	5,855	7,670	1985	8,973	8,404
1965	6,841	8,990	1986	11,569	10,530
1966	11,170	9,099	1987	12,677	8,153

[a] *Count of marked fish was not recorded at Gold Ray Dam prior to 1971, or at Winchester Dam prior to 1960 or after 1981. Return of hatchery fish during those periods was judged to be minimal as no juvenile winter steelhead were released in either system.*

Appendix Table A-7. Harvest regulations in the Rogue River relevant to winter steelhead large enough to be recorded on salmon-steelhead cards, 1967-87.

Run year, harvest area	Harvest period	Daily limit
1967-68:		
RK 0-202	10/15-3/31	2
1974-75:		
RK 0-77	10/15-3/31	2
RK 77-202	11/01-3/31	2
RK 202-253	02/01-3/31	2
1975-87:		
RK 0-253	01/01-12/31	2

Appendix Table A-8. Estimated harvest of winter steelhead in the Rogue River, 1966-67 through 1986-87 run years. Catch estimated from salmon-steelhead cards returned by anglers to ODFW (includes some summer steelhead).

Run year	December	January	February	March	April[a]	Total
1966-67	1,684	1,586	958	925	--	5,153
1967-68	1,970	2,081	1,559	1,458	--	7,068
1968-69	1,771	705	1,258	2,087	--	5,821
1969-70	1,399	1,569	2,516	1,406	--	6,890
1970-71	2,103	1,385	2,318	1,222	--	7,028
1971-72	3,096	2,715	2,949	665	--	9,425
1972-73	1,433	2,308	3,508	2,009	--	9,258
1973-74	1,080	1,141	1,354	596	--	4,171
1974-75	3,739	4,797	2,466	2,438	1,016	14,456
1975-76	3,033	2,475	2,221	2,704	614	11,047
1976-77	1,839	1,571	1,269	882	227	5,788
1977-78	1,704	3,727	2,569	2,313	750	11,063
1978-79	3,552	3,150	2,795	3,419	772	13,688
1979-80	3,163	2,173	2,529	2,068	856	10,789
1980-81	1,446	1,716	2,047	1,697	710	7,616
1981-82	321	1,025	891	1,032	385	3,654
1982-83	1,145	1,066	778	1,459	894	5,342
1983-84	382	150	149	499	424	1,604
1984-85	1,959	1,499	2,414	2,081	755	8,708
1985-86	1,435	1,320	1,191	1,393	735	6,074
1986-87	948	1,563	4,353	3,672	1,067	11,603

[a] *Season closed during April 1967-74.*

Appendix Table A-9. Data used to assess factors that affected the harvest of winter steelhead in the Rogue River, 1966-67 through 1986-87 run years.

Run year	Catch[a]	Abundance[b]	Flow[c]
1966-67	1,883	4,989	3,945
1967-68	3,017	6,949	3,730
1968-69	3,345	6,056	3,671
1969-70	3,922	12,126	4,130
1970-71	3,540	8,647	5,974
1971-72	3,614	16,463	9,382
1972-73	5,517	7,935	2,500
1973-74	1,950	6,464	6,694
1974-75	4,904	8,267	6,354
1975-76	4,925	5,202	3,698
1976-77	2,151	4,633	1,208
1977-78	4,882	5,664	3,191
1978-79	6,214	12,579	2,525
1979-80	4,597	11,807	2,513
1980-81	3,744	7,472	1,567
1981-82	1,923	6,213	5,960
1982-83	2,237	8,596	6,776
1983-84	648	9,184	5,111
1984-85	4,495	10,318	2,318
1985-86	2,584	13,382	6,522
1986-87	8,025	16,213	2,942

[a] *Estimated February-March catch from salmon-steelhead cards.*
[b] *Estimated passage of winter steelhead at Gold Ray Dam, 1 February through 15 May.*
[c] *Mean flow (cfs) at Raygold during February-March.*

Appendix Table A-10. Data used to assess factors that affected weekly index of angler effort for winter steelhead in the lower river, 1977-78 through 1980-81 run years (week calendar is in **APPENDIX C**).

