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Effects of temperature, flow, and disturbance on adult spring-run chinook salmon

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Abstract

Spring-run chinook salmon (Oncorhynchus tshawytscha) have an unusual life history pattern in that they move into their spawning streams in the spring, hold there all summer in deep pools, and then spawn in the fall. Populations in the Sacramento-San Joaquin and Klamath-Trinity drainages have declined dramatically in recent years perhaps due to their exceptional vulnerability to the negative effects of water diversions (e.g. low flows/high temperatures) and human disturbances in their stream habitat. We examined the limits of pool holding capacity under varying conditions of temperature, flow, and human use primarily in a 2.3 km study stretch in the upper reaches of Deer Creek (Tehama County) during 1991.

We found some evidence that spring-run chinook salmon continually move upstream over the summer. However, pool depth also affected the presence of adult salmon. The number of salmon counted reached an asymptote in many pools over the summer, suggesting that pools have a limited holding capacity. Human rafting activity caused an increase in salmon movement in pools, and may stress salmon if it is a common activity. We documented substantial evidence of possible harassment and poaching of salmon in a 2.3 km study stretch of Deer Creek during 1991. This evidence included the presence of heavy line and treble hooks in pools containing adult salmon, and we even observed people with snorkeling equipment trying to capture adult salmon with a dipnet. Estimated spawning success was about 50-60% in Butte Creek in 1989 and Deer Creek in 1990 and 1991.

Problem and research objectives

Spring-run chinook salmon (Oncorhynchus tshawytscha), once the largest stock of Central Valley salmon, have been declining drastically over the past few decades (Campbell and Moyle 1991). Because similar declines have also occurred in the Klamath-Trinity drainage, it is being considered for state listing as a threatened species (Moyle et al. 1990). Significant spawning runs (> 50 fish) that involve natural stocks occur in Deer and Mill Creeks, Tehama County. A run also occurs in Butte Creek, Butte County, although the relative contributions of natural and hatchery stocks to this run are uncertain. Water diversions in the lower reaches of all three streams probably have resulted in the misdirection and decreased survival of out-migrating juveniles. Additionally, water is diverted in Butte Creek at a higher elevation for purposes of power. This diversion may affect the flow rate and associated variables such as temperature in the higher reaches of Butte Creek where returning adult spring-run chinook salmon hold in pools during the summer. The current drought may be causing similar effects in Deer and Mill Creeks. Furthermore, high levels of human use on some portions of all three creeks may be resulting in increased poaching and stress to adult fish. These factors may in turn affect the survival and spawning success of adult spring-run chinook salmon.

Prior work (Sato and Moyle 1989; Campbell and Moyle 1990) has indicated that adult spring-run chinook salmon may prefer or require deep pools and that other pool characteristics such as substrate type are of lesser importance. In this study, we examined more closely the limits of pool holding capacity under varying conditions of temperature, flow, and human use, and the effects of such conditions on spawning success. Specifically, we examined the following hypotheses:

(1) Adult spring-run chinook salmon continually move upstream throughout the summer provided that flows are sufficient to allow movement among pools. If this is true, it would suggest that upstream movement is genetically influenced, i.e. that adult salmon tend to move upstream over time regardless of temperature/flow regime, crowding in pools, or other factors.

(2) There is an upper limit to the number of spring-run chinook salmon contained within a pool. If this is true, it would suggest that crowding in pools, and factors that may exacerbate its effects (e.g. high temperatures/low flows, human disturbance) determine the presence of spring-run chinook salmon in pools.

(3) Human recreational use of pools containing adult spring-run chinook salmon increases the activity of the salmon. If this is true, it would suggest that human recreational use can cause stress to adult salmon.

(4) Spawning success varies with temperature/flow regime and amount of human disturbance experienced by adults during the summer holding period. If this is true, it would suggest that

stress is experienced by the adults under particular conditions and that this stress can affect spawning success.

The drought made it difficult to find an acceptable study stretch on Butte Creek, and Mill Creek was too turbid in 1990-91 to study adult salmon effectively. Consequently, we concentrated our study on Deer Creek. Our objectives were to (a) identify throughout the summer the numbers of adult spring-run chinook salmon holding in various pools in a study stretch of Deer Creek, (b) determine the number of hours on a daily, weekly, and monthly basis during which adult salmon in the study stretch are subjected to lower flows and/or higher water temperatures (over 20 C), (c) assess the effects of recreational rafting on the behavior of adult salmon, and (d) in the fall, count the number of chinook salmon carcasses and the number of redds located in or near the different pools in the study stretches of Deer and Butte Creeks.

Methodology

Adult chinook salmon counts and assessment of flow and temperature

Adult spring-run chinook salmon were counted by snorkeling a 2.3 km study stretch in the upper reaches of Deer Creek seventeen times during May-August, 1991. The basic procedure was to snorkel the study stretch on two consecutive days every two weeks in order to gain an idea of count variability over both the short and long term. We defined a pool as containing three or more fish at the same time at least once during the summer. Temperature data was collected hourly with a thermograph located in the study stretch. Flows were obtained from a U.S. Geological Survey gage located below the study stretch but above any major water diversions.

If spring-run chinook salmon continue moving upstream all summer (Hypothesis 1), we would expect the numbers present in the uppermost pools to continually increase as long as flows are high enough to permit movement among pools. However, if there is a limit to the number of fish that can hold in a pool (Hypothesis 2), we would expect the number of fish holding in a particular pool to reach an asymptote and/or vary over the summer in response to temperature/flow regime or amount of human disturbance. This would also suggest that particular conditions may be stressful to adult spring-run chinook salmon.

Rafting experiments and other assessment of human disturbance

We conducted experiments in pools in Butte Creek in 1990 and Deer Creek in 1991 in which we assessed the effect of human rafting activity on the behavior of adult spring-run chinook salmon (Hypothesis 3). In these rafting experiments, the pool was visually divided into upstream and downstream halves, and for 20 minutes an observer counted the number of times the salmon crossed the centerline i.e. moved upstream or downstream within the pool. This procedure was repeated for an additional 20 minutes during which a second experimenter, with some kicking and splashing, floated through the pool on a raft. Whether rafting was conducted during the first or second 20 minute period was determined by coin toss.

Beginning in July 1991, we documented evidence of disturbance and possible poaching of adult spring-run chinook salmon in the study stretch of Deer Creek. We considered this "evidence" to be fishing items (e.g. fishing line, lures, etc.) and human activity observed in pools containing adult salmon, human testimony, and carcasses/remains of adult salmon found anywhere in the study stretch. Since trout fishing is a common activity in Deer Creek, fishing items found in riffles were not considered to be evidence of possible salmon poaching. Furthermore, we described many of the items we found (e.g. heavy fishing line, large treble hooks, etc.) to demonstrate that such gear probably was <u>not</u> used for trout fishing.

Carcass and redd counts

In October 1990, we counted the number of redds and carcasses in the 2.3 km study stretch of Deer Creek and compared the number of adult salmon previously counted to obtain an estimate of spawning success (Hypothesis 4). This work was conducted in cooperation with the California Department of Fish and Game and Lassen National Forest, and was repeated by Colleen Harvey (CDFG) in September and October 1991. We compared these data to those obtained by Curtis Steitz (PG&E) for Butte Creek in 1989.

Data analysis

Counts of adult spring-run chinook salmon in the study stretch of Deer Creek were analyzed using multiple regression techniques on log-transformed data. Additional analyses of these and all other data involved a variety of nonparametric tests.

Principal findings and significance

Flow and temperature

Flow in Deer Creek from May through August, 1991 in was highly (negatively) correlated with date (Figure 1; $r_s = -0.98$, p-value < 0.001; $n = 123$). Although this may have made travel among more difficult for adult salmon toward the end of the summer, the variability in the counts suggests that movement remained common (see Adult chinook salmon counts, below). We were able to obtain temperature data only from mid-July through August, 1991 (Figure 2). These data also appear to be related to date, but daily maximum temperature and temperature range tended to <u>decline</u> during this period. The cooling effect of decreasing day length must have had a greater effect on water temperature in

Deer Creek than the heating effect of decreasing flows. The maximum temperature observed in the study stretch of Deer Creek was 19 °C, which was the daily maximum reached on July 27-30, 1991. We suspect that this represents the annual peak in temperatures. Thus, the 20 oC critical level which we set prior to the study was not reached in the study stretch of Deer Creek during the summer of 1991. However, temperatures as high as 23 oC have occurred in Butte Creek with severe effects including mortality on adult spring-run chinook salmon (Beth Campbell and Lesa Meng, personal observation).

