CALIFORNIA DEPARTMENT OF FISH AND GAME
Habitat Conservation Division
Native Anadromous Fish and Watershed Branch
Stream Evaluation Program

Upper Sacramento River
Fall-Run Chinook Salmon Escapement Survey
September–December 1999

by

Bill Snider
Bob Reavis
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Habitat Conservation Division
Stream Evaluation Program Technical Report No. 00-3
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2/ Stream Evaluation Program Technical Report No. 00-3

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SUMMARY

The California Department of Fish and Game's Stream Evaluation program conducted a fall-run chinook salmon, *Oncorhynchus tshawytscha*, spawner escapement survey in the upper Sacramento River during fall 1999 to acquire data on spawner abundance, age and sex composition of the spawner population, pre-spawning mortality and temporal and spatial distribution of spawning. This was the fifth consecutive year a fall-run escapement survey was conducted as part of a multi-year investigation to determine salmon habitat requirements in the Sacramento River system (Snider *et. al.* 1997; Snider *et. al.* 1998a; Snider *et. al.* 1998b; and Snider *et. al.* 1999). The survey was conducted from 27 September through 16 December 1999. It covered 25.5 miles of the Sacramento River, from Cottonwood Creek (river-mile 273) to Anderson-Cottonwood Irrigation District (ACID) dam (river-mile 298.5) located just 3.5 miles downstream of Keswick Dam (the upstream limit to anadromous fish migration).

Mean weekly flow was 6,700 cfs, ranging from 6,000 cubic feet per second (cfs) during survey periods 3–5 (12–28 October 1999) to 8,100 cfs during survey period 11 (6–10 December 1999). Mean weekly water temperature ranged from 52 °F to 53 °F through out the survey. Water visibility (Secchi depth) ranged from 7 ft to 12 ft.

A total of 5,652 fall-run carcasses were collected (1,227 fresh and 4,425 decayed) of which 1,137 fresh carcasses were measured, sexed, and aged. The peak in the fresh carcass weekly counts (194 salmon) occurred during period 4 (18–21 October 1999); the peak in total weekly carcass counts (809 salmon) occurred during period 5 (25–28 October 1999); 53% of all fresh carcasses were collected between periods 3 and 6 (12 October–4 November 1999) indicating that peak spawning occurred between periods 1 and 4. Carcasses were observed during every period of the survey.

Length frequency distributions were used to estimate the size distinguishing adults (>2-years old) from grilse (2-years old) by sex. Males >71 cm fork length (FL) and females >66 cm FL were classified as adults. Based upon these criteria, 77% of the population were adult salmon and 23% were grilse; 29% were adult males, 48% were adult females, 21% were male grilse and 2% were female grilse (50% male; 50% female).

We examined 494 females for egg retention: 463 (94%) had completely spawned, 10 (2%) still contained a substantial number of eggs, and 21 (4%) were unspawned.

The spawner population was estimated using both the Schaefer and Jolly-Seber mark-recapture models. Per the Schaefer model, 835 fresh adult carcasses were marked and 287 (34%) were subsequently recaptured yielding an escapement estimate of 18,295 total salmon (14,031 adult and 4,264 grilse). Per the Jolly-Seber model, 3,412 fresh and decayed carcasses were marked and 1,077 (32%) were subsequently recaptured yielding an estimate of 13,818 total salmon (10,598 adults and 3,220 grilse). Both estimates are considerably less than the mean annual fall-run chinook salmon

escapement estimate made between1956 and 1999 (65,492 grilse and adult). Estimated escapement during the five carcass surveys conducted during our investigations have ranged from 14,211 to 28,890 (mean = 22,287, SD = 5,598).

INTRODUCTION

The California Department of Fish and Game's (DFG) Stream Evaluation Program (STEP) conducted an intensive fall-run chinook salmon, *Oncorhynchus tshawytscha*, escapement survey on the upper Sacramento River during the fall of 1999 to estimate spawner abundance and distribution. This survey was carried out to fulfill the mandates of Section 3406(b)(1)(B) of the Central Valley Project Improvement Act (CVPIA), PL. 102-575, which requires the Secretary of the Interior to determine instream flow needs for all Central Valley Project controlled streams and rivers. Flow-need recommendations are to be provided to the Secretary by the U. S. Fish and Wildlife Service (FWS) after consultation with the DFG. In response to this Act, the FWS and the DFG have signed a "Cooperative Agreement" by which the FWS will fund DFG to conduct studies to determine flow needs of salmon in the upper Sacramento River.