Year, week	Effort[a]	Catch rate[b]	Flow[c]	Temperature[d]	Turbidity[e]
1977:					
48	24.1	0.041	20,941	9.4	18.0
49	64.2	0.038	10,700	9.1	6.5
50	33.5	0.035	52,689	8.6	37.2
51	26.0	0.067	27,461	7.1	36.0
52	88.6	0.034	20,226	8.0	13.1
1978:					
1	85.8	0.043	25,773	7.7	8.3
2	117.8	0.041	20,172	8.7	11.6
3	38.0	0.025	36,656	8.8	21.5
4	147.6	0.040	15,238	7.5	4.9
5	52.2	0.023	34,026	8.1	7.5
6	12.6	0.036	39,856	8.1	33.9
7	75.0	0.048	15,369	7.4	4.8
8	51.4	0.025	11,472	9.9	3.2
9	30.5	0.035	7,823	9.2	2.4
48	18.8	0.035	4,105	7.5	3.6
49	69.2	0.047	5,036	7.0	6.2
50	111.0	0.024	4,857	6.6	5.1
51	72.2	0.040	3,438	6.1	1.9
52	92.3	0.016	3,045	5.1	1.4
1979:					
1	53.6	0.007	2,586	3.0	1.1
2	32.0	0.078	20,191	6.7	58.8
3	200.8	0.055	8,246	5.9	7.4
4	85.4	0.035	4,337	4.7	1.9
5	41.9	0.024	3,296	3.9	1.1
6	70.5	0.046	7,628	7.1	10.4
7	78.8	0.046	26,079	7.5	27.8
8	137.8	0.053	17,395	7.3	9.6
9	102.8	0.039	19,749	7.9	16.2
10	77.0	0.023	14,581	10.6	6.8

[a] *Mean daily count of bank anglers at 0900, 1200, and 1600 hours.*
[b] *Mean catch rate (fish per hour) by bank anglers.*
[c] *Mean flow (cfs) downstream of the Illinois River.*
[d] *Mean maximum water temperature (°C) at Agness.*
[e] *Mean daily turbidity (JTU) at Canfield (RK 8).*

Appendix Table A-10. Continued.

Year, week	Effort[a]	Catch rate[b]	Flow[c]	Temperature[d]	Turbidity[e]
1979 (continued):					
48	22.2	0.021	13,389	7.8	6.6
49	56.8	0.042	22,039	8.7	16.9
50	67.8	0.012	6,894	6.3	2.2
51	34.0	0.006	14,938	7.6	5.5
52	112.8	0.029	20,063	7.2	3.6
1980:					
1	163.2	0.044	21,106	8.7	2.7
2	78.2	0.029	53,098	8.3	33.2
3	37.0	0.035	43,276	7.4	23.6
4	194.5	0.045	12,406	5.9	10.9
5	107.8	0.035	8,952	5.0	14.4
6	127.7	0.044	8,855	7.4	3.4
7	95.8	0.048	7,320	7.9	1.6
8	111.2	0.063	18,978	8.9	12.4
9	118.2	0.040	15,715	9.9	4.8
10	46.3	0.036	9,480	10.1	4.4
48	25.7	0.034	16,661	8.4	3.2
49	34.0	0.072	30,605	7.8	43.5
50	65.3	0.052	6,438	5.2	4.0
51	56.8	0.041	6,140	7.0	3.8
52	103.5	0.050	19,938	9.1	15.7
1981:					
1	134.3	0.030	6,696	7.5	3.2
2	58.0	0.016	4,099	6.9	1.9
3	38.0	0.001	3,599	7.1	1.8
4	92.8	0.047	9,635	8.4	14.4
5	131.5	0.034	8,258	6.8	5.3
6	61.0	0.017	4,633	6.4	3.0
7	109.0	0.023	15,187	8.8	24.0
8	142.3	0.031	13,350	8.7	22.2
9	60.0	0.019	8,161	8.8	3.7
10	23.0	0.008	6,390	9.4	3.2

Appendix Table A-11. Correlation matrix of variables used in analyses of weekly catch rate and index of angler effort for winter steelhead in the lower river, 1977-78 through 1980-81 run years. Description of variables is given in Appendix Table A-10.

Variable	Angler effort	Catch rate	Flow	Temperature	Turbidity
Angler effort	1.00				
Catch rate	0.21	1.00			
Flow	-0.18	0.23	1.00		
Temperature	-0.12	0.07	0.36[a]	1.00	
Turbidity	-0.22	0.50[a]	0.70[a]	0.16	1.00

[a] $P \leq 0.05$ *in two-tailed test.*

Appendix Table A-12. Data used to assess factors that affected weekly index of angler effort for winter steelhead in the middle river, 1978-81 (week calendar is in **APPENDIX C**).