Adult chinook salmon counts

Counts of adult spring-run chinook salmon holding in 13 pools in the study stretch of Deer Creek from May through August, 1991 varied over time and in different pools. There were four potential sources of the variability: (1) movement of salmon into and out of the study stretch, (2) movement of salmon within the study stretch, (3) death of salmon due to poaching or other variables, and (4) sampling error. These sources of variability may be related to flow and pool size.

Evidence of movement into and out of the study stretch is apparent in that the total number of fish counted varied substantially over time. We expected this movement to decline after about June 30 because of lower flows. However, we found that the total number of adult salmon in the study stretch was correlated with date and tended to increase throughout the summer (Figure 3; $r_s = 0.72$, $0.001 < p\text{-value} < 0.002$, $n = 17$). If this trend is due to salmon migrating upstream, then it may lend general support to Hypothesis 1.

The effects of pool size and associated variables on the numbers of adult salmon contained in pools were assessed in an earlier study (Sato and Moyle 1989; Campbell and Moyle 1990). Maximum depth of the pool was found to be the most consistent predictor of number of adult spring-run chinook salmon--more salmon were found in deeper pools. Although there was a large amount of variability, this pattern was apparent in the pools in the Deer Creek study stretch in 1991 (Figure 4). In contrast, the median number of adult salmon contained within a pool did not appear to depend on the pool's location in the study stretch (Figure 5). However, the pattern of change in the number of adult salmon contained in a pool over time did not appear related to pool depth and may be related to the location in the pool in the study stretch (see below).

Movement of adult salmon within the study stretch indicated that there may be a relationship between Hypotheses 1 and 2. The data showed some agreement with Hypothesis 1 in that pools in which the number of salmon increased over the summer tended to be in the upper part of the study stretch, i.e. the salmon may have been moving continually upstream over the summer. If the uppermost pool is deleted from consideration due to an inability to obtain accurate counts due to excessive turbulence at Lower Falls, then four of six pools in the upper half of the stretch exhibited increases over the summer. However, in the lower half of the study stretch, three of six pools also exhibited increases. A key distinguishing characteristic may be related to the timing of the increases. Of the seven pools that exhibited increases, those that were higher in the study stretch tended to increase and reach an asymptote by mid-late June (Figure 6). In contrast, pools that were lower in the stretch tended to increase to an asymptote in mid-July to mid-August (Figure 7). The only exceptions were the shallowest (depth = 1 m) and deepest (depth = 7 m) pools in the stretch. The former is located in the upper half of the stretch, but did not reach an asymptote until mid-August. The latter is located in the lower half of the stretch and reached an asymptote in mid-June. Thus, these data provide some support for Hypothesis 1, but do show pool maximum depth to be important as well. Also, although inspection of the data indicates that the number of salmon in a pool tends to reach an asymptote (Hypothesis 2), the highest number of salmon counted in three pools occurred in the last week of the study. This suggests that given more time, the number of salmon present may have continued to increase in some pools.

The five pools in which the number of adult salmon remained stable or declined over the summer were widely spread through the study stretch (Figure 8). Two of the five pools were notably open and contained little cover, and this probably contributed to the decline in the number of salmon they contained. The other three pools exhibited no clear change over the summer. They tended to contain a variable, intermediate number (0 to 20 fish) of adult salmon. Although these pools had intermediate depths, they had fairly small volumes and may have reached the limits of their holding capacity early in the summer. Also, the uppermost pool was very close to other deep pools, and this may have mediated any tendency for the number of adult salmon it contained to increase.

The best statistical model we found to represent the counts explains 77% of the variance and reinforces the observations made above. The model includes date, pool depth, individual pool, and a date x individual pool interaction as independent variables. Pool location in the study stretch was highly correlated with individual pool, so pool location was dropped from the model. All of these variables were highly significant (Table 1). The effects of pool depth and individual pool explain the difference in mean number of fish per pool, i.e. some (larger) pools tended to contain more salmon than others. However, the date x pool interaction suggests specifically that the effect of date on number of salmon differed from pool to pool. In other words, although the number of salmon in the study stretch increased over the summer, this increase was not uniform in all of the pools. In fact, the number of salmon stayed about the same or even decreased in some pools.

We don't think poaching or death of salmon contributed greatly to the variability in our counts. We found the remains of only three adult salmon in the study stretch during summer 1991 (see Evidence of other disturbance and possible poaching, below), and, as stated above, the number of adult salmon in the study stretch increased with time. If much poaching or death of salmon did occur, its effects were masked by migration of salmon into the study stretch.

Although snorkeling is a common method for assessing some stream fish populations, little is known about the accuracy of the method in regard to spring-run chinook salmon populations. Counts made on consecutive days in the study stretch have provided some insight regarding the error of the snorkeling method regarding adult fish. Counts in many pools were consistent. However, some counts were quite variable (e.g. 28 adults were counted in Pool 6 on May 23, whereas only 15 were counted on May 24). We did detect heterogeneity of variance in consecutive-day counts among different pools even when adjusted for total number of chinook salmon (Bartlett's test; chi-square = 42.6, P-value < 0.001, df =12). However, this difference in variance among pools apparently was not related to pool depth or location in the stretch. Therefore, other pool characteristics such as shade, visibility, and topography may affect the accuracy of the counts.

It is obvious that snorkeling induces movement of adult salmon in the short term, i.e. the salmon move back-and-forth in the pool as snorkelers pass overhead (personal observation). However, snorkeling has also been demonstrated to induce movement of summer steelhead (<u>Oncorhynchus</u> <u>mykiss</u>) over a longer period (T. Roelefs, Humboldt State University and W. Jones, CDFG, personal communication; M.B. Ward, Humboldt State University, unpublished manuscript). Specifically, the number of steelhead holding in study pools declined during consecutive day snorkel counts (M.B. Ward, unpublished manuscript). There was a strong indication that snorkelers were induced the steelhead to move out of the pools. Movement often occurred between dawn and dusk.

Our work on spring-run chinook salmon suggests that they may be less affected by snorkelers than steelhead. First, although counts made on consecutive days could be quite variable, there little evidence that adult salmon were induced to move out of the study stretch entirely from the first day to the second day (Figure 9; Sign test, p-value = 0.36, n = 8). Second, we looked specifically for patterns of movement on consecutive days that may be related to particular pools, e.g. we thought that salmon in shallower pools may be more prone to stress and thus easily induced to move to deeper pools. We found little evidence that more salmon tended to be in any pool on either the first or second day. Finally, we conducted snorkel counts June 4-5, 1992, and observed the upper and lower limits of the study stretch for salmon from dusk until dawn (approximately 9 PM June 4 to 5 AM June 5). We observed no salmon moving into or out of the stretch during this period, even though the counts differed substantially on the two days; we counted 52 salmon on the first day and 78 on the second day. However, Colleen Harvey (CDFG) did observe 5 fish move within the stretch at about 8:15 AM June 5. Thus, salmon movement during the early morning hours (5-10 AM) may be important.

Adult chinook salmon behavior--rafting experiments

We conducted a total of three rafting experiments in Butte Creek in 1990 and ten experiments in Deer Creek in 1991. We found a significant effect of rafting on the movement of adult spring-run chinook salmon (Figure 10; sign test, p-value = 0.003, n = 13). More upstream/downstream movement occurred during the rafting period in 12 of 13 paired experiments. However, median number of movements per fish per 20 minutes was 1.1 when rafting occurred and 0.2 when no rafting occurred. Thus, although almost 6x more movement occurred during rafting experiments versus no rafting experiments, in general the amount of movement was small. Rafting could be an important source of stress to salmon if it is a common activity in their summer habitat (Hypothesis 3).

Evidence of other human disturbance and possible poaching

We regularly found evidence that adult spring-run chinook salmon were being disturbed and possibly poached in the study stretch of Deer Creek (Table 2). We found fishing tackle in pools such as heavy line with a steel leader and large treble hooks that was probably used to snag adult salmon. On one occasion we talked with two people who were trying to capture adult salmon with a dipnet while snorkeling. We saw the remains of three salmon which may have been taken by poachers, although predation by other animals cannot be ruled out.