The primary charge of STEP - to improve understanding of the relationships between salmon and habitat in the upper Sacramento River - requires reliable estimates of the spawner population to help distinguish habitat versus population influences on temporal and spatial spawning distribution (Snider and McEwan 1992, Snider *et al*. 1993, Snider and Vyverberg 1995). Changes in spawning activity related to changes in flow and temperature need to be distinguished from changes due to population size. Spawning density, redd superimposition, habitat use, and other parameters can be affected by both changes in habitat conditions (flow dependent) and spawner population size. A reliable population estimate developed concurrently with redd surveys allows this distinction. An intensive spawning escapement survey also provides additional baseline information on egg retention (pre-spawning mortality), age and sex composition, and behavior relative to habitat conditions and population size.

Carcass tag-and-recapture surveys have been routinely used to estimate salmon spawner escapements in Central Valley tributary streams (e.g., American, Yuba, and Feather rivers). During these surveys, carcasses are tagged and released into running water for later recapture. This protocol was initially used in the Central Valley in 1973 to estimate the Yuba River escapement (Taylor 1974). Fall-run carcass surveys were also conducted in 1995, 1996, 1997, and 1998 (Snider *et. al*. 1997; Snider *et. al*. 1998a; Snider *et. al*. 1998b, and Snider *et. al*. 1999) in the upper Sacramento River.

Three models have been used by the DFG to estimate escapement using carcass tag-and-recovery data: Petersen (Ricker 1975), Schaefer (1951) and Jolly-Seber (Seber 1982). The Petersen model is the simplest but least accurate (Law 1994). It has been used primarily when data are insufficient to allow calculation with the other models. It is occasionally used to calculate estimates for tributary streams with typically small spawner populations (e.g., Cosumnes, Merced, Stanislaus, and Tuolumne rivers). A modification of the Schaefer model has been used in larger Central Valley tributary streams (e.g Feather and American rivers) since 1973 when it was first used to estimate the Yuba River escapement. Based on Law's (1994) analysis, the Schaefer model will overestimate escapement when carcass "survival" (carry-over from period-to-period) and recovery rates are equivalent to those typically observed in Central Valley tributaries. Similarly, based on Law's (1994) analysis, the Jolly-

Seber model will slightly underestimate Central Valley spawner escapement. This model was first used to estimate escapement in the Central Valley in 1988. The Jolly-Seber model is more accurate when model assumptions are met and recovery rates are $\geq$ 10% (Boydstun 1994, Law 1994). Still, there has been considerable disagreement about model use among fisheries managers responsible for estimating spawner escapement for California streams. They believe that population estimates obtained by the Jolly-Seber model are too low (Fisher and Meyer, pers. comm.)[1]. Law (1994) states that both models could produce low estimates if the basic assumption of equal mixing of tagged carcasses with all carcasses is violated, resulting in the recaptured carcasses constituting a different subpopulation.

Historical Background

The history of efforts to enumerate spawner escapement in the upper Sacramento River has been described by Needham *et. al*. (1943), Fry (1961), Menchen (1970), Snider *et. al*. (1997), and Snider *et. al*. (1998); therefore, it is only briefly reviewed here.

- **1937–1942** Spawner escapement estimates were first made by counting salmon moving through the fish ladder at the ACID dam at river mile (RM) 298.5, near Redding. Annual counts were normally made from April through October or early November, when the dam was installed for irrigation.

- **1943--1945** Salmon were counted at a weir located downstream of Balls Ferry Bridge (RM 278.5).

- **1945--1952** The FWS estimated escapement using "ground level spawning area surveys" (Fry 1961).

- **1950--1955** The DFG estimated spawner escapement by first capturing, tagging, and releasing live salmon at Fremont Weir (RM 82.5), then later recovering them as carcasses on the spawning grounds in the upper Sacramento River (Fry 1961).

- **1956--1968** The DFG estimated escapement using carcass counts and aerial redd counts. Experienced personnel estimated the proportion of salmon observed, based upon survey conditions and previous years' experience then expanded the "counts" accordingly.

- **1969--1985** Estimates were based on season-long counts of salmon moving through the fish ladders at Red Bluff Diversion Dam (RBDD) (RM 243). Aerial redd counts were used to determine the proportions of the run spawning above and below RBDD.
- **1986--present** The DFG has annually estimated fall-run escapement using both counts

[1] Personal communication with Frank Fisher (DFG-Inland Fisheries Division, Red Bluff) and Fred Meyer (DFG -Region 2, Sacramento (retired)).

made at RBDD and aerial redd surveys. Since 1986, RBDD's gates are typically open between mid-September and mid-May of the following year improving fish passage but eliminating direct counts at the ladders during up to 8 months of the year. The number of fall-run spawners migrating upstream of RBDD is now based upon an expansion of the number of fish counted when the gates are lowered and fish have to pass through the ladders to migrate above the diversion dam.

