ASSESSMENT OF THERMAL EFFECTS ON SALMON SPAWNING AND FRY EMERGENCE, UPPER McKENZIE RIVER, 1992

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ABSTRACT

From August 1992 to April 1993 we studied the biological characteristics of spring chinook salmon *Oncorhynchus tshawytscha* in the upper McKenzie River in relation to water temperature changes caused by the operations of Cougar and Blue River dams. Our observations of water temperature regimes in the river comported with the results of previous U.S. Army Corps of Engineers (COE) studies. Water discharged from the dams was cold enough to cool segments of the upper river during important times for upstream migration of adult fish. Discharges from the dams warmed the river flow during critical times for salmon spawning and egg incubation. Adult female salmon within the thermal influence of the federal dams appeared to sustain markedly increased prespawning mortality, although we do not know the mechanism that may have caused this mortality. Although 57% of the salmon redds in the McKenzie River in 1992 were deposited downstream of the federal projects, about 30% of the total redds in the river lay in the area most likely to be affected by thermal modifications. An aerial survey conducted in late September 1992 accounted for about half of the actual number of salmon redds deposited in the river above the South Fork. A few salmon fry began migrating down the McKenzie River in mid-November 1992, two months earlier than pre-dam studies indicated was a natural time for the earliest emergence and downstream movement. We associated the earliest migrators with accelerated emergence from spawning in the South Fork McKenzie River and in the portions of the mainstem most influenced by Cougar and Blue River dams. Based on studies conducted on the Rogue River, early emergence and migration of salmon fry likely diminishes the potential for these fry to survive. Because only the latest spawning in the stream areas affected by the federal projects produced fry that emerged with reasonably natural timing, selective pressures on survival may continue the trend of producing late-spawning adults. These selective survival pressures could eventually produce two populations of spring chinook in the McKenzie River that are temporally isolated by time of spawning.

INTRODUCTION

With the completion of the evaluation of fish passage facilities at Cougar Dam (Ingram and Korn 1969), the state and federal fish management agencies voiced concerns over the potential effects of temperature changes on fish migration and production in the McKenzie River. In 1981 the state and federal fishery management agencies advised the COE of biological observations indicating that operation of Cougar and Blue River dams had changed the water temperature regime in the upper McKenzie River (COE 1981). This project-caused change in temperature likely diminished the potential for production of spring chinook salmon. Ingram and Korn (1969) made observations suggesting cold water discharged from the Cougar project during the spring and summer substantially delayed migration of adult salmon into the South Fork of the McKenzie River. This observed discharge of cold water from Cougar and Blue River dams could inhibit migration of adult salmon as far downstream as Leaburg Dam. Zakel and Reed (1984) observed salmon fry migrating down the river months ahead of the expected times of fry emergence under natural temperature conditions. The fishery management agencies saw these gross biological observations as only indicators of extensive, but more subtle alteration of the aquatic environment in the upper McKenzie River. These temperature changes represented potentially serious problems. The fishery management agencies urged COE to study the problem and provide appropriate mitigation.

The COE received a congressional appropriation to study the temperature effects of Cougar and Blue River dams in 1983. COE completed studies verifying that operation of Cougar and Blue River dams had changed the thermal regime of important parts of the upper McKenzie River during several months each year (Morse et al. 1987).

In summary, COE's investigations determined (1) "From June through November the operation of Blue River and Cougar projects have a measurable effect on the temperature of the McKenzie River". Discharges from the federal projects reduced mean daily water temperatures from June through August, a transition of effects occurred during early September, and water temperatures warmed from late September through mid-October. (2) Temperature effects were most marked in the South Fork McKenzie River and in Blue River. Diminished effects occurred in the mainstem, because each of these tributaries contributed less than 20% of the flow volume to the mainstem. (3) Thermal modeling indicated temperature effects diminished with distance from the federal dams. Minor temperature effects of the COE projects (0.9° to 1.9°F) could be detected downstream as far as Leaburg Dam, 21 miles below the South Fork confluence.

The COE then began feasibility investigations designed to determine the need for and practicality of retrofitting Cougar and Blue River dams with temperature control devices. As part of this justification process, COE contracted with the Fish Research and Development Section of the Oregon Department of Fish and Wildlife (ODFW) in 1992 to conduct field studies designed to evaluate and document the effects of water temperature modifications on the spring chinook salmon of the upper McKenzie River.

We began field studies on 13 August 1992 and completed these investigations on 22 April 1993. We did not duplicate the COE temperature modeling study, but we documented the variability in water temperature regimes that occur in the upper mainstem McKenzie River and in selected major tributaries, placing special emphasis on the apparent thermal changes resulting from the operation of Cougar and Blue River dams. We conducted field studies to determine how these modified water temperatures affected the biology of juvenile and adult spring chinook salmon, including (1) effects on the timing, location and survival of naturally spawning adult salmon; (2) effects on the timing of salmon egg hatching and emergence of salmon fry; and (3) effects on timing of downstream migration of salmon fry.

STUDY AREA

The McKenzie River drains 1,342 square miles of the western slope of the Cascade Mountain range, flowing generally east to west throughout Oregon's south Willamette River Basin to meet with the Willamette River just north of the city of Eugene (Figure 1). The McKenzie River is approximately 90 miles long from the river origin at Clear Lake to the Willamette River confluence.

The confluences of Blue River and the South Fork McKenzie River with the mainstem lie at River Mile 57 and 60, respectively. Blue River Dam is 1.8 miles up Blue River, and Cougar Dam is 4.5 miles above the South Fork confluence.

Leaburg Dam obstructs the river and diverts flow into a power canal at River Mile 38.8. Our studies concentrated on investigating the mainstem McKenzie River and the major tributaries upstream from Leaburg Dam, the part of the subbasin that supports most of the remaining natural spawning of spring chinook salmon and also contains the stream areas most subject to the water temperature influences of Cougar and Blue River dams.

We divided the upper river into two major segments: the "upper study section," which included the mainstem McKenzie River and major tributaries between Trail Bridge Reservoir and the confluence of the South Fork, and the "lower study section," which included the mainstem downstream from the South Fork confluence to just below Leaburg Dam.

METHODS

Water Temperature Records

Together with COE and U.S. Geological Survey (USGS) personnel, we identified nine strategic locations within the upper McKenzie River subbasin

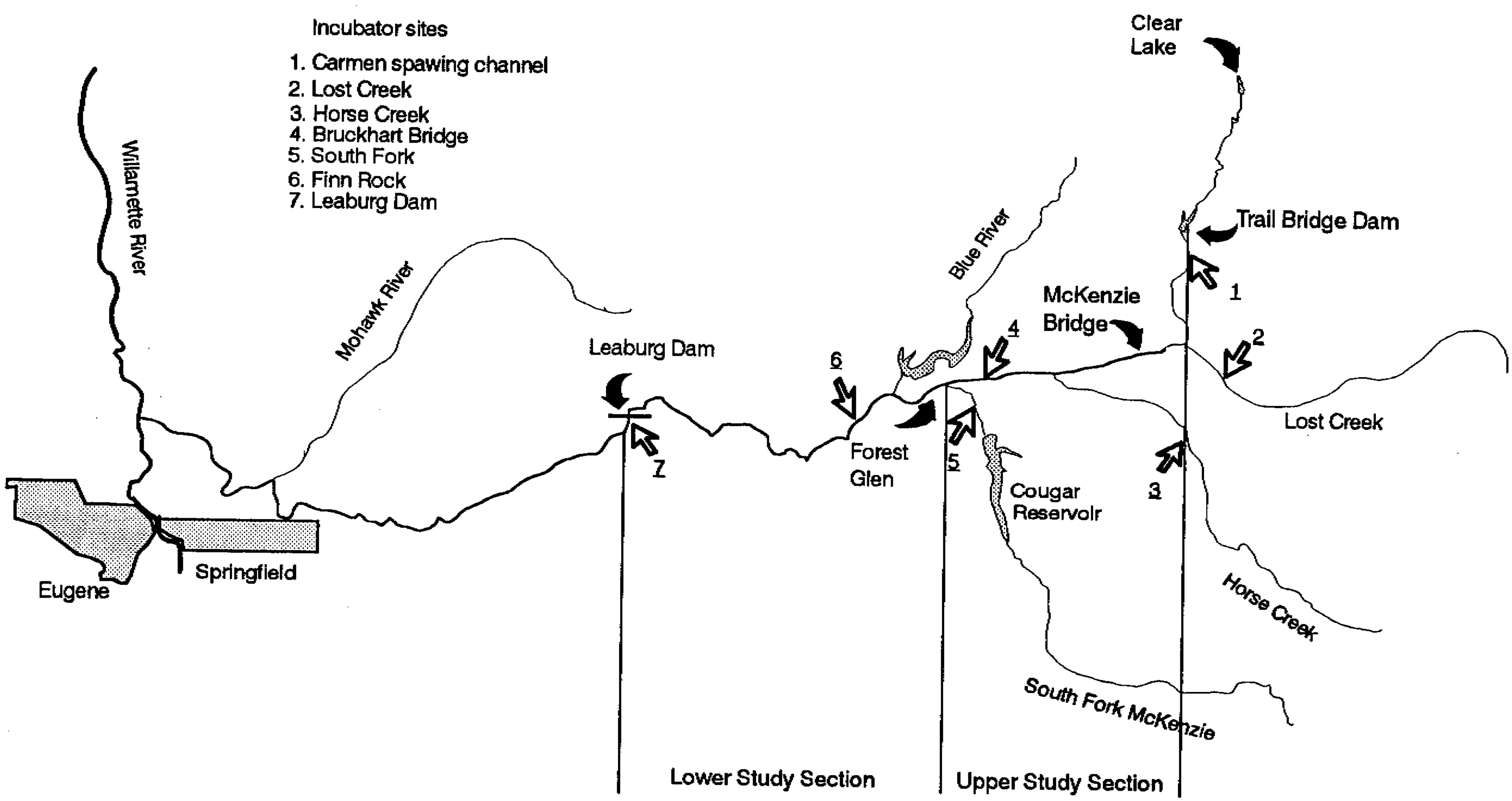

Figure 1. Diagram of McKenzie River illustrating key study locations.

to install temperature recording devices (Figure 1 and Appendix Table A-1). We chose these locations as the basis for making comparisons of temperature differences; some represent stream segments unaffected by COE reservoir operations and some are influenced by the waters discharged from Cougar Dam, Blue River Dam, or both. We also placed a temperature recorder immediately below Leaburg Dam as a point of reference for downstream temperature effects. The Leaburg Dam location is important because it is strategically situated below our primary area of study. The dam is equipped with a sophisticated fish trap that we used during the field study to monitor passage of downstream-migrating salmon fry.