Redd and carcass counts

In October 1990, we counted 43 spring-run chinook salmon redds and 31 carcasses on the study stretch of Deer Creek. We measured and sexed all the carcasses--standard lengths ranged from 420 to 780 mm, and there were 20 females and 14 males (Figure 11). A count of adults holding in pools in the same stretch prior to spawning was made on August 28, 1990 in cooperation with the California Department of Fish and Game and Lassen National Forest and totaled 161. Thus, if two fish used each redd, there is evidence that about half the fish (53%) in this stretch spawned in 1990. Colleen Harvey (CDFG) counted redds and carcasses of Deer Creek spring-run chinook salmon in September and October 1991. In the study stretch, she counted a total of 52 complete redds and 16 carcasses (not measured or sexed). We counted a maximum of 168 spring-run chinook salmon adults prior to spawning on August 27, 1991. Therefore, there is evidence that about 61% of the fish spawned in 1991. The difference in the estimated number of spawners does not appear to differ greatly between 1990 and 1991 in Deer Creek. Also, Curtis Steitz (PG&E) conducted both snorkel counts and redd and carcass counts in Butte Creek in 1989. These data suggest that about 60% of the spring-run chinook salmon in upper Butte Creek spawned in 1989. Considering the potential variability in snorkel counts, redd and carcass counts, and actual spawning success, all three estimates of spawning success (Deer Creek 1990 and 1991; Butte Creek 1989) are surprisingly similar. Although spawning success may vary among years and streams and may be related to temperature/flow regime (Hypothesis 4), there is no clear evidence from these data.

Additional work

Although the focus of this study was on adult spring-run chinook salmon, little is known about the timing of the outmigration of juveniles. Therefore, we attempted to collect juvenile spring-run chinook salmon in lower Deer and Mill Creeks during January, February, and March 1991 by seining. This effort yielded none in January, one individual in February, and three individuals in March (Figure 12). We also caught some fall-run chinook salmon. We progressively increased the amount of effort and the amount of night seining since the yield was so low. The fish that we caught provide evidence of some outmigration in 1991.

Publications

Campbell, E.A., and P.B. Moyle. 1991. Historical and recent population sizes of spring-run chinook salmon in California. Pages 155-216 in T.J. Hassler, editor. Proceedings of the 1990 Northeast Pacific Chinook and Coho Salmon Workshop. American Fisheries Society and Humboldt State University. Arcata, California.

Campbell, E.A., and P.B. Moyle. 1992. Variability in stream snorkel counts of adult spring-run chinook salmon. In progress.

Campbell, E.A., and P.B. Moyle. 1992. Spring-run chinook salmon population sizes: Importance of intra-annual flow timing. In progress.

References

Campbell, E.A., and P.B. Moyle. 1990. Ecology and conservation of spring-run chinook salmon: Reversing the effects of water projects. Technical Completion Report, Water Resources Center Project W-719.

Campbell, E.A., and P.B. Moyle. 1991. Historical and recent population sizes of spring-run chinook salmon in California. Pages 155-216 in T.J. Hassler, editor. Proceedings of the 1990 Northeast Pacific Chinook and Coho Salmon Workshop. American Fisheries Society and Humboldt State University. Arcata, California.

Moyle, P.B., J.E. Williams, and E. Wikramanayake. 1989. Fish species of special concern of California. Report to California Department of Fish and Game.

Sato, G., and P.B. Moyle. 1989. Ecology and conservation of spring-run chinook salmon. Annual Report, Water Resources Center Project W-719, July 30, 1988-June 30, 1989.

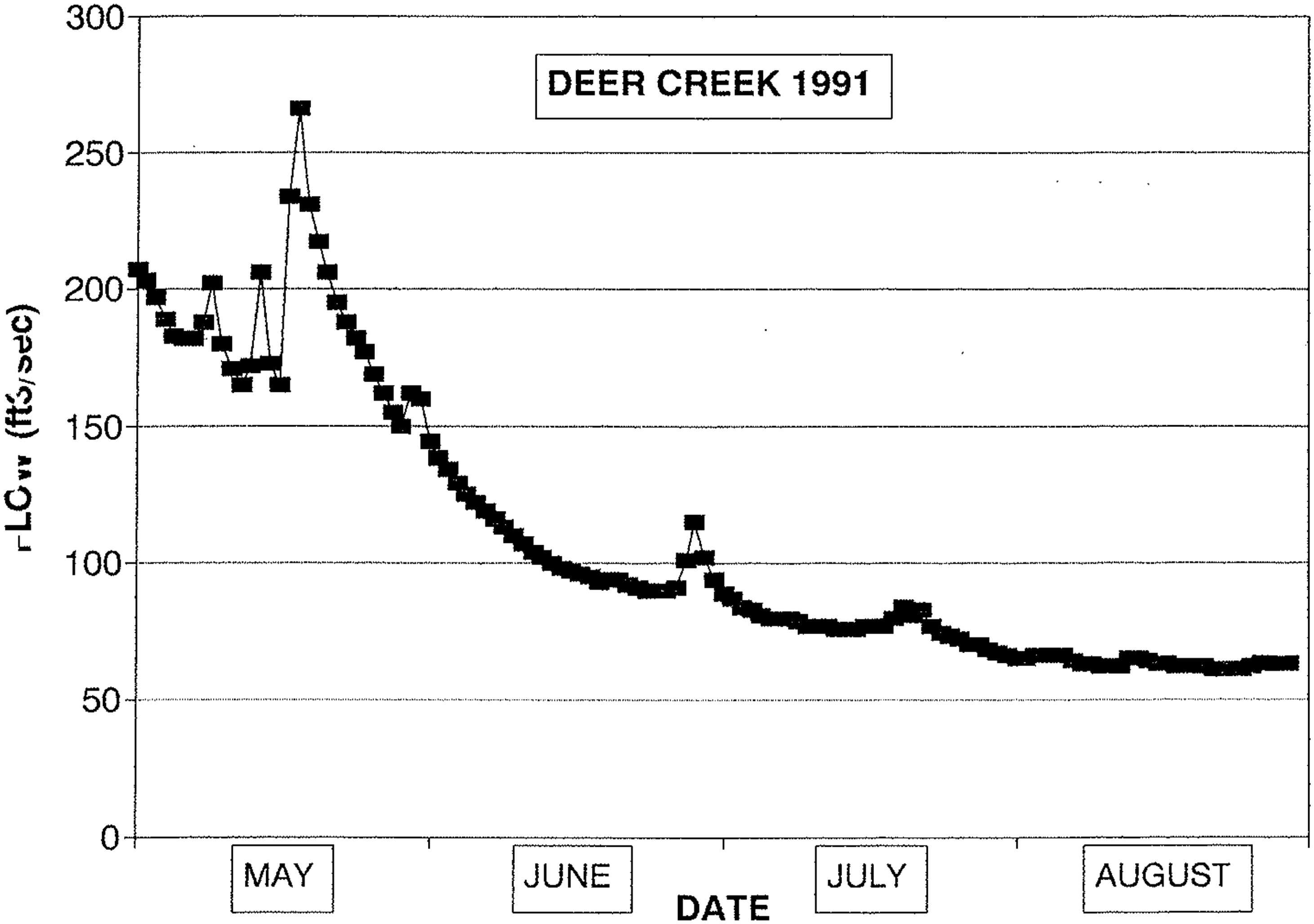
Table 1. Importance of five independent variables in a multiple regression model of log-transformed counts of adult spring-run chinook salmon in pools in a 2.3 km study stretch of Deer Creek, May-August, 1991.

Variable	F-statistic	P-value	df
Date	42.9	< 0.001	1, 197
Pool Depth	33.9	< 0.001	1, 197
Individual Pool	9.74	< 0.001	11, 197
Date x individual pool	10.7	< 0.001	12, 197

Table 2. Evidence of poaching/attempted poaching of spring-run chinook salmon in a 2.3 km study stretch of Deer Creek (Tehama County) during 1991-92. We considered "evidence" to be fishing items found in pools containing adult salmon, and carcasses/remains of adult salmon found anywhere in the study stretch.