Year, week	Angler effort Bank[a]	Angler effort Boat[b]	Catch rate Bank[c]	Catch rate Boat[d]	Flow[e]	Temperature[f]	Turbidity[g]
1978:							
6	4.2	11.4	0.04	0.10	8,591	7.4	23.6
7	31.8	29.1	0.12	0.28	3,487	6.7	7.3
8	35.6	54.3	0.09	0.22	2,865	9.4	4.9
9	12.5	35.6	0.09	0.29	2,237	8.6	3.0
10	22.8	37.8	0.09	0.26	3,275	9.4	5.7
11	10.4	31.6	0.07	0.01	3,050	9.3	4.6
12	19.3	34.7	0.06	0.26	2,747	11.7	3.9

[a] *Mean daily count of bank anglers at 0900, 1200, and 1600 hours.*
[b] *Mean daily count of boat trailers at 0900, 1200, and 1600 hours.*
[c] *Mean catch rate (fish per hour) by bank anglers.*
[d] *Mean catch rate (fish per hour) by boat anglers.*
[e] *Mean flow (cfs) at Grants Pass.*
[f] *Mean maximum water temperature (^{o}C) at Grants Pass.*
[g] *Mean daily turbidity (JTU) at Griffin Park (RK 145).*

Appendix Table A-12. Continued.

Year, week	Angler effort Bank[a]	Angler effort Boat[b]	Catch rate Bank[c]	Catch rate Boat[d]	Flow[e]	Temperature[f]	Turbidity[g]
1979:							
6	7.0	27.0	0.02	0.01	2,171	6.7	10.1
7	6.8	17.5	0.05	0.13	4,028	6.7	27.1
8	29.9	55.9	0.12	0.26	3,155	6.7	19.0
9	16.8	49.2	0.06	0.12	3,688	7.2	20.5
10	28.0	70.8	0.05	0.11	3,370	10.0	12.8
11	43.2	88.8	0.06	0.11	3,850	9.0	4.8
12	29.6	62.0	0.01	0.12	3,027	9.9	5.5
13	15.6	14.4	0.02	0.01	2,268	10.1	3.6
1980:							
6	20.4	34.8	0.05	0.14	2,271	6.3	10.4
7	37.1	47.9	0.04	0.08	1,845	7.0	4.4
8	3.2	17.8	0.04	0.08	3,557	7.8	25.0
9	23.2	35.3	0.04	0.14	3,021	9.1	11.2
10	15.8	31.2	0.07	0.12	2,964	9.2	8.4
11	4.2	9.6	0.06	0.19	5,988	7.6	23.8
12	16.6	25.0	0.08	0.11	4,217	8.6	9.9
13	13.3	16.4	0.02	0.12	2,877	9.4	5.3
1981:							
6	5.5	26.2	0.00	0.09	1,221	5.6	2.6
7	1.8	4.7	0.03	0.00	2,975	8.4	33.8
8	24.4	36.8	0.05	0.08	2,798	8.3	10.8
9	35.3	34.2	0.02	0.09	1,757	8.3	5.2
10	18.8	29.4	0.04	0.14	1,605	8.9	6.6
11	13.0	15.2	0.04	0.06	1,365	10.1	4.7
12	6.5	11.7	0.02	0.03	1,314	11.3	2.6
13	2.0	12.2	0.02	0.02	1,780	10.9	4.4

Appendix Table A-13. Correlation matrix of variables used in analyses of weekly catch rate and index of angler effort for winter steelhead in the middle river, 1978-81. Description of variables can be found in Appendix Table A-12.

Variable	Bank effort	Boat effort	Bank fish/hr	Boat fish/hr	Flow	Temperature	Turbidity
Bank effort	1.00						
Boat effort	0.81[a]	1.00					
Bank fish/hr	0.37[b]	0.29	1.00				
Boat fish/hr	0.36[b]	0.31[b]	0.70[a]	1.00			
Flow	-0.14	-0.05	0.15	0.26	1.00		
Temperature	0.02	0.00	-0.13	-0.15	-0.22	1.00	
Turbidity	-0.39[a]	-0.27	-0.11	0.07	0.59[a]	-0.42[a]	1.00

[a] $P \leq 0.05$ *in two-tailed test.*
[a] $P \leq 0.05$ *in one-tailed test.*

APPENDIX B

Tables of Data Relating to Studies of Juvenile Winter Steelhead

Appendix Table B-1. Estimated mean length (cm) ± 95% confidence interval at each freshwater annulus for three life history types of wild winter steelhead collected by electrofishing in the lower river, 1977-78 through 1980-81 run years.