The COE contracted separately with USGS to monitor, compile and publish the water temperature information at the nine locations listed in Appendix Table A-1. These data include daily, monthly and water year summaries of maximum, minimum and mean water temperatures at each location monitored. The USGS published the temperature data collected during water year 1993 in the standard surface water quality report for Water Year 1993 (USGS 1993). However, the records provided to us separately by USGS were described in tenths of a degree Celsius while the standard report rounds these figures to the nearest half degree. We have noted some minor differences between the temperature values in Appendix Table A-1 and the standard published report.

Since biologists typically define incubation temperature units in degrees Fahrenheit, we converted all temperatures in this report to the Fahrenheit scale.

Instream Sampling

We walked the stream or used drift boats to access the study areas to observe adult spawning and to seine for emergent salmon fry. In those stream areas that we could not conveniently or safely navigate by drift boat, we walked the streambanks or waded. In general, we walked the survey sites at Carmen-Smith Spawning Channel, Horse Creek, Lost Creek, and in the South Fork of the McKenzie River immediately downstream of Cougar Dam. The study site below Leaburg Dam was very localized, so we also walked and waded to this location.

We could not effectively conduct surveys by boat in the mainstem above Bruckhart Bridge. We used drift boats to access the lower segment of the South Fork and the mainstem from Bruckhart Bridge to Finn Rock.

Surveys for Adult Salmon

Surveys to locate adult salmon and spawning redds occurred on 26 days between 13 August 1992 and 15 October 1993. We attempted to survey each transect at least once each week during this interval. Typically, two or three people conducted each survey to more completely observe the stream area within each transect. We counted all adults and redds seen in each transect on each survey, thus recounting some of each on subsequent trips.

We picked up all the salmon carcasses we could find and recover, collected scales from each recovered carcass for later analysis of age composition, and removed the snouts from adipose-marked carcasses to recover coded-wire tags. We opened each female salmon carcass found and recorded the observed degree of spawning success: fully spawned, partially spawned, or unspawned (prespawning mortality). After examination, we returned each carcass to the stream, but we cut off the tail to prevent recovering the same carcass on later surveys.

We estimated peak spawning time by backcalculating from weekly carcass counts (ODFW 1990). Because salmon exhibit a postspawning longevity of 9 days (van der Berghe and Gross 1986) and we conducted our carcass surveys weekly, we assumed spawning in week X was reasonably demonstrated by summing half the number of carcasses collected in week X+1 and half the number of carcasses collected in week X+2.

Study personnel used a contracted helicopter to conduct an aerial survey of salmon spawning areas on 29 September 1992. We surveyed all mainstem areas downstream from Trail Bridge Dam plus portions of the major tributaries observable from the air, recorded the fish and redds observed, and documented the results.

Surveys for Emergent Fry

Salmon eggs incubate at rates directly related to water temperature (Alderdice and Velsen 1978; Lietritz and Lewis 1980). We used predictor calculations from Gordon et al. (1987) and Murray and McPhail (1988) to estimate that fry would emerge from spring chinook salmon eggs deposited in the upper McKenzie River after exposure to about 1,800 accumulated temperature units (ATUs). One temperature unit equals one degree Fahrenheit above freezing for 24 hours (Lietritz and Lewis 1980). USGS periodically sent us updated temperature records, and we converted these to ATU's for each temperature monitoring station. We began surveys for presence and abundance of salmon fry when, based on the time of first observed spawning at a specific location, the appropriate level of ATUs to cause fry emergence occurred at each study site.

Biologists sampled stream areas for emergent fry on 53 days beginning on 25 November 1992 and ending on 6 April 1993, surveying the same areas and using the same transportation methods employed on the adult surveys. Fine-mesh, relatively short (6-foot or 12-foot) seines or dip nets were used to sample the shallow, slow-moving stream areas and side channels typical of fry rearing habitats. As far as practical, we attempted to sample the same stream areas and side channels within each transect on each sampling trip. We recorded the number of fry collected on each sample attempt in each transect on each sampling day.

Eugene Water & Electric Board (EWEB) personnel agreed to let us have long-term use of the downstream-migrant fish trap at Leaburg Dam. We used this trap to monitor the timing and magnitude of fry migration out of the upper McKenzie River over time. This trap can recover all fish screened from a 2,300-cfs capacity diversion canal. Typically, this trap catches a substantial portion of the fish migrating down the river. We operated this trap over night at least once each week, river debris conditions permitting. We succeeded in catching fry in this trap on 39 occasions from 18 November 1992 to 19 April 1993. However, we noted in early December that substantial portions of the captured salmon fry were escaping from the trap sanctuary. In mid-December 1992 we modified the sanctuary portion of the trap to more efficiently retain the captured fry. As a result, records of the number of fry caught before 15 December are very conservative.

Controlled Tests of Fry Emergence

Because emergent fry have limited capacity to migrate upstream in fast-flowing water, we felt confident that emergent fry collected in any of the tributary streams or in Carmen-Smith Spawning Channel had originated within those water bodies. However, fry captured at any point in the mainstem McKenzie River may have hatched and emerged at any point upstream and migrated down to the point of capture. We attempted to more clearly relate time of emergence of salmon fry to temperature exposure at individual locations by using artificial egg incubators. This experimental technique entailed burying small incubators containing live salmon eggs from a known, common fertilization date at each of the sites identified by numerals 1-7 in Figure 1. In this way we were sure that only site-specific temperature effects controlled the emergence timing of the eggs in the incubators.

The incubators, built from a pattern provided by Washington Department of Fisheries personnel (Thomas Burns, April 1992, Habitat Management Division, Olympia, Washington, personal communication), consisted of 12-inch long cylinders of 4-inch diameter plastic pipe with major portions of the sides removed to leave only a rigid tubular framework. We lined the inside of the cylinders with 1/8-inch Vexar mesh and capped the tube ends.

On 28 September 1992, near the peak of salmon spawning, we obtained the freshly fertilized eggs from two female spring chinook salmon spawned at McKenzie Salmon Hatchery. We filled 28 incubator tubes with 2-inch-minus grade river rock along with 300 fertilized eggs, capped both ends of the tubes securely to retain the eggs and gravel, and transported the incubators in water to the study locations. On the date of fertilization, while the eggs were still in the green (non-sensitive) stage of development, we buried four incubators in the streambed at each of the seven "incubator site" locations illustrated in Figure 1. We buried the incubators in gravel below briskly flowing, well oxygenated portions of the streambed. We anchored the individual incubators securely into the substrate with nylon cords attached to steel stakes driven into the gravel. Small floats attached to each securing stake aided future identification and recovery.

We progressively revisited and exposed one incubator at each of the test sites based on accumulated temperature exposure from 28 September: at 1,600 ATU, 1,700 ATU, 1,800 ATU, and after 1,900 ATU. At retrieval, we recorded the presence or absence of apparently emerged fry using complete closure of the yolk sac on the belly of the fry as a practical indicator of fry emergence capability.

We could not recover or observe all of these artificial incubators at all sites tested. Recreationists disturbed some, freshets washed some away, and the eggs buried at the Leaburg Dam location were all fungused and dead when first checked. We miscalculated the thermal exposure record for the incubators buried at the Finn Rock site, so all surviving eggs at Finn Rock were hatched and emerged when first exposed on 4 March 1993. As a result of these difficulties, we gained only limited information from our artificial incubator tests.

RESULTS AND DISCUSSION

Environmental Conditions During the Study

River flows in the McKenzie River during our study were generally low, and warmer than average water temperatures persisted during the fall of 1992.

From August 1992 through March 1993, mean monthly streamflow volumes in the mainstem above Leaburg Dam ran lower than average (USGS 1992 and 1993). During this same time, the indexes of mean monthly air temperatures for the North Cascades geographic area remained near average (NOAA 1993), although cold weather in January and February 1993 drove the mean monthly air temperatures to more than 4°F below the long-term average.

From June through September 1992, mean daily water temperatures at Finn Rock and Leaburg Dam frequently exceeded the combined 1969-1984 mean water temperatures at Vida recorded by Morse et al. (1987). Vida is located approximately half way between Finn Rock and Leaburg Dam, but USGS did not monitor temperatures at Vida in 1992-1993.

We concluded that adult salmon in the mainstem McKenzie River migrated and spawned in relatively low, warm water conditions in the summer and fall of 1992. The spawn from these adults initially incubated in warmer-than-average water temperatures. Those eggs that incubated through January and February produced fry that had experienced average to colder-than-average water temperatures during incubation.

Water Temperatures

During the critical stages of salmon spawning and egg incubation from September through December 1992, both Cougar Dam and Blue River Dam discharged water that was warmer than the water flowing out of the upper mainstem McKenzie River (Figure 2). Operation of the federal dams contributes to this observed warming. Morse (et al. 1987) illustrated that at times in the fall the water discharged from Cougar Dam will be 5.8°F warmer than if the project did not exist, and at times Blue River Dam discharged water 10.8°F warmer than the reservoir inflow.