Date	Poaching/disturbance evidence
July 2-3, 1991	Line with treble hook, saw family swimming and jumping into pool from surrounding cliffs saw two people swimming with snorkeling equipment attempting (unsuccessfully) to capture adult salmon with dipnet
July 16-17, 1991	Remains of one adult salmon, fishing line
July 29-30, 1991	Line with two large treble hooks, steel leader with treble hook
August 13-15, 1991	Remains of two adult salmon, fishing line, one lure
August 26-28, 1991	Two large treble hooks in different locations, broken fishing rod with steel leader and four large treble hooks, three sets of two large treble hooks/lures on fishing line in a single pool, fishing line on pool bank, fishing line in pool, trout fisherman said he hooked a salmon and his line broke
June 4-5, 1992	Dipnet, heavy line with multiple large hooks, line with steel leader and treble hooks, piece of heavy fishing rod, three lures

Figure 1. Mean daily flow (ft3/second) for Deer Creek, May-August, 1991. Flow was measured by a U.S.G.S. gauge below the study stretch but above any major water diversions.



DEER CREEK 1991
300
250
200
150
100
50
0
FLOW (ft3/sec)
MAY
JUNE
JULY
AUGUST
DATE

Figure 2. Maximum and minimum daily temperature and temperature range (oC) for the study stretch of Deer Creek, July-August, 1991. Temperatures were recorded with a thermograph located in the upper part of the study stretch.

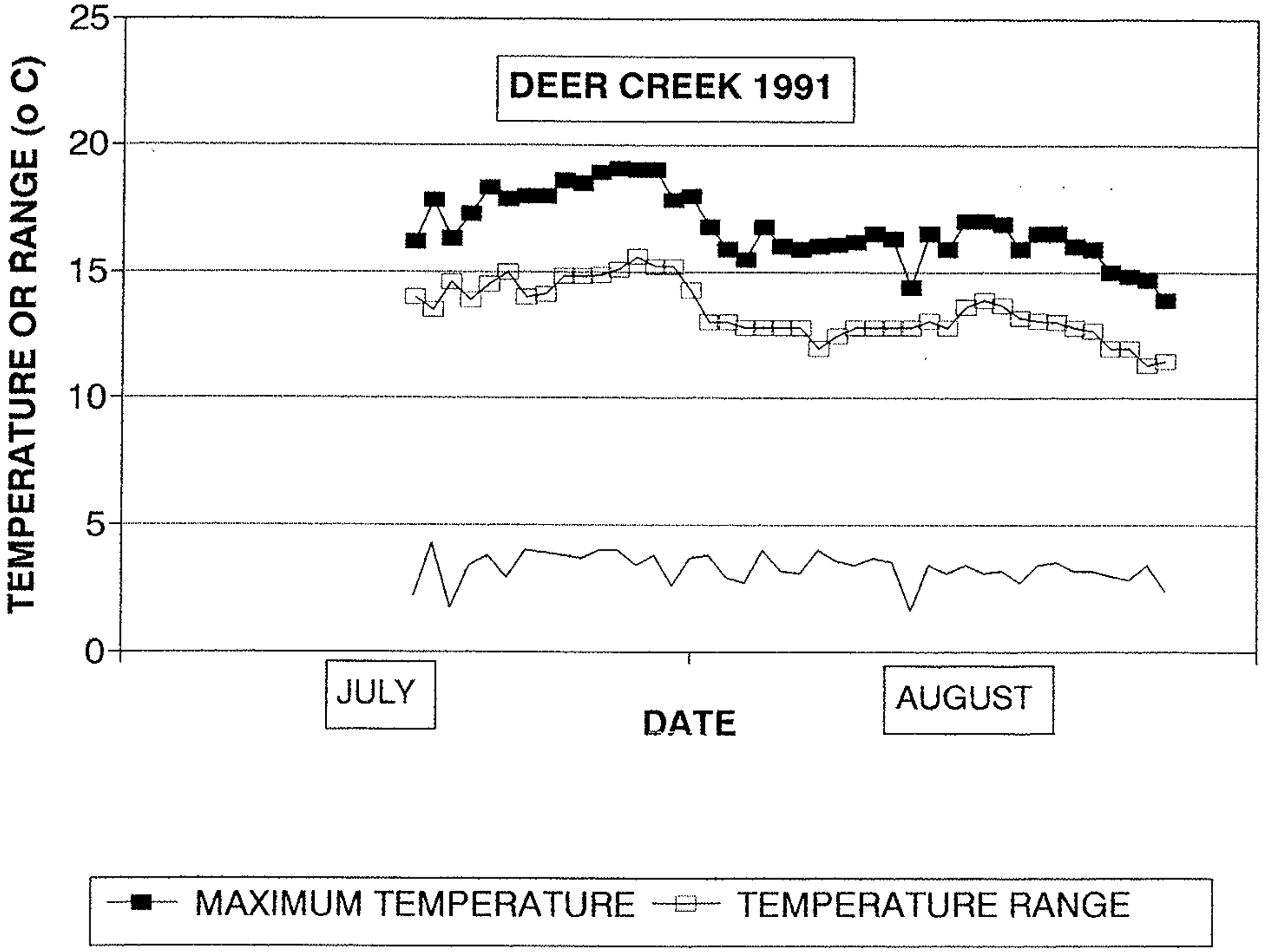
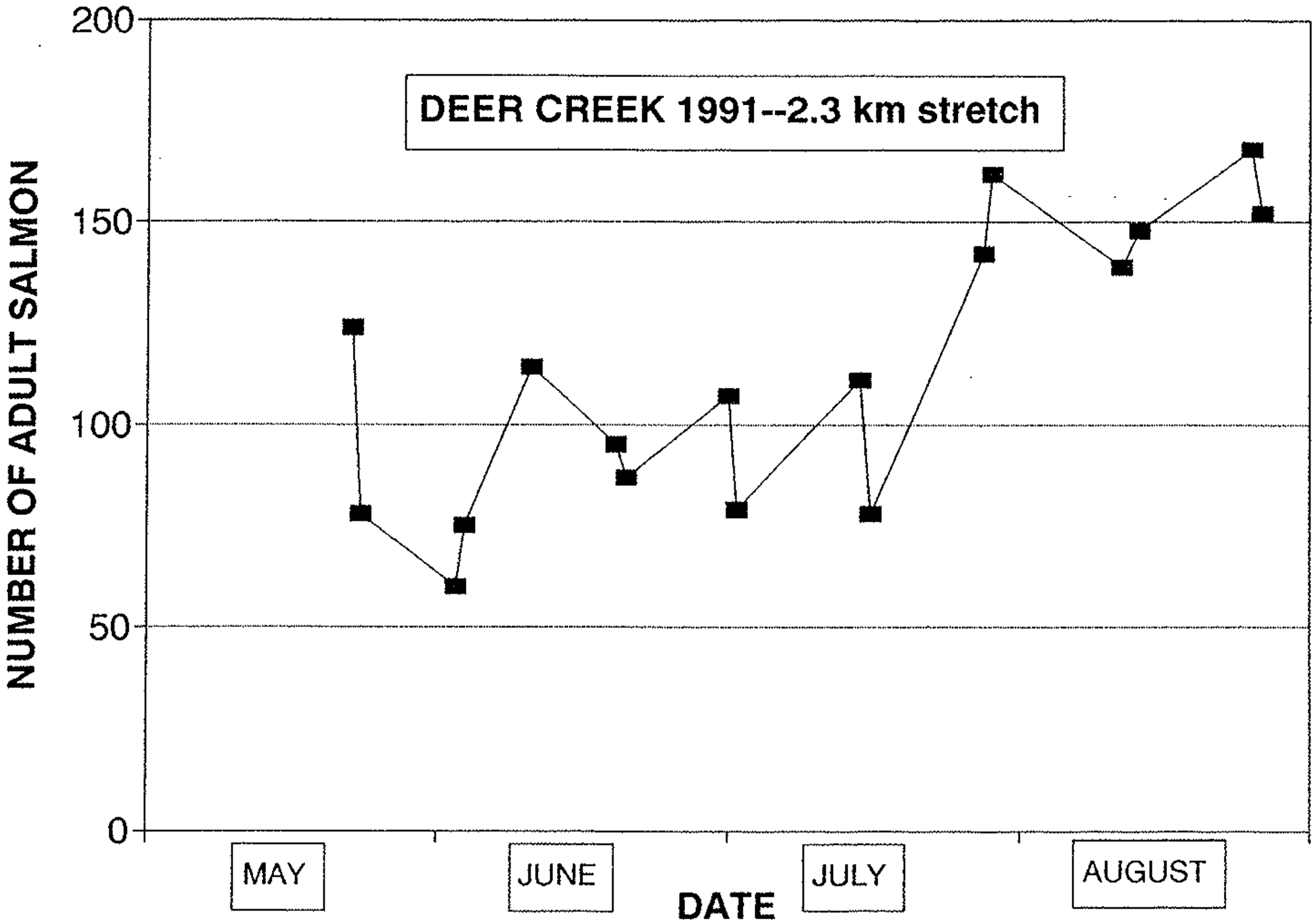

DEER CREEK 1991
TEMPERATURE OR RANGE (o C)
25
20
15
10
5
0
JULY
AUGUST
DATE
MAXIMUM TEMPERATURE
TEMPERATURE RANGE

Figure 3. Total number of adult spring-run chinook salmon counted in a 2.3 km study stretch in the upper reaches of Deer Creek, May-August 1991. Counts were obtained by two people snorkeling the stretch on two consecutive days approximately every two weeks.