Annulus, brood year	Smolt age	Adult life history type		
		One-salt	Two-salt	First spawning migrant
Annulus 1:				
1974	2	--	9.4 ± 0.3	--
1975	2	9.5 ± 0.7	9.2 ± 0.3	9.0 ± 0.4
1976	2	8.5 ± 0.8	8.7 ± 0.3	8.8 ± 0.4
1977	2	9.6 ± 0.9	9.1 ± 0.4	8.4 ± 0.4
1973	3	--	9.4 ± 0.5	--
1974	3	9.7 ± 0.4	9.1 ± 0.5	--
1975	3	8.5 ± 1.1	8.2 ± 0.5	--
1976	3	9.0 ± 1.2	8.5 ± 0.4	--
Annulus 2:				
1974	2	--	14.7 ± 0.5	--
1975	2	15.7 ± 1.4	15.5 ± 0.5	13.3 ± 0.9
1976	2	14.7 ± 1.5	14.1 ± 0.5	14.2 ± 0.5
1977	2	15.9 ± 2.5	14.5 ± 0.5	14.0 ± 1.1
1973	3	--	13.8 ± 0.6	--
1974	3	15.1 ± 1.0	14.4 ± 1.2	--
1975	3	12.9 ± 2.2	12.0 ± 0.8	--
1976	3	14.0 ± 5.3	12.1 ± 0.5	--

Appendix Table B-2. Freshwater growth of wild juvenile winter steelhead as estimated from scales of one-salts collected by electrofishing in the lower river, 1977-78 through 1980-81 run years.

Smolt age, brood year	*N*	Increase (cm) in mean length ± 95% confidence interval			
		Nucleus-annulus 1	Annulus 1-annulus 2	Annulus 2-annulus 3	Plus-growth
Smolt age 2:					
1975	15	9.5 ± 0.7	6.2 ± 1.6	--	7.3 ± 2.1
1976	13	8.5 ± 0.8	6.2 ± 1.4	--	8.1 ± 2.1
1977	8	9.6 ± 0.9	6.3 ± 2.1	--	8.3 ± 3.3
Smolt age 3:					
1974	21	9.7 ± 0.4	5.4 ± 1.0	5.1 ± 1.4	7.3 ± 2.0
1975	8	8.5 ± 0.5	4.4 ± 1.2	5.5 ± 2.0	7.6 ± 3.2
1976	3	9.0 ± 1.2	--	--	--

Appendix Table B-3. Freshwater growth of wild juvenile winter steelhead as estimated from scales of two-salts collected by electrofishing in the lower river, 1977-78 through 1980-81 run years.

Smolt age, brood year	*N*	Increase in mean length (cm) ± 95% confidence interval			
		Nucleus-annulus 1	Annulus 1-annulus 2	Annulus 2-annulus 3	Plus-growth
Smolt age 2:					
1974	69	9.4 ± 0.3	5.3 ± 0.6	--	5.4 ± 0.8
1975	70	9.2 ± 0.3	6.3 ± 0.6	--	6.9 ± 1.0
1976	62	8.7 ± 0.2	5.4 ± 0.5	--	6.6 ± 0.8
1977	37	9.1 ± 0.4	5.5 ± 0.1	--	5.4 ± 0.2
Smolt age 3:					
1973	31	9.4 ± 0.5	4.4 ± 0.8	4.2 ± 1.0	4.0 ± 1.3
1974	15	9.1 ± 0.5	5.4 ± 1.3	4.4 ± 1.9	7.0 ± 2.3
1975	22	8.2 ± 0.5	3.9 ± 0.6	4.3 ± 0.8	6.0 ± 1.0
1976	19	8.5 ± 0.3	3.6 ± 0.2	3.6 ± 0.4	5.6 ± 0.5

Appendix Table B-4. Freshwater growth of wild juvenile winter steelhead as estimated from scales of first spawning migrants collected by electrofishing in the lower river, 1977-78 through 1980-81 run years.