All streams in the upper study section ran colder than the South Fork during the critical period of salmon spawning and egg incubation from 1 September through November (Figure 3). However, Lost Creek, which is primarily spring fed, maintained remarkably stable mean daily temperatures throughout the fall and winter. Temperatures in Lost Creek were the warmest measured among all monitoring sites after early December.

Morse (et al. 1987) determined that under average conditions of air temperature and streamflows, discharges from the COE projects had the effect of raising mainstem temperatures September through October. Although our study did not perform comparable temperature modeling, we saw the potential for warming effects through mid-November (Figure 4). The overall warming

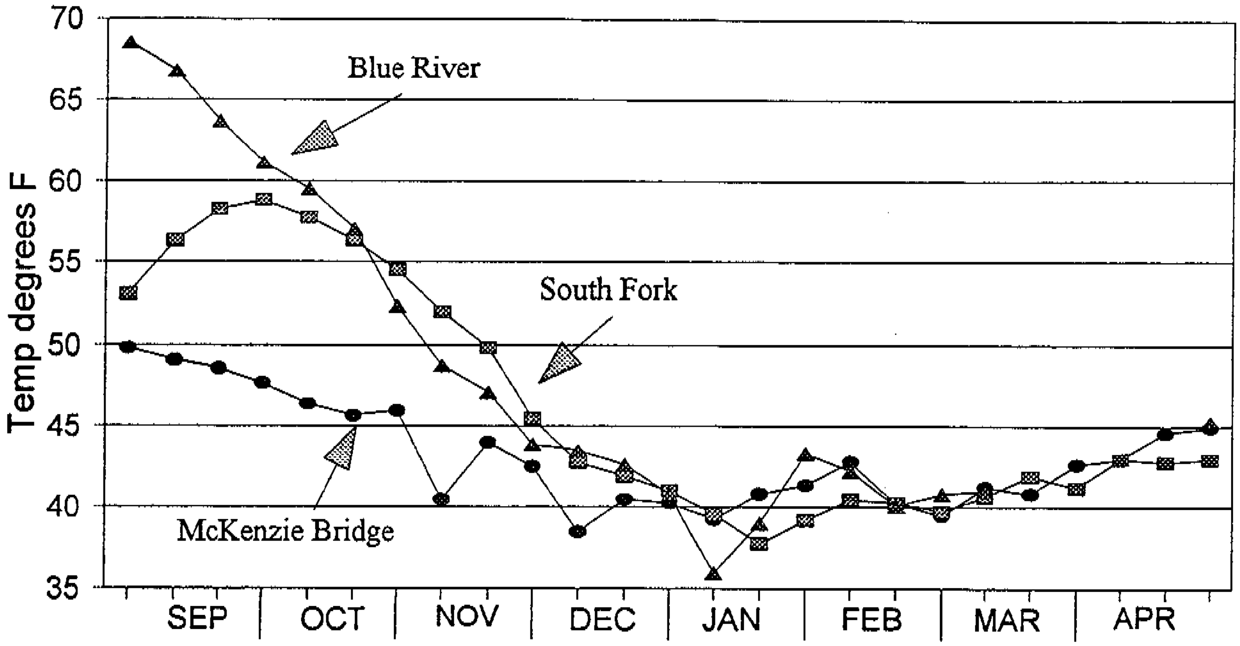

Figure 2. Progression pattern of mean daily water temperatures in the lower South Fork McKenzie River, in Blue River, and at McKenzie Bridge, 1 September 1992-30 April 1993.

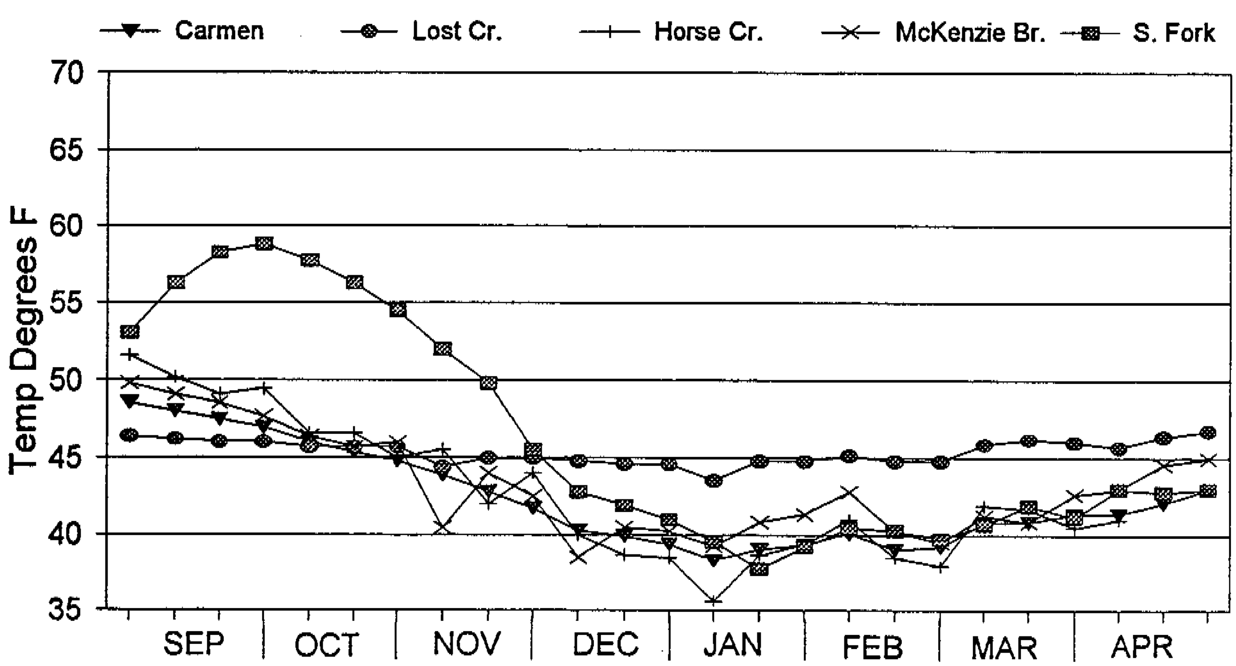

Figure 3. Progression pattern of mean daily water temperatures in the South Fork McKenzie River and at four locations in the upper study section, 1 September 1992-30 April 1993.

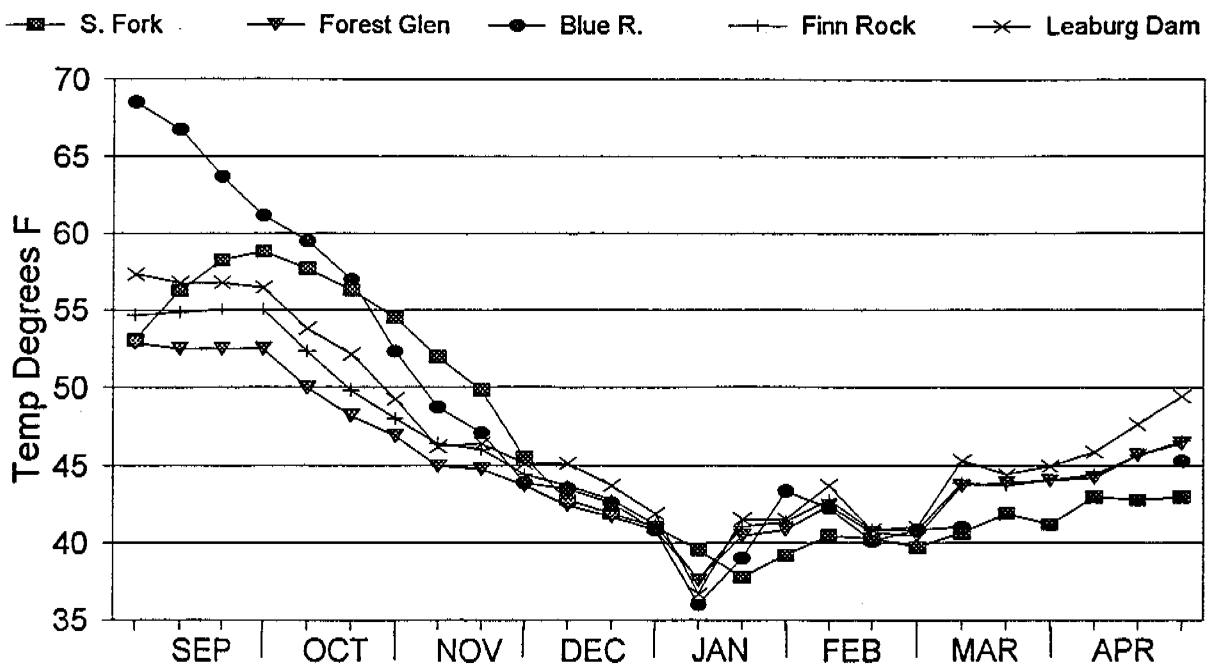

Figure 4. Progression pattern of mean daily water temperatures in the South Fork McKenzie River, in Blue River, and at three mainstem locations in the lower study section, 1 September 1992-30 April 1993.