DEER CREEK 1991--2.3 km stretch
NUMBER OF ADULT SALMON
200
150
100
50
0
MAY
JUNE
JULY
AUGUST
DATE

Figure 4. Median number of adult spring-run chinook salmon versus pool depth for 13 pools in a 2.3 km study stretch of Deer Creek, May-August, 1991. Error bars represent upper and lower quartiles. Counts were obtained by two people snorkeling the stretch on two consecutive days approximately every two weeks.

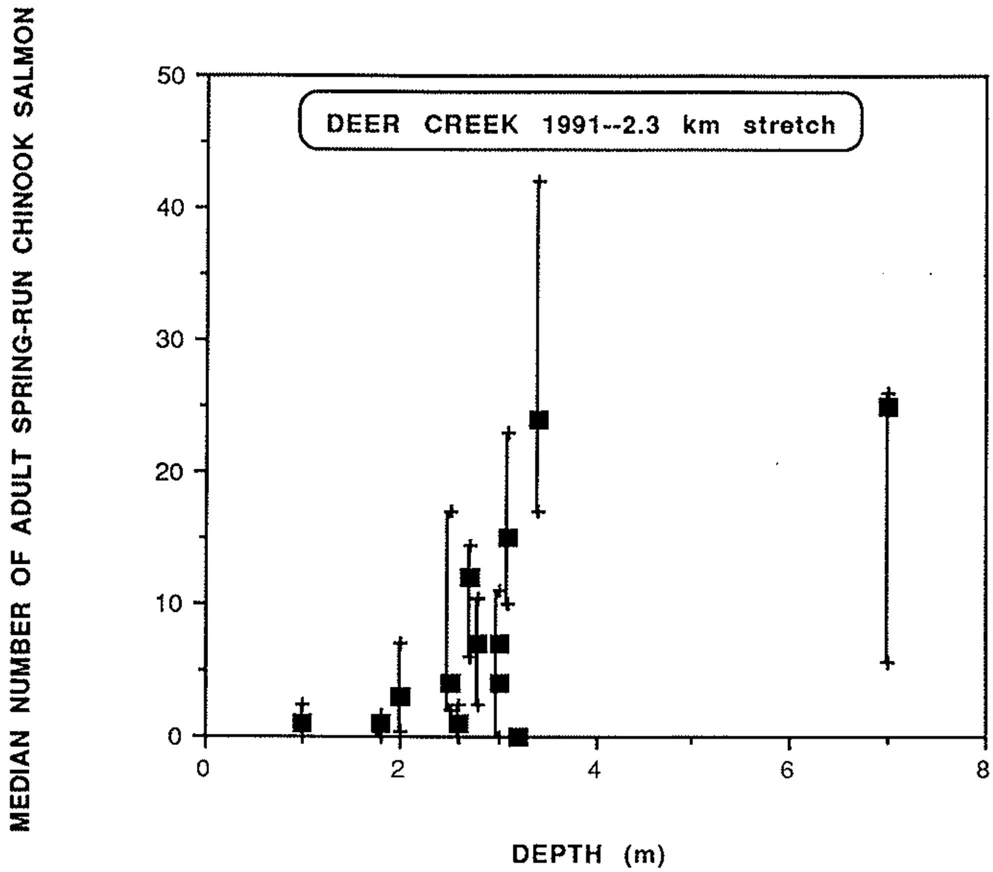
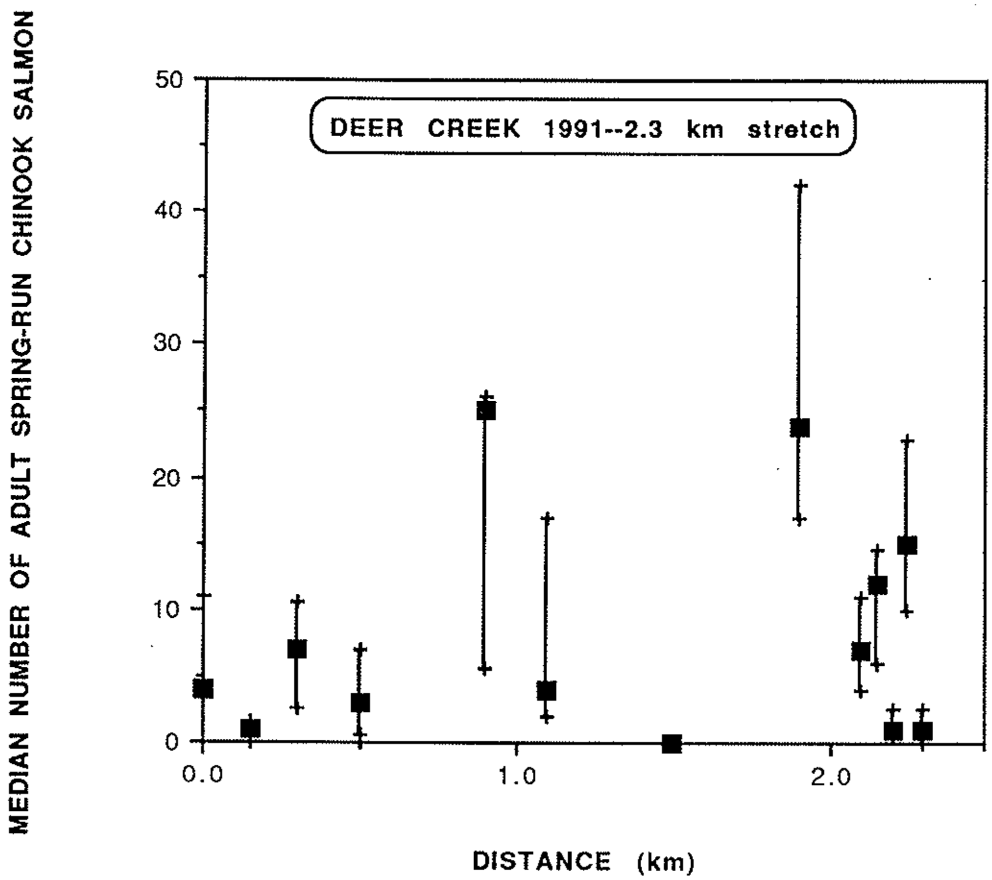

DEER CREEK 1991--2.3 km stretch
MEDIAN NUMBER OF ADULT SPRING-RUN CHINOOK SALMON
DEPTH (m)
0
10
20
30
40
50
0
2
4
6
8

Figure 5. Median number of adult spring-run chinook salmon versus pool location for 13 pools in a 2.3 km study stretch of Deer Creek, May-August, 1991. Pool locations (distance) were obtained from a topographical map; the bottom of the stretch is designated 0 km and the top is designated 2.3 km. Error bars represent upper and lower quartiles. Counts were obtained by two people snorkeling the stretch on two consecutive days approximately every two weeks.



DEER CREEK 1991--2.3 km stretch
MEDIAN NUMBER OF ADULT SPRING-RUN CHINOOK SALMON
DISTANCE (km)
0
10
20
30
40
50
0.0
1.0
2.0

Figure 6. Number of adult spring-run chinook salmon in pools in a 2.3 km study stretch of Deer Creek, May-August, 1991. Pools are shown only in which the number of adult salmon present tended to increase over the summer in the upper half of the study stretch. Number of salmon is plotted as a function of date and pool location (distance). Pool locations (distance) were obtained from a topographical map; the bottom of the stretch is designated 0 km and the top is designated 2.3 km. Counts were obtained by two people snorkeling the stretch on two consecutive days approximately every two weeks.