Smolt age, brood year	*N*	Increase in mean length (cm) ± 95% confidence interval		
		Nucleus-annulus 1	Annulus 1-annulus 2	Plus-growth
Smolt age 1:				
1974	5	10.9 ± 1.2	--	9.8 ± 2.3
1975	25	10.9 ± 0.4	--	9.7 ± 0.7
1976	8	11.2 ± 1.1	--	10.0 ± 2.0
Smolt age 2:				
1975	22	9.0 ± 0.4	4.3 ± 0.8	6.9 ± 1.1
1976	52	8.8 ± 0.3	5.4 ± 0.7	8.4 ± 0.9
1977	23	8.4 ± 0.4	5.6 ± 1.2	8.2 ± 1.5

Appendix Table B-5. Age at ocean entry estimated from scales of wild winter steelhead collected by electrofishing in the lower river, 1977-78 through 1980-81 run years.

Life history, smolt age	Percentage within adult life history				
	1977-78	1978-79	1979-80	1980-81	Mean
One-salt:					
1	0	11.1	0	--	3.7
2	37.9	50.8	64.9	--	51.2
3	52.1	38.1	20.3	--	36.8
4	10.0	0	14.8	--	8.3
N	40	24	13	4	
Two-salt:					
1	2.7	3.5	2.5	3.5	3.1
2	64.5	80.3	70.9	63.2	69.7
3	30.0	16.2	26.6	33.3	26.6
4	1.9	0	0	0	0.5
N	94	88	86	58	
First spawning migrant:					
1	14.4	28.4	24.7	--	22.5
2	72.0	65.2	72.7	--	70.0
3	13.6	6.4	2.6	--	7.5
N	30	82	32	11	
All life histories:					
0	0	0	0.8	0	0.2
1	4.5	13.7	21.2	6.5	11.5
2	61.1	71.6	62.3	69.2	66.1
3	31.9	14.7	14.1	23.3	21.0
4	2.5	0	1.1	1.0	1.2
N	195	223	204	92	

Appendix Table B-6. Size of wild juvenile winter steelhead at the time of ocean entry as estimated from scales of three life history types of adults collected by electrofishing in the lower river, 1977-78 through 1980-81 run years.

Smolt age, brood year	Mean length (cm) ± 95% confidence interval		
	One-salt	Two-salt	First spawning migrant
Age 1:			
1975	--	--	20.7 ± 2.5
1976	--	--	20.6 ± 0.6
1977	--	--	21.2 ± 1.5
Age 2:			
1974	--	20.1 ± 0.7	20.2 ± 1.0
1975	23.1 ± 1.6	22.4 ± 0.9	22.5 ± 0.7
1976	22.7 ± 1.8	20.6 ± 0.7	22.2 ± 1.0
1977	24.2 ± 2.8	19.9 ± 0.7	--
Age 3:			
1973	--	21.9 ± 1.1	--
1974	27.5 ± 1.7	25.9 ± 1.8	--
1975	25.6 ± 2.9	22.3 ± 1.4	--
1976	--	21.3 ± 1.3	--

APPENDIX C

Relation between Gregorian Week and Week-of-Year.

Gregorian week	Week-of-year	Gregorian week	Week-of-year
1-7 January	1	2-8 July	27
8-14 January	2	9-15 July	28
15-21 January	3	16-22 July	29
22-28 January	4	23-29 July	30
29 January-4 February	5	30 July-5 August	31
5-11 February	6	6-12 August	32
12-18 February	7	13-19 August	33
19-25 February	8	20-26 August	34
26 February-4 March	9	27 August-2 September	35
5-11 March	10	3-9 September	36
12-18 March	11	10-16 September	37
19-25 March	12	17-23 September	38
		24-30 September	39
26 March-1 April	13		
2-8 April	14	1-7 October	40
9-15 April	15	8-14 October	41
16-22 April	16	15-21 October	42
23-29 April	17	22-28 October	43
30 April-6 May	18	29 October-4 November	44
7-13 May	19	5-11 November	45
14-20 May	20	12-18 November	46
21-27 May	21	19-25 November	47
28 May-3 June	22	26 November-2 December	48
4-10 June	23	3-9 December	49
11-17 June	24	10-16 December	50
18-24 June	25	17-23 December	51
25 June-1 July	26	24-31 December	52