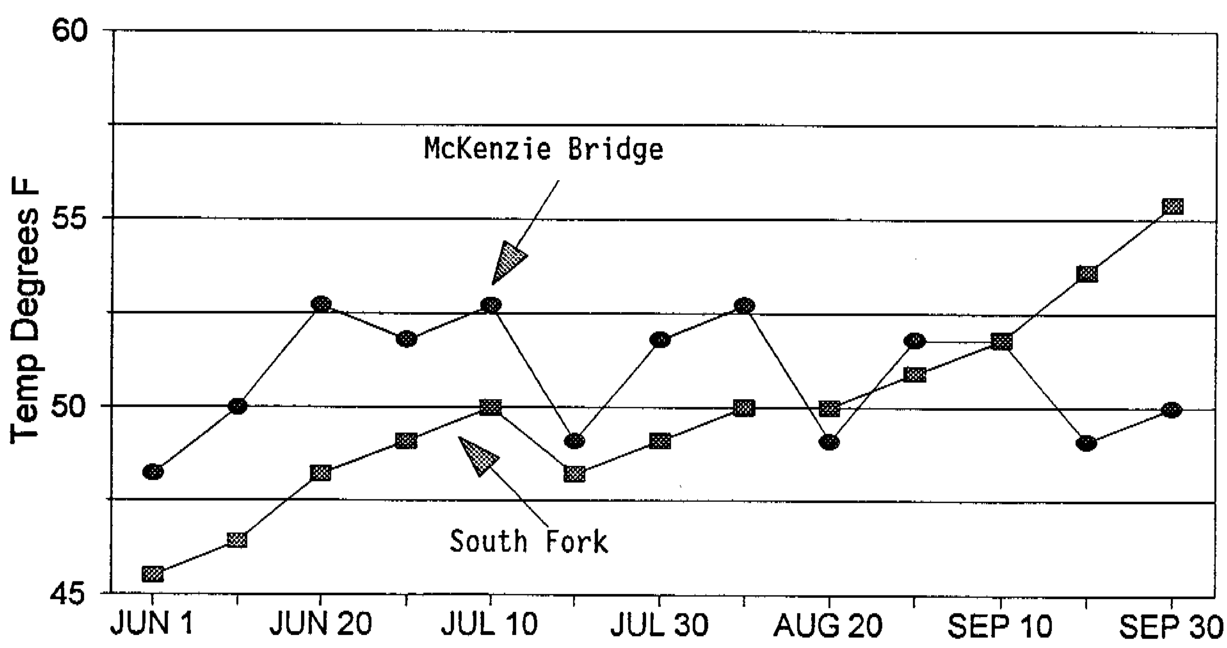

Figure 5. Progression pattern of maximum daily water temperatures in the lower South Fork McKenzie River and at McKenzie Bridge, 1 June-30 September 1992.

effects resulting from operation of the COE projects may intensify during conditions of low flow, such occurred in 1992.

Temperature records collected June through September 1992, during the primary time for upstream migration of adult salmon, indicated water discharged from the South Fork was somewhat colder than contemporary upper mainstem flows through mid-August (Figure 5). Discharges from Cougar Dam warmed rapidly after 10 September 1992, and by the end of September water in the South Fork was substantially warmer than the mainstem temperatures in the upper study section.

In general, we saw that the COE projects discharged water colder than natural mainstem flows in the late spring and early summer through mid-August. We then observed a "crossing over" period of approximately comparable temperatures occurring from mid-August through 10 September. From about mid-September through November, discharges from Cougar and Blue River dams were warmer than water flowing out of the upper study section, and this temperature difference was most marked from late September through mid-November.

Biological Effects

Adult Salmon

Ziller (et al. 1993) estimated that approximately 8,900 spring chinook salmon returned to the McKenzie River in 1992. About 1,200 were caught by anglers, 477 spawned naturally in mainstem areas below Leaburg Dam, 3,407 entered McKenzie Salmon Hatchery, and 3,816 passed over Leaburg Dam to enter the upper river. The estimated total McKenzie River entry of 8,900 spring chinook salmon in 1992 was slightly greater than the previous 10-year (1982-1991) mean of 7,835 fish, but smaller than the previous five-year (1987-1991) mean of 10,864 fish. Some of the largest returns to the river since inventory began in 1970 occurred from 1988 through 1991, when each year's return exceeded 10,000 fish.

Spring chinook salmon passed Leaburg Dam from 26 April to 5 October in 1992. Peak daily count at the fishway occurred on 25 May when the maximum daily water temperature at Leaburg Dam, after a short period of rising temperature trend, reached 59°F. The timing pattern observed in 1992 represents relatively early and efficient passage timing of spring chinook salmon at Leaburg Dam (T.W. Downey, Eugene Water and Electric Board Staff Ecologist, May 1995, personal communication), because in some years, peak daily passage of spring chinook salmon at Leaburg Dam occurs in July.

Temperature Effects on Migration of Adults: Adult Willamette River spring chinook salmon can obviously migrate in cold water temperatures, but biologists have observed these fish begin fast and effective mass migration at water temperatures of about 53°F (Collins 1980). Peak annual passage over Willamette Falls frequently occurs when water temperatures reach 53°F and the water temperature trend is rising. Temperature may influence peak passage timing at Willamette Falls more than river flow (Bennett 1990).

Ingram and Korn (1969) ascribed delays in migration of adult salmon into the South Fork to "water quality" problems, but they enticed adult fish to enter the South Fork earlier when they experimentally spilled warm surface water from Cougar Reservoir. Discharges of cold water from Blue River Dam also appeared to delay movement of adult chinook salmon into lower Blue River (Downey and Smith 1990). Morse (et al. 1987) calculated maximum cooling effects of Blue River in July to be 21.6°F. However, Blue River typically discharges relatively little flow in July.

Apparently, naturally occurring water temperatures in the upper McKenzie River are always marginally colder than adult spring chinook salmon prefer for most efficient migration. The maximum daily water temperature in the South Fork below Cougar Dam did not exceed 50°F until late August in 1992. Water temperatures at McKenzie Bridge, unaffected by operation of the COE projects, exceeded 50°F in early June, but 53°F was never exceeded at this site in 1992 (Figure 5). Even colder water flowing from the Cougar Dam during May through August may serve to discourage adults from entering the South Fork until late August or September, as Ingram and Korn (1969) described.

Timing of Adult Spawning: We first saw salmon redds in Horse Creek and Lost Creek on the last day of August. Onset of salmon spawning occurred as late as 23 September in our downstream-most (Leaburg Dam) survey location (Table 1).

Among our study transects, all peak dates of spawning occurred during the 17-day period from 22 September to 8 October (Table 1). We combined all the 1992 carcass recovery data to calculate that spring chinook salmon in the river from Leaburg Dam upstream spawn from very late August to mid-October, with a peak week of spawning centered around 23 September and a median spawning week (the week when half the spawning completed) occurring during the week with a midpoint of 16 September (Figure 6).

The time of adult salmon spawning observed in the McKenzie River in 1992 appears to vary considerably from historic spawning patterns. From 1902-1907, hatchery operations on the McKenzie River began egg takes in early-to-mid August, and peak egg collections generally occurred during the second week of

Table 1. Date of first observed spawning, first calculated date of fry emergence, and peak spawning date at eight McKenzie River locations, 1992-93.

Location	First redd observation	Date of first 1800 ATU	Peak redd count
Carmen Smith	8 Sep 1992	4 Mar 1993	29 Sep 1992
Lost Creek	31 Aug 1992	13 Jan 1993	1 Oct 1992
Horse Creek	31 Aug 1992	1 Feb 1993	29 Sep 1992
McKenzie Bridge	11 Sep 1992	16 Feb 1993	8 Oct 1992
South Fork	8 Sep 1992	21 Nov 1992	22 Sep 1992
Forest Glen	16 Sep 1992	30 Jan 1993	6 Oct 1992
Finn Rock	10 Sep 1992	27 Dec 1992	30 Sep 1992
Leaburg Dam	23 Sep 1992	26 Jan 1993	1 Oct 1992

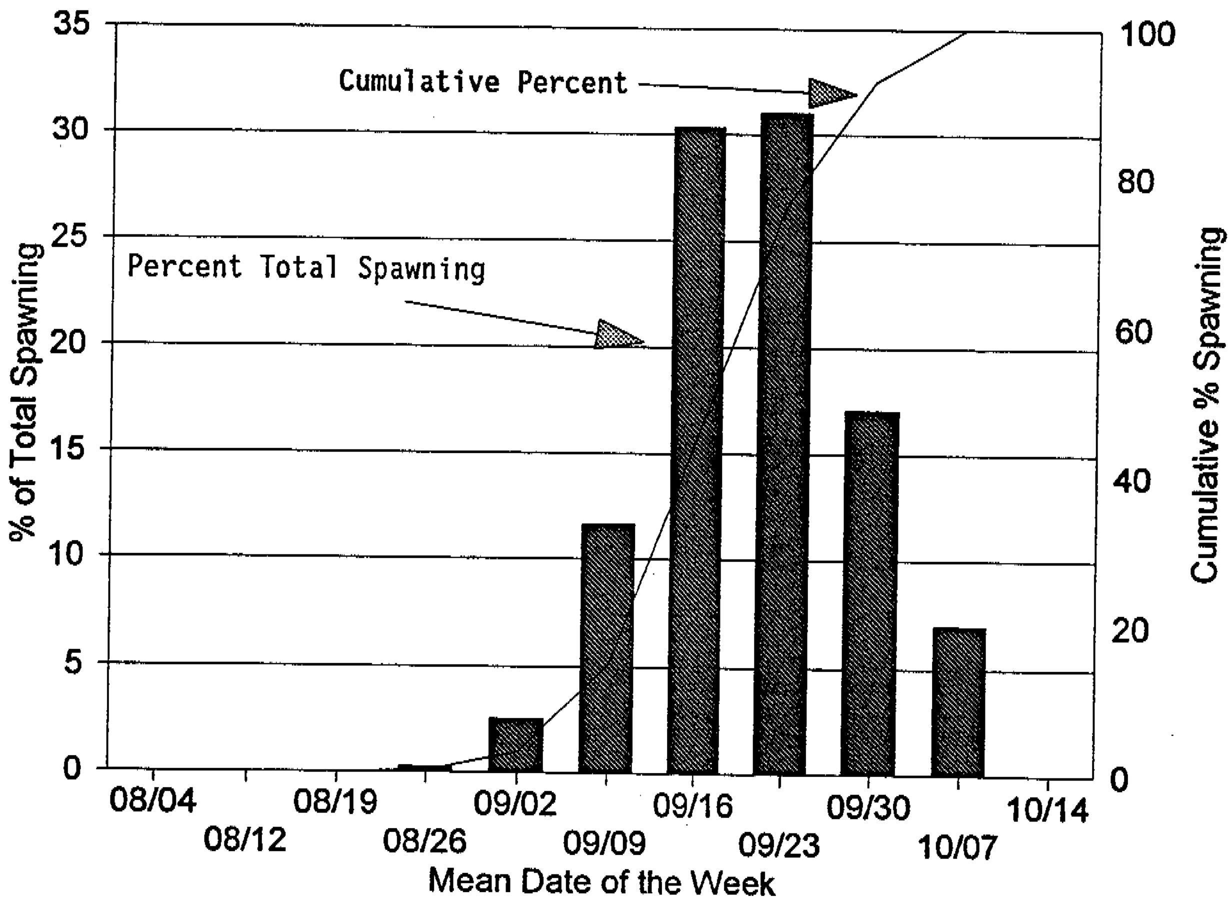

Figure 6. Timing of spring chinook salmon spawning by week in the McKenzie River in 1992.