DEER CREEK 1991

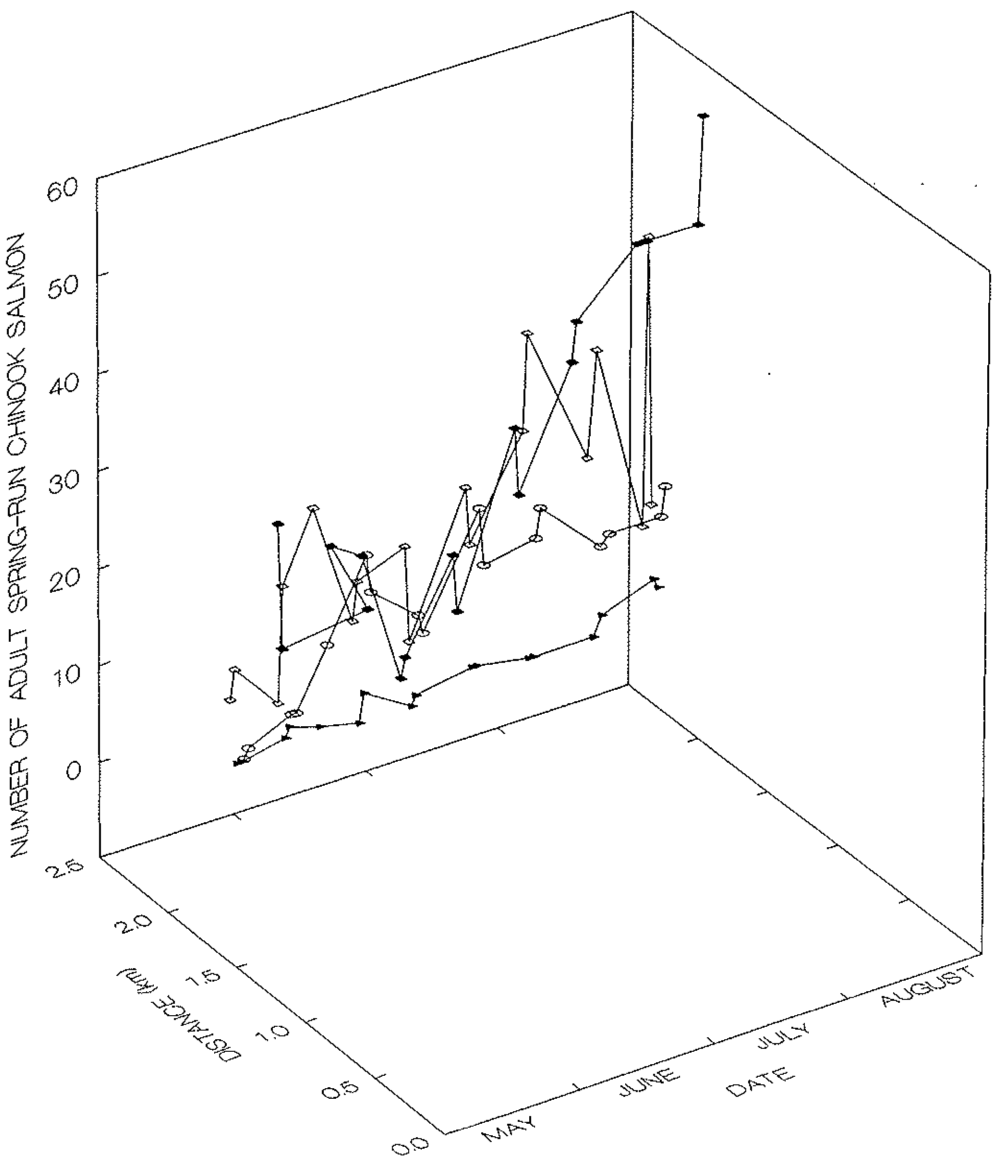


Figure 7. Number of adult spring-run chinook salmon in pools in a 2.3 km study stretch of Deer Creek, May-August, 1991. Pools are shown only in which the number of adult salmon present tended to increase over the summer in the lower half of the study stretch. Number of salmon is plotted as a function of date and pool location (distance). Pool locations (distance) were obtained from a topographical map; the bottom of the stretch is designated 0 km and the top is designated 2.3 km. Counts were obtained by two people snorkeling the stretch on two consecutive days approximately every two weeks.

DEER CREEK 1991

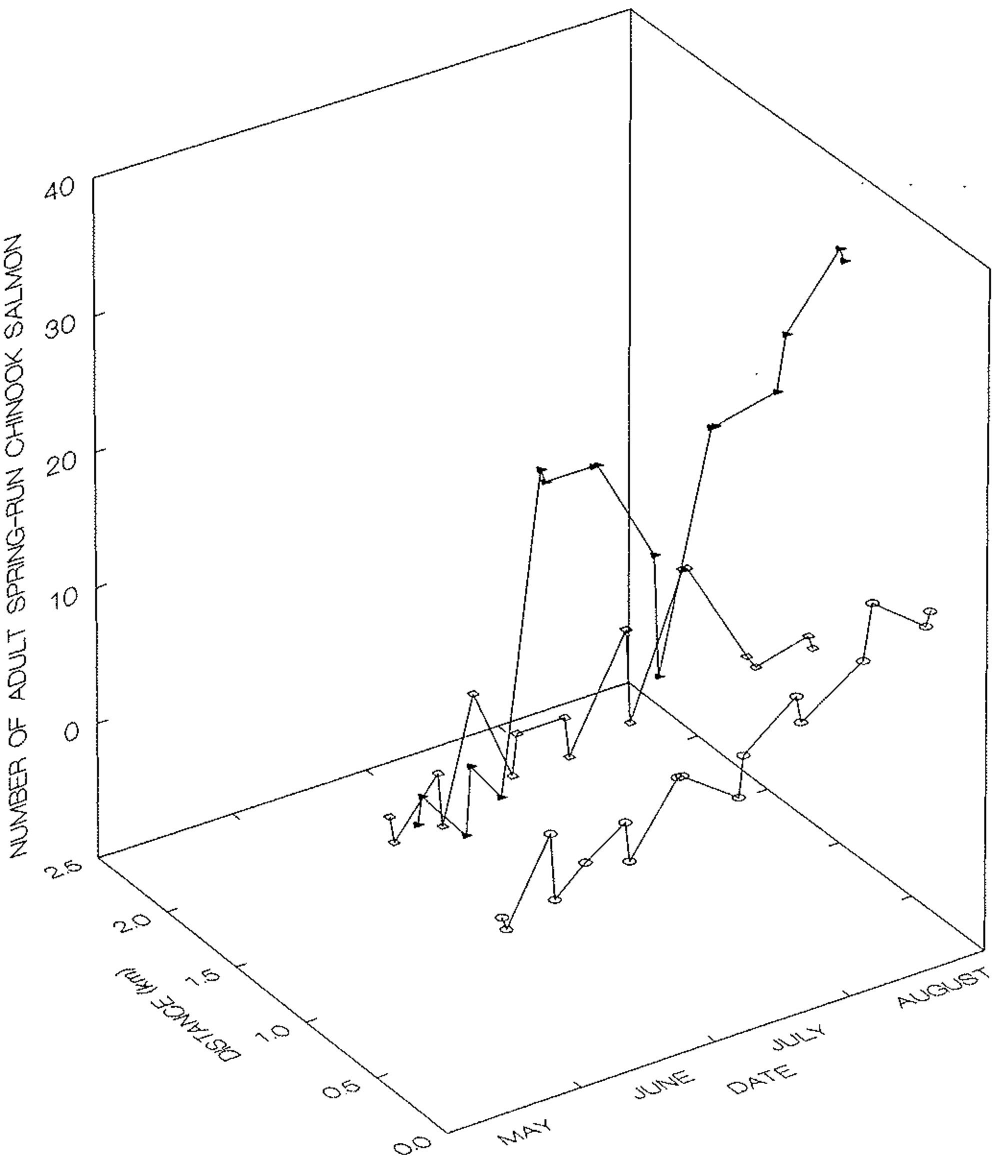


Figure 8. Number of adult spring-run chinook salmon in pools in a 2.3 km study stretch of Deer Creek, May-August, 1991. Pools are shown only in which the number of adult salmon present tended to decrease or remain stable over the summer. Number of salmon is plotted as a function of date and pool location (distance). Pool locations (distance) were obtained from a topographical map; the bottom of the stretch is designated 0 km and the top is designated 2.3 km. Counts were obtained by two people snorkeling the stretch on two consecutive days approximately every two weeks.