September (Howell et al. 1988). Spawning inception and peak spawning are now delayed by 2-3 weeks. We do not know the implications of this shift in spawning time, but long-term exposure of the McKenzie stock of spring chinook to hatchery operations (Wallis 1961) and changing environmental conditions may have contributed to the observed changes.

Location of Adult Spawning: The 29 September 1992 aerial survey for spawning redds illustrated that the river above Leaburg Dam continues to support the majority of naturally spawning spring chinook salmon in the McKenzie subbasin. In most recent years, this annual index flight has indicated two-thirds of the total spring chinook salmon redds occur upstream of Leaburg Dam. This is likely a conservative representation because riparian vegetation covers much of the available spawning habitat in the headwater areas, obstructing view from the air (T.W. Downey, EWEB Staff Ecologist, May 1995, personal communication).

During the single-pass helicopter flight in 1992, observers recorded 106 redds in the entire 38 miles of river below Leaburg Dam, 136 redds in the lower study section including the South Fork, and 96 redds in those portions of the mainstem and major tributaries above Blue River that we could see from the air. As we anticipated, our estimate of total redds in the upper survey section, based on foot and boat survey methods, was higher (191) than the aerial count (96) for the same section. In our analysis, we used the larger value because our foot and boat surveys covered the available spawning area more comprehensively. The aerial survey accounted for only about half of the actual number of redds occurring in the upper study section.

Based on our revised redd distribution picture, three-quarters of the salmon redds in the river were deposited upstream of Leaburg Dam in 1992. We counted over 30% of the river's total salmon redds in the South Fork and in the lower study section, the stream reaches most likely to be substantially affected by the thermal discharges from the COE projects. Although a total of 242 redds (57%) were counted downstream of Cougar Dam, the COE temperature model (Morse et al. 1987) indicated that only minor levels of temperature modification could be detected as far downstream as Leaburg Dam.

Temperature Effects on Adult Survival: We found a possible correlation between warm water discharged from Cougar and Blue River dams in late August and September and the prespawning survival of female salmon. During our spawning surveys, we recovered the carcasses of 169 female chinook. We found only 5% of the females in all stream areas surveyed upstream of the South Fork confluence died before spawning. However, 20% or more of the dead females found in the lower South Fork or in the lower study section had died before spawning (Table 2). These results suggest a possible thermal influence on the

Table 2. Analysis of spring chinook spawning success in the McKenzie River, 1992.

Location	Total Female Carcasses Recovered	Total Number Unspawned	Percent Unspawned
Above South Fork	82	4	5%
South Fork	26	6	23%
Below South Fork	61	12	20%

Table 3. Calculated time difference to achieve 1,800 ATU's (thermal requirement for emergence of spring chinook salmon fry) at several upper McKenzie River locations in 1992, assuming four selected dates of spawning. The difference is compared to the estimated emergence timing for eggs deposited in the lower South Fork of the McKenzie River.

Spawning Location	Difference in Days Required to Reach 1,800 ATU's			
	Spawning Date 09/01/92	Spawning Date 09/15/92	Spawning Date 09/28/92	Spawning Date 10/15/92
Carmen-Smith	+98	+106	+84	+55
Lost Creek	+63	+57	+35	-8
Horse Creek	+91	+99	+84	+74
McKenzie Bridge	+84	+85	+70	+35
South Fork	-0-	-0-	-0-	-0-
Main Stem at Finn Rock	+28	+36	+28	+14
Main Stem at Leaburg Dam	+21	+30	+28	+7

prespawning survival of adult female salmon, which may be a serious and previously unacknowledged effect of the federal projects.

Egg Incubation and Emergence of Fry

Direct Mortality Effects: Blue River Dam discharged very warm water in September (Figure 2). Chinook salmon eggs sustain 50% mortality when incubated in water temperatures of 61°F or warmer (Beacham and Murray 1990; Gordon et al. 1987). Salmon eggs deposited in lower Blue River before about 1 October were subjected to average water temperatures ranging from 61.2°F to 68.5°F. These eggs would most likely exhibit very poor hatching success. Although we did not survey lower Blue River for spawners in 1992, this stream segment lacks spawning gravel, and few salmon spawned in this stream in recent years (Downey and Smith 1990). However, discharges of warm water from Blue River in September potentially diminishes the success of incubation in the area of mainstem immediately below the Blue River confluence.

Calculated Fry Emergence Timing: Our analysis of the temperature information provided by USGS (Appendix Table A-1) suggested salmon eggs deposited in the South Fork McKenzie River, as influenced by the warm water discharges from Cougar Dam, would not necessarily die, but they would likely incubate and hatch very quickly. The calculated time of emergence, or attainment of 1,800 ATUs, for salmon eggs deposited in the South Fork on 28 September 1992 would occur approximately three months earlier than for comparable eggs deposited simultaneously in Carmen-Smith Spawning Channel or in Horse Creek (Figure 7). Although this difference in required incubation times is less marked for sites in the lower study section, our calculations predicted early emergence would also occur in mainstem areas closest to the federal projects.

Because the discharges from the COE reservoirs cool over time within the spawning season (Figure 2), we extended this prediction of emergence timing to account for three additional assumed spawning times (Table 3). These calculations indicated that emergence times are most comparable among the study sites only for the latest-spawned eggs. However, we have seen that only a very small proportion of the adult fish spawn as late as mid-October (Figure 5).

If selection favors late-emerging fry, the analysis in Table 3 has serious implications for the long-term survival of naturally spawning McKenzie stock spring chinook salmon. Selection for survival of late-spawned fry would likely be manifested over time in a shift toward late-spawning adult salmon. Howell (et al. 1988) documented that shifts have already occurred

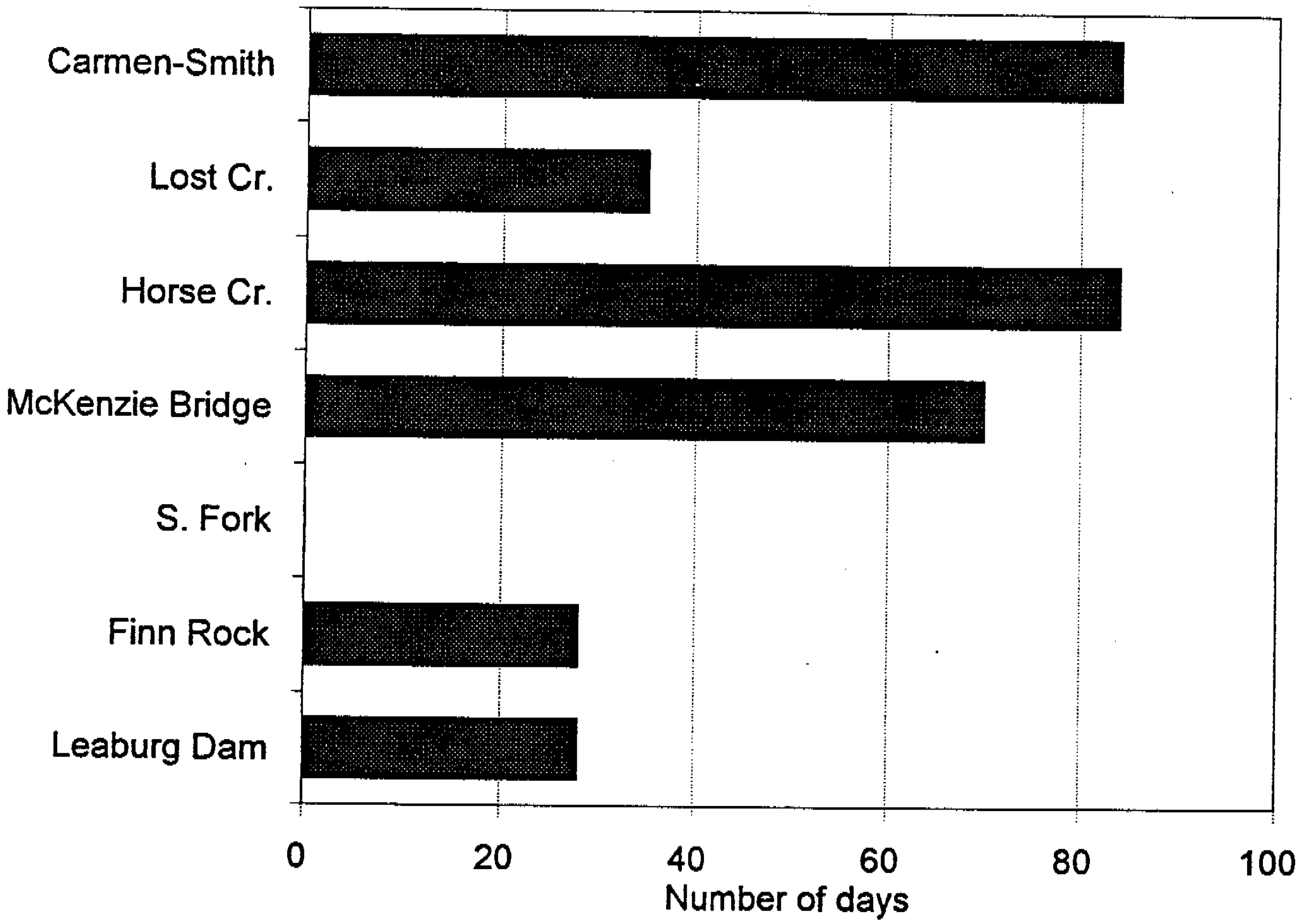

Figure 7. Calculated additional days of incubation required to achieve fry emergence at six McKenzie River locations compared to the South Fork. This comparison assumes 1,800 ATU's thermal exposure requirement for fry emergence and a common spawning date of 28 September 1992.

toward later spawning onset and spawning peak in McKenzie River hatchery operations.