DEER CREEK 1991

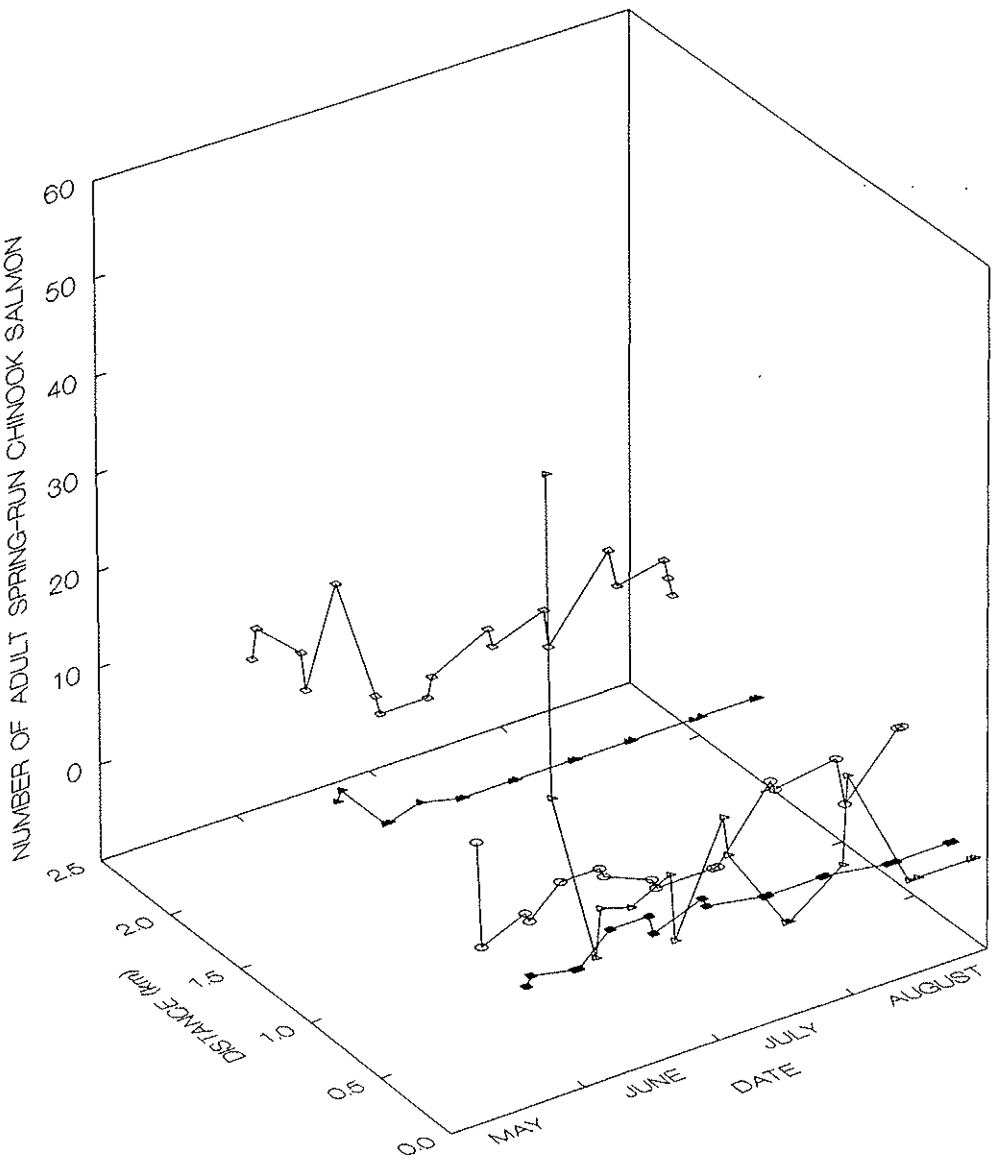


Figure 9. Differences between eight pairs of consecutive day counts of adult spring-run chinook salmon in the 2.3 km study stretch of Deer Creek, May-June 1991. Positive differences indicate more salmon were counted on the first day, whereas negative differences indicate more salmon were counted on the second day. Counts were obtained by two people snorkeling the stretch on two consecutive days approximately every two weeks.

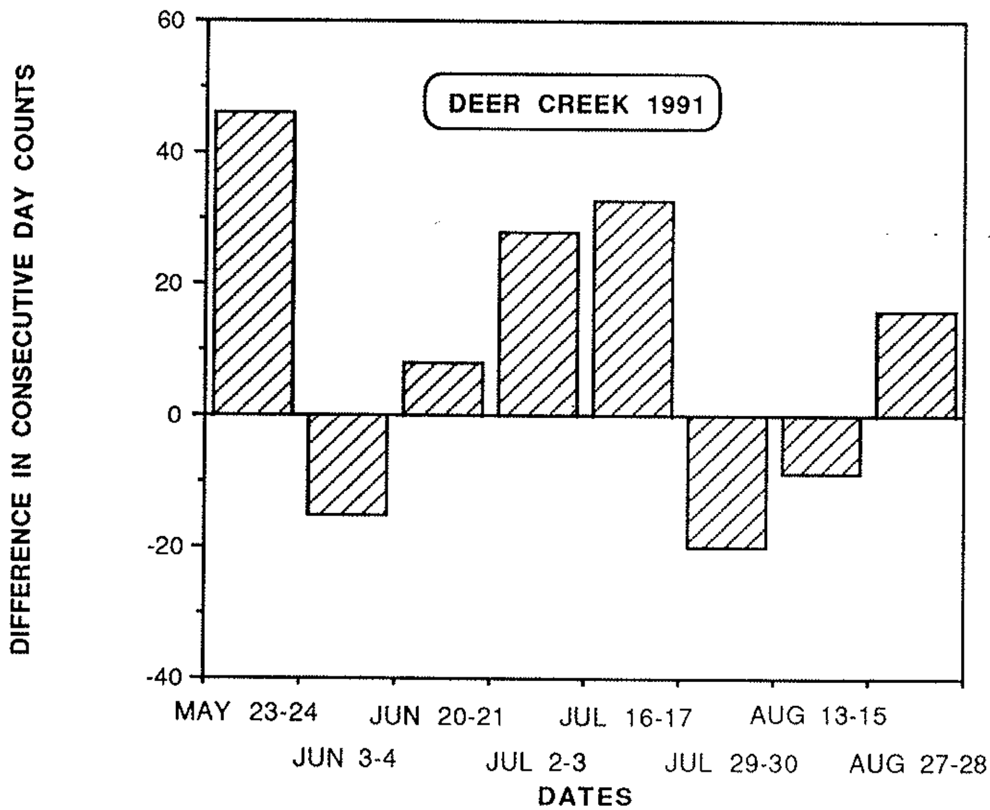
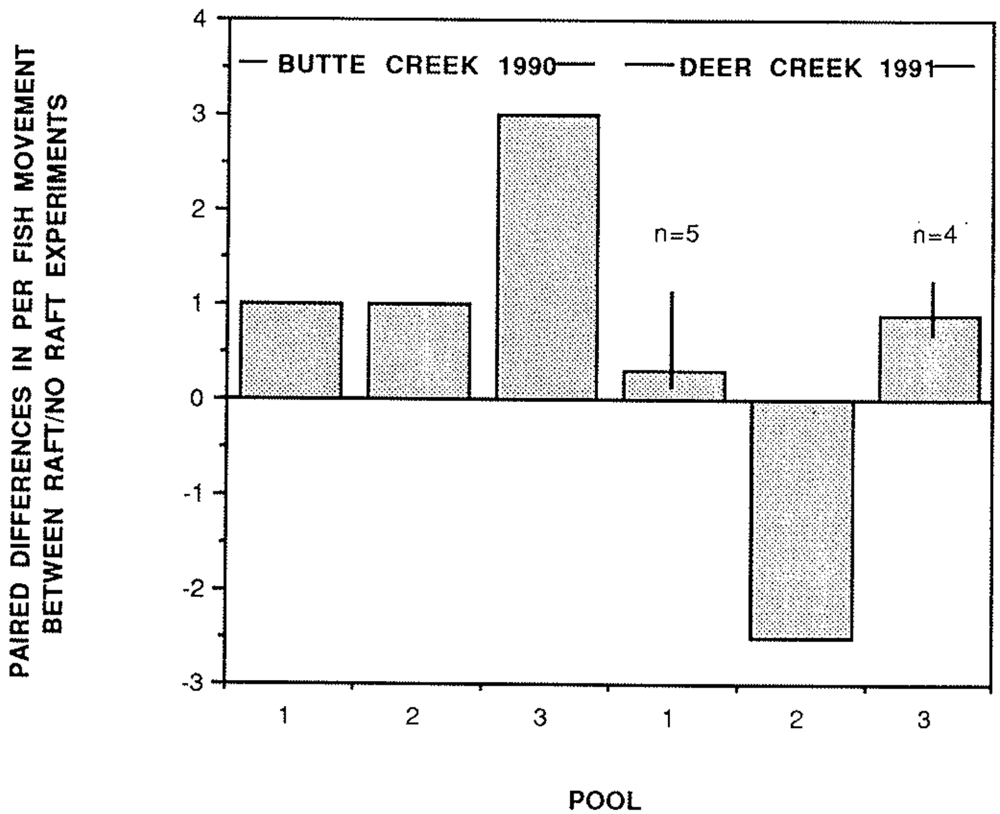