Observed Fry Emergence Timing: Our calculations indicated salmon fry would emerge first in the South Fork McKenzie River and then immediately downstream in the mainstem. Field sampling generally verified this prediction. We began catching salmon fry in the lower South Fork in early December 1992 (Figure 8), and we first caught fry in the mainstem below the South Fork in late December 1992. In comparison, we caught our first emergent fry in Carmen-Smith Spawning Channel in mid-March, in Lost Creek and Horse Creek in early February, and in the mainstem above the South Fork confluence in late January. We likely did not detect the first fry emerging from any location, but our field sampling gave an indication of the relative timing of emergence by date of first fry capture.

We also verified the very early emergence of chinook salmon fry in the lower South Fork through the use of the experimental incubators. Eggs in these incubators, all fertilized and deployed on 28 September 1992, required only 79 days to observed emergence in the lower South Fork. Eggs buried at the same time in spring-fed Lost Creek, with a remarkably stable temperature regime throughout the winter, required more than 140 days to observed emergence (Figure 9). Eggs in Horse Creek and in Carmen-Smith Spawning Channel required more than 180 days after 28 September to yield emergent fry, more than three months after the observed fry emergence date in the South Fork.

We observed that spring chinook salmon fry lost their yolk sacs ("buttoned up") in the artificial incubators after approximately 1,800 ATUs. This verified our predicted 1,800-ATU thermal requirement to achieve emergence of fry in the upper McKenzie River.

Observed Timing of Fry Migration: Clearly, some salmon fry now migrate downstream in the McKenzie River very early. We caught one spring chinook fry in the Leaburg Dam trap on 18 November 1992, and we caught 30 fry during the first two days of December, although we know the trap ran inefficiently until we modified it in mid-December. A pattern of protracted fry migration followed, extending through April 1993 (Figure 10) and beyond. We would expect to see such a prolonged pattern of migration if early-emerging fry from areas subjected to higher water temperatures were later followed by fry migrating from stream areas with natural temperatures.

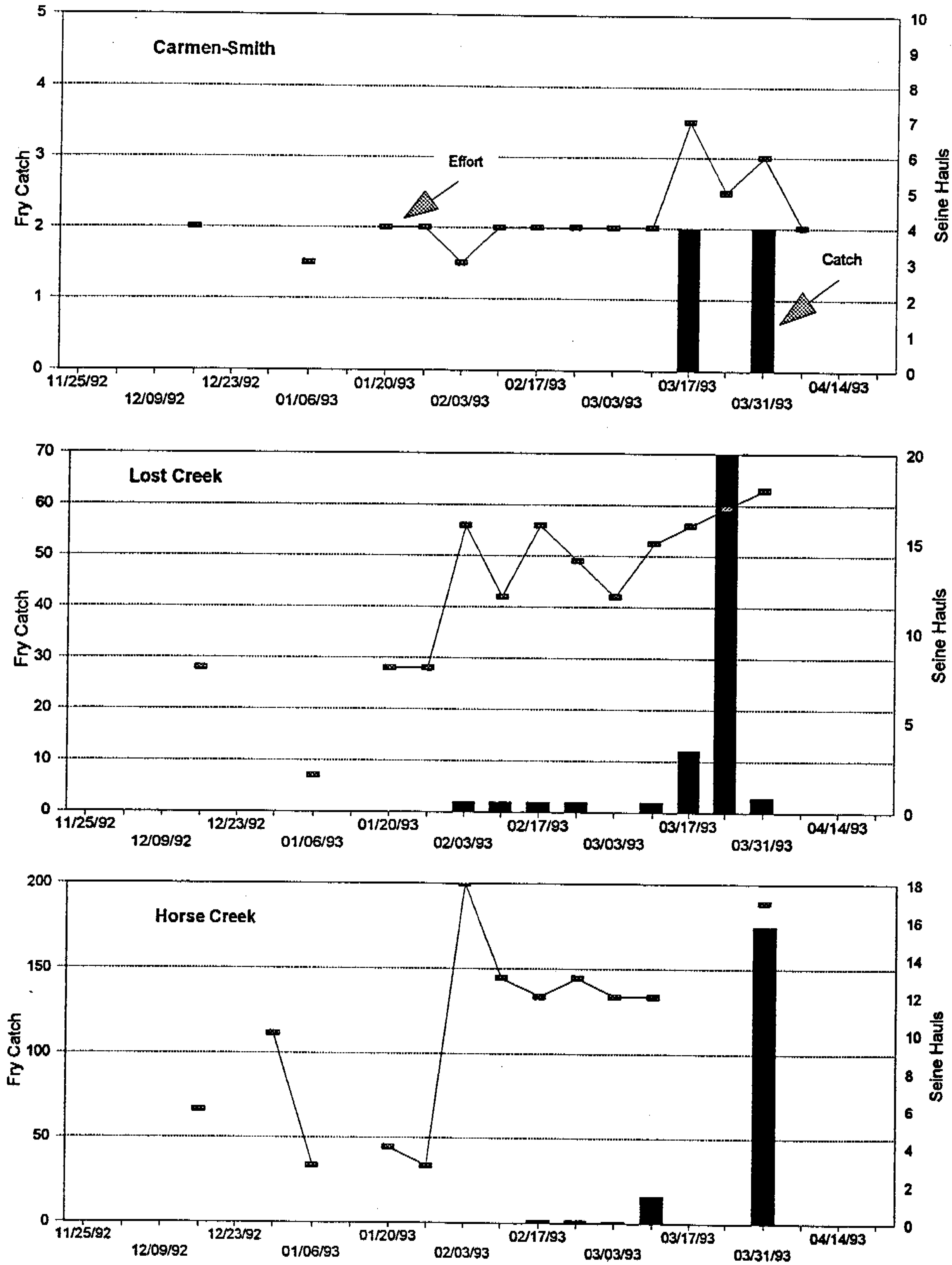

Figure 8. Results of seining for salmon fry in the McKenzie River, 1992-1993. Note variable Y Axes.

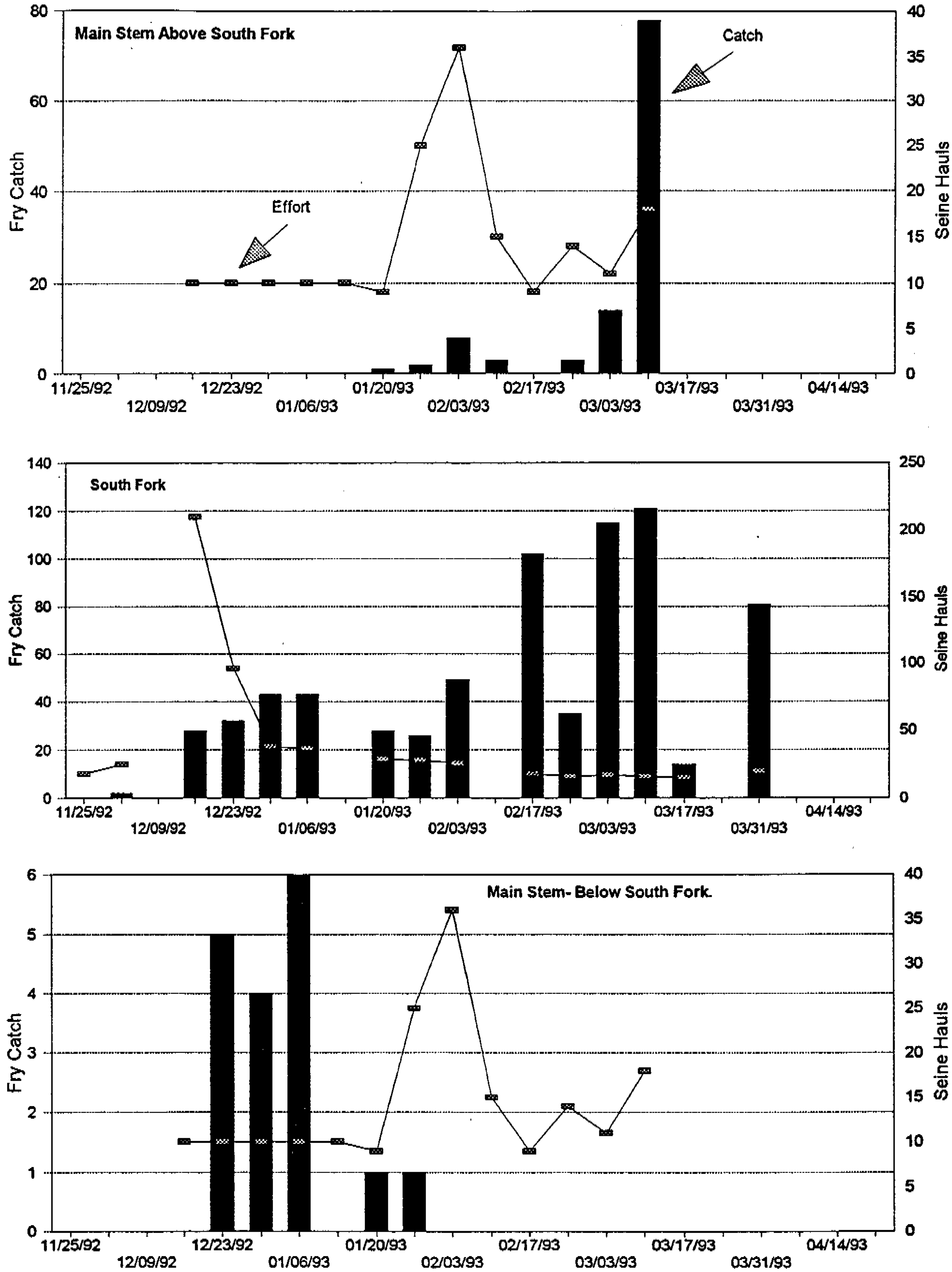

Figure 8 Concluded. Results of seining for salmon fry in the McKenzie River, 1992-1993. Note variable Y axes.

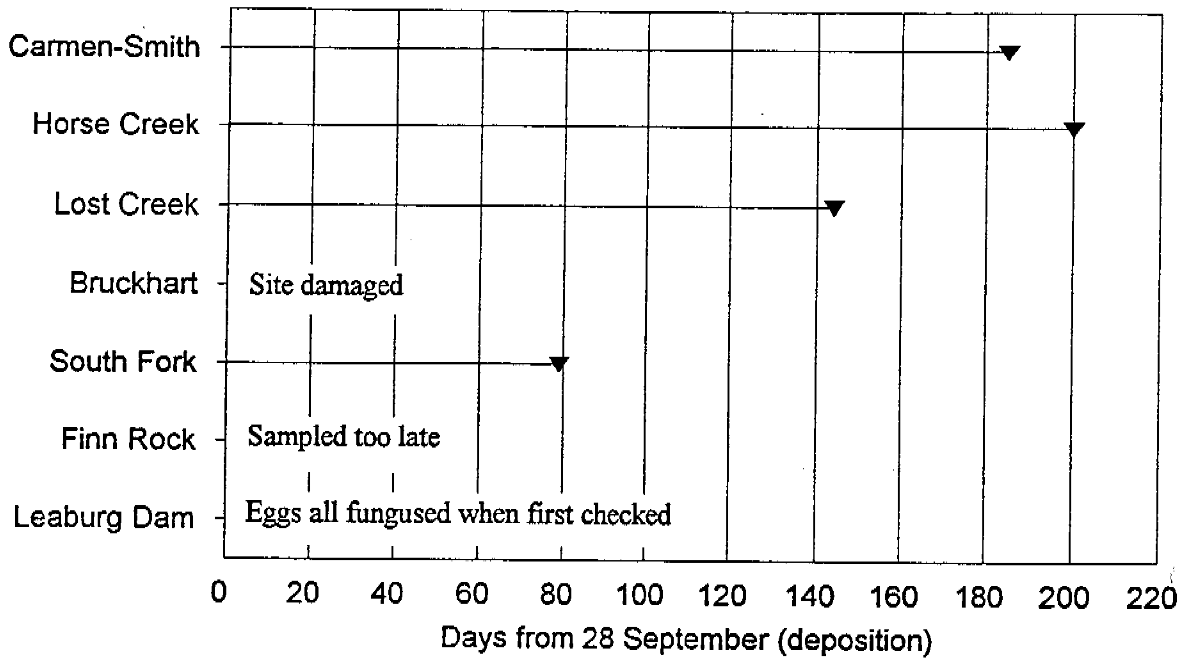

Figure 9. Observed time required for fry emergence from salmon eggs deposited in artificial incubators at seven study sites in the upper McKenzie River on 28 September 1992.

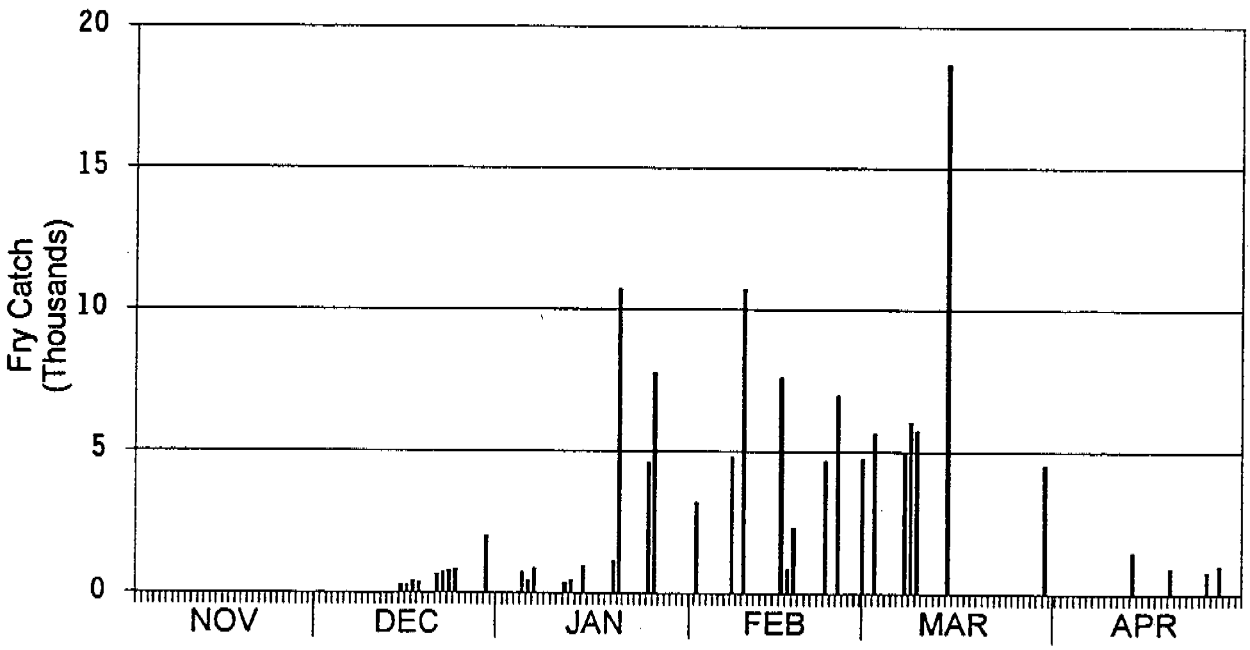

Figure 10. Pattern of downstream migration of spring chinook salmon fry past Leaburg Dam, 1 November 1992-30 April 1993.

By calculating ATUs beginning with the first observed dates of spawning by location (Table 1), we determined that the earliest-migrating fry, those appearing in the Leaburg trap before mid-January, likely originated from the earliest spawners in the South Fork and mainstem areas immediately below the confluences of Blue River and the South Fork. Based on our observations of first spawning dates by location, stream areas with unaltered temperature regimes would not produce migrant fry until mid-January, and these would likely originate in the stable water temperatures of Lost Creek.

Historical Timing of Fry Migration: Studies conducted on the McKenzie River before the construction of the COE projects indicated that salmon fry first appeared in Leaburg canal in January (OSGC 1948). Before Cougar Dam was built, salmon fry began migrating in the South Fork McKenzie River in March (USBCF 1960). In the early 1960s, Hagey (1968) captured the earliest salmon fry moving out of the Carmen-Smith Spawning Channel in March, but peak movement occurred in May. The fry migration timing in Carmen-Smith Spawning Channel probably represents natural condition for fry migration under the cold temperature regimes of headwater areas in the McKenzie subbasin.

Mortality Effects of Early Emergence: Early hatching, emergence and migration of salmon fry likely limits their ultimate survival. ODFW researchers conducted detailed studies on the Rogue River in Oregon that correlated early emergence of spring chinook salmon fry to diminished potential for survival (Cramer et al. 1985). The operation of Lost Creek Dam warmed the water of the upper Rogue River during January, advancing chinook salmon fry emergence by one month. The abundance of salmon fry in the upper Rogue River statistically correlated to two factors--the number of adult spawners and the environmental conditions that existed while the eggs were still in the gravel. Cramer et al. (1985) concluded: "We believe that increased water temperatures during January were negatively correlated to fry production, because higher water temperatures caused fry to emerge from the gravel early when environmental conditions were poor for their survival."

Cramer et al. (1985) also referenced a study linking fry mortality to delay in ingestion of first food. Salmon fry would likely have difficulty finding food if they emerged prematurely into a cold, turbid, winter runoff environment.

Future generations of adult spring chinook returning to the South Fork and other stream areas affected by warm discharges from the COE projects may be the products of selective environmental pressures that promote late spawning. Only the latest-spawning adults produce fry that emerge at a time conducive to fry survival. Because other McKenzie River salmon also spawn in stream areas unaffected by the warm discharges of the federal projects, different selective pressures could, over time, lead to the development of two populations of spring chinook River temporally isolated by time of spawning.