DEER CREEK 1991
DIFFERENCE IN CONSECUTIVE DAY COUNTS
60
40
20
0
-20
-40
MAY 23-24
JUN 3-4
JUN 20-21
JUL 2-3
JUL 16-17
JUL 29-30
AUG 13-15
AUG 27-28
DATES

Figure 10. Median paired differences between raft/no raft experiments in movement of adult spring-run chinook salmon between upper and lower halves of six summer holding pools. Positive differences indicate more movement during a raft experiment, whereas negative differences indicate more movement during a no raft experiment. Number of pairs of experiments (n) in each pool is 1 unless otherwise indicated. Error bars represent upper and lower quartiles. Data were obtained through observation while snorkeling.



PAIRED DIFFERENCES IN PER FISH MOVEMENT
BETWEEN RAFT/NO RAFT EXPERIMENTS
BUTTE CREEK 1990
DEER CREEK 1991
n=5
n=4
4
3
2
1
0
-1
-2
-3
1
2
3
1
2
3
POOL

Figure 11. Length frequency by sex of carcasses of adult spring-run chinook salmon collected after spawning in a 2.3 km study stretch of Deer Creek in October, 1990. Three carcasses collected from Mill Creek are included for a total of 34 carcasses.

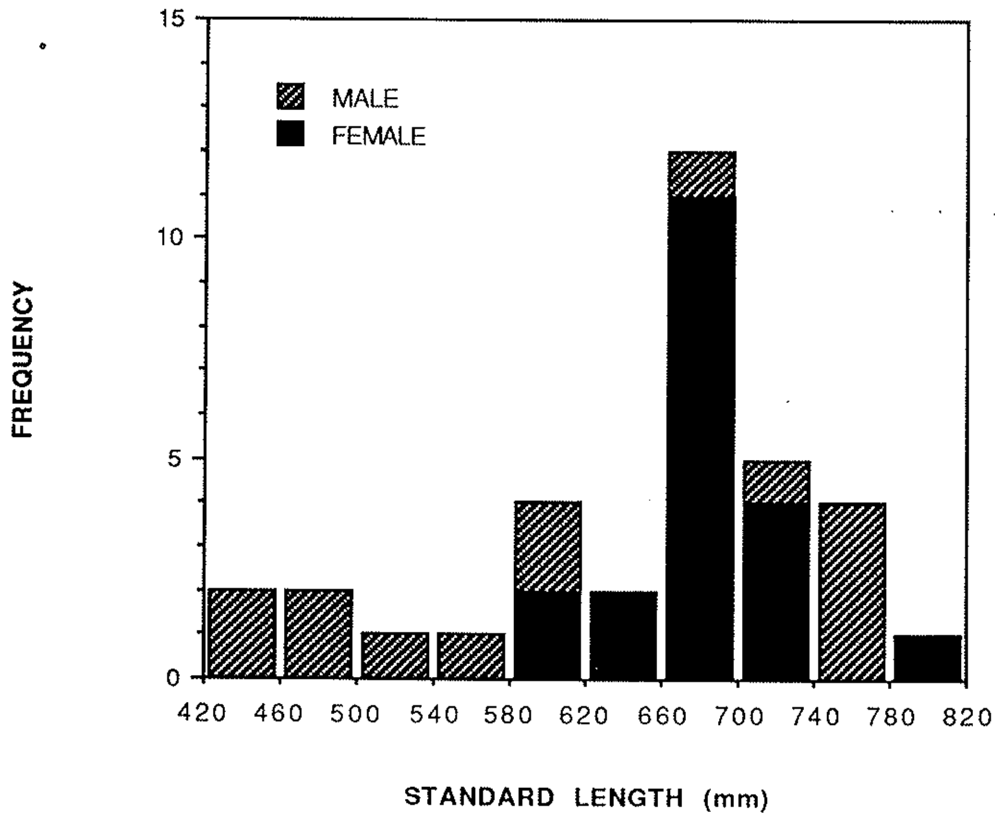
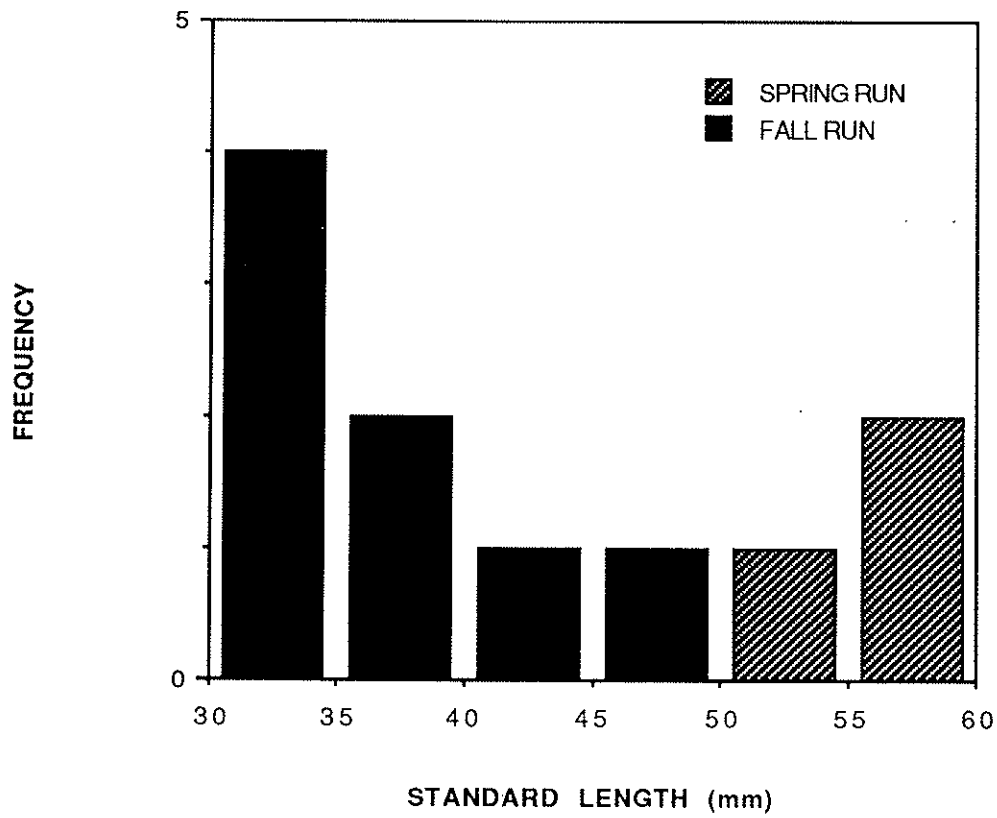

15
10
5
0
MALE
FEMALE
FREQUENCY
420 460 500 540 580 620 660 700 740 780 820
STANDARD LENGTH (mm)

Figure 12. Length frequency of juvenile fall-run and spring-run chinook salmon collected in lower Deer and Mill Creeks on March 18, 1991.



5
0
FREQUENCY
SPRING RUN
FALL RUN
30
35
40
45
50
55
60
STANDARD LENGTH (mm)