SUMMARY

Temperature records collected in 1992-1993 generally reflected the results of previous COE temperature modeling studies (Morse et al. 1987) which showed that discharges from Cougar and Blue River dams cool important parts of the upper McKenzie River in June, July and early August. Conversely, the federal projects act to warm Blue River, the lower South Fork and parts of the mainstem from early September through October. Warm water influences persisted for up to four months in 1992 during critical periods for salmon spawning and egg incubation, but we observed the greatest warming effects of the federal projects in September and October.

Atypically low flows occurred in the McKenzie River during our study. Water temperatures from August 1992 through year's end were warmer than average, but colder-than-average air and water temperatures prevailed in January and February 1993.

Water discharged from Blue River Reservoir in September was warm enough to cause high levels of mortality to salmon eggs deposited in this stream. However, because Blue River lacks spawning gravel, the greatest effect of this warm water on salmon likely occurs in the mainstem McKenzie River immediately downstream of Blue River.

In 1992 peak daily water temperatures at McKenzie Bridge did not exceed 53°F June through September. Water temperatures optimum for fast and efficient migration of adult spring chinook salmon may rarely occur in the upper McKenzie River. Cougar Dam discharged water 2.5°F to 4.5°F colder than mainstem temperatures in the upper study section during June and July, which are the primary months of adult chinook migration. Results of previous studies suggested these discharges of cold water slowed or stopped migration of adult salmon into the South Fork until August or September.

Our carcass surveys showed at least 20% of adult female salmon in the South Fork and in the lower study section had died before they spawned. Comparatively, we saw only 5% prespawning mortality in the upper study section and major tributaries. These observations suggest existence of a dam-associated thermal influence on survival of maturing females in the McKenzie River. Because we do not fully understand why this occurred, the serious implications of these results justify verification by additional study.

Adult salmon first began spawning in headwater tributaries on the last day of August in 1992. We did not observe salmon spawning below Leaburg Dam until 23 September. Salmon spawned in the river from the last day of August to mid-October, with the peak of spawning occurring during the week centered around 23 September 1992. Compared to egg-take records from the McKenzie River hatchery from 1902-1907, onset of spawning and peak spawning now occur two to three weeks later.

Our detailed surveys of spawning grounds in the upper study section indicated that the annual aerial survey located only half of the actual number of salmon redds. Management Biologists may find this factor useful in projecting a more accurate estimate of total redd counts from the results of the annual aerial index survey.

Fry emerge from Spring chinook salmon eggs in the upper McKenzie River after approximately 1,800 ATUs of temperature exposure.

Some salmon fry now emerge from spawning gravel in the McKenzie River subbasin and begin migrating downstream from two to four months earlier than they would under unaltered temperature regimes. Our studies showed that the very earliest migrating fry likely originated in the South Fork of the McKenzie River or from mainstem areas immediately downstream of the South Fork and Blue River. Streams with unaltered temperature regimes did not produce migrant fry until about mid-January, similar to results obtained in studies conducted before the construction of Cougar and Blue River dams.

Studies on the Rogue River in Oregon associated fry losses with a one-month acceleration in emergence from the gravel. By inference, fry that now migrate down the McKenzie River from mid-November through mid-January experience diminished potential for survival.

Because warm water discharged from Cougar and Blue River dams accelerates the incubation of salmon eggs deposited within the thermal influence of these projects, selective pressures may tend to produce later-spawning adults. We may ultimately see the development of two populations of salmon in the McKenzie River temporally isolated by time of spawning.

Approximately 57% of the total redds located in the McKenzie River in 1992 were deposited in the South Fork or in the mainstem McKenzie River downstream of the South Fork confluence, and thus subjected to potential influences of the discharges of warm water from the COE projects during critical times of salmon spawning and egg incubation. However, because only minor temperature effects occur below Leaburg Dam, about 30% of the redds in the river were likely most affected.

ACKNOWLEDGMENTS

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APPENDIX A

Mean Daily Water Temperatures Recorded at Five-Day Intervals from Nine Locations in the McKenzie River, 1992 (Excerpted from USGS Data)

Appendix Table A. Mean water temperatures (F) at five-day intervals from monitoring locations on the upper McKenzie River, 1 September 1992 to 30 April 1993.

Date	Carmen Spawning Channel	Lost Creek	Horse Creek	McKenzie Bridge	South Fork	Forest Glen	Blue River	Finn Rock	Leaburg Dam
01-Sep	48.6	46.4	51.6	49.8	53.1	52.9	68.5	54.7	57.4
05-Sep	48.4	46.0	50.4	49.1	54.9	52.2	68.0	54.1	55.8
10-Sep	48.0	46.2	50.2	49.1	56.3	52.5	66.7	54.9	56.8
15-Sep	47.3	45.7	47.3	47.7	57.4	50.7	64.0	53.2	54.0
20-Sep	47.5	46.0	49.1	48.6	58.3	52.5	63.7	55.0	56.8
25-Sep	47.1	45.9	48.9	48.0	58.5	52.0	61.9	54.5	55.4
30-Sep	46.9	46.0	49.5	47.7	58.8	52.5	61.2	55.0	56.5
05-Oct	46.6	45.5	46.6	46.2	59.4	50.9	60.4	53.8	54.9
10-Oct	46.0	45.7	46.6	46.4	57.7	50.0	59.5	52.3	53.8
15-Oct	45.3	44.8	43.3	44.2	58.1	47.5	58.5	49.6	49.3
20-Oct	45.3	45.7	46.6	45.7	56.3	48.2	57.0	49.8	52.2
25-Oct	45.0	45.5	46.2	47.0 a	55.6	48.6	56.8	49.8	51.6
31-Oct	44.8	45.7	45.0 a	46.0 a	54.5	46.9	52.3	48.0	49.3
05-Nov	44.4	45.5	46.0 a	41.9	52.7	47.3	49.8	48.2	49.5
10-Nov	43.9	44.4	45.5 a	40.5	52.0	45.0	48.7	46.4	46.2
15-Nov	43.3	45.0	42.5 a	43.5 a	51.3	45.9	48.0	46.9	47.3
20-Nov	42.8	45.0	42.0 a	44.0 a	49.8	44.8	47.1	46.0	46.4
25-Nov	42.1	44.6	45.0 a	43.5 a	46.9	43.5	44.4	44.6	45.3
30-Nov	41.7	45.0	44.0 a	42.5 a	45.5	43.7	43.9	44.4	45.1
05-Dec	40.6	43.9	41.3 a	41.0 a	44.1	41.0	40.5	41.7	42.3
10-Dec	40.3	44.8	40.0 a	38.5 a	42.8	42.4	43.5	43.7	45.1
15-Dec	40.5	44.8	40.5	41.5 a	42.6	42.4	43.3	43.2	44.6
20-Dec	39.9	44.6	38.7	40.5 a	41.9	41.7	42.6	42.8	43.7
25-Dec	39.9	44.4	39.6	41.0 a	41.5	41.0	42.3	41.9	43.3
31-Dec	39.4	44.6	38.5	40.3 a	41.0	40.8	40.8	41.2	41.9

Appendix Table A. Mean water temperatures (F) at five-day intervals from monitoring locations on the upper McKenzie River, 1 September 1992 to 30 April 1993 (concluded).

Date	Carmen Spawning Channel	Lost Creek	Horse Creek	McKenzie Bridge	South Fork	Forest Glen	Blue River	Finn Rock	Leaburg Dam
05-Jan	39.2	44.4	37.6	40.3 a	40.5	40.3	39.4	40.5	40.6
10-Jan	38.3	43.5	35.6	39.3 a	39.6	37.6	36.0	37.6	36.7
15-Jan	38.7	44.6	37.9	40.8	39.0	40.3	37.4	40.3	39.7
20-Jan	39.0	44.8	38.7	40.8	37.8	40.5	39.0	41.0	41.5
25-Jan	39.0	45.1	39.9	41.5	38.7	41.4	42.8	41.9	42.4
31-Jan	39.4	44.8	39.4	41.4	39.2	40.8	43.3	41.4	41.5
05-Feb	39.7	45.3	41.0	42.4	39.7	42.3	42.4	42.6	43.5
10-Feb	40.1	45.1	41.0	42.8	40.5	42.4	42.3	42.8	43.7
15-Feb	40.1	44.2	38.7	41.5	41.2	40.8	41.5	41.2	42.4
20-Feb	39.0	44.8	38.5	40.3 a	40.3	40.6	40.1	40.8	40.8
25-Feb	39.0	44.2	36.5	39.5 a	39.9	39.4	40.3	39.7	40.1
28-Feb	39.2	44.8	37.9	39.5 a	39.7	40.5	40.8	40.8	41.0
05-Mar	39.9	45.5	40.8	41.3 a	40.3	43.2	42.3	43.7	44.6
10-Mar	40.8	45.9	41.9	41.3 a	40.6	43.7	41.0	43.9	45.3
15-Mar	41.0	45.9	41.7	43.0 a	41.0	43.3	40.8	43.2	44.2
20-Mar	40.8	46.2	41.7	40.8 a	41.9	43.9	--	43.7	44.4
25-Mar	40.8	45.7	40.8 a	42.8 a	42.4	43.3	--	43.5	43.7
31-Mar	41.4	46.0	40.5 a	42.6	41.2	44.1	--	44.1	45.0
05-Apr	41.2	46.0	40.5 a	43.0	42.6	44.2	--	44.4	45.0
10-Apr	41.4	45.7	41.0 a	43.0	43.0	44.2	--	44.4	45.9
15-Apr	41.7	46.4	41.0 a	44.2	42.6	45.5	--	45.5	47.5
20-Apr	42.1	46.4	--	44.6	42.8	45.7	--	45.7	47.7
25-Apr	42.4	46.4	--	44.1	42.8	45.3	45.1	45.5	47.5
30-Apr	43.0	46.8	--	45.0	43.0	46.4	45.3	46.6	49.5

a USGS data missing due to equipment malfunction, temperatures measured by ODFW.