When monitoring stocks over a long period, as is the case for the Central Valley salmon escapement surveys, the sampling design should assure the data be collected in a consistent manner and represent the population as a whole (Ney 1993). Lack of these attributes from the Central Valley surveys should not reflect on persons who made population estimates, but on logistic limitations. Annual budgets for temporary employees needed to conduct the escapement surveys were often reduced or eliminated resulting in estimates based on less data. In addition, population estimates were often based on counts made upstream of substantial areas of fall-run spawning activity, e.g., ACID dam, Balls Ferry, and RBDD (Figure 1).

Objectives

The objectives of the upper Sacramento River fall-run chinook salmon escapement survey were:

- To estimate the in-river, fall-run chinook salmon spawning population in the upper Sacramento River upstream of Cottonwood Creek.

- To determine egg-retention rate and sex and age composition of fall-run chinook salmon spawning in the upper Sacramento River.

- To augment redd surveys to provide baseline information on spawning distribution, spawning habitat availability, instream flow requirements, and the status of chinook salmon in the upper Sacramento River.

METHODS

The 1999 spawner escapement surveys began immediately following the initial observation of spawning activity and then were conducted weekly from 27 September through 16 December 1999. The 26.5-mile-long survey section, from ACID dam (RM 298.5) downstream to the mouth of Cottonwood Creek (RM 273.0; Figure 1), was divided into four reaches (Table 1). Each reach was surveyed one day per week.

Table 1. Location of survey reaches during the upper Sacramento River fall-run chinook salmon escapement survey, September–December 1999.

Reach	Location	River mile (length in miles)
1	ACID Dam to Cypress St. Bridge	298.5–295 (3.5)
2	Cypress St. Bridge to Bonnyview Bridge	295–292 (3.0)
3	Bonnyview Bridge to North St. Bridge	292–284 (8.0)
4	North St. Bridge to Cottonwood Bridge	284–273 (11.0)

Surveys were primarily conducted using two boats with two observers per boat. The observers attempted to locate and collect carcasses as each boat traversed the river between the center of the channel and one of the channel margins. Collected carcasses were checked for completeness (i.e., with the head intact) and previous tags. Complete, untagged carcasses were usually tagged by attaching a colored ribbon (to indicate period tagged) to the jaw using a hog ring. Carcasses that were not tagged were chopped in half. Chopped carcasses included:
i) those previously tagged, ii) those on shore in a "leathery condition"; iii) those in Reach 4 (the most downstream reach) that would likely wash out of the survey area and never be recovered; and, iv) carcasses in excess of the number that crews could tag during a day. Tagged carcasses were released into running water for recapture to simulate conditions of a naturally dying or dead fish. Data collected included number tagged, number chopped, and number recovered.

All carcasses were also examined for eye clarity and gill color to determine freshness. Carcasses were considered fresh if either eye was clear or gills were pink. Data collected from a subsample of the fresh carcasses included gender, fork length (FL) in centimeters, reach of the stream that each carcass was observed, and egg retention for females. Females were classified as spent if few eggs were remaining; as partially spent if a substantial amount of the eggs remained; and unspent if the ovaries appeared nearly full of eggs.

To be consistent with the standard protocol that has been used on most Central Valley streams, escapement estimates were determined using fresh carcass data to calculate a Schaefer model

estimate, and both fresh and decayed carcass data to calculate a Jolly-Seber model estimate.

The formulas used to derive the escapement estimates (E) are as follows:

Schaefer model (as described by Taylor 1974): $E = N_{ij} = R_{ij}(T_iC_j/R_iR_j) - T_i$

where:

N_{ij} = Population size in tagging period *i* recovery period *j*,
R_{ij} = number of carcasses tagged in the *i*th tagging period and recaptured in the *j*th recovery period,
T_i = number of carcasses tagged in the *i*th tagging period,
C_j = number of carcasses recovered and examined in the *j*th recovery period,
R_i = total recaptures of carcasses tagged in the *i*th tagging period, and
R_j = total recaptures of tagged carcasses in the *j*th recovery period.

This model differs from the original in that the number of tags applied after the first period is subtracted from the population estimate to account for sampling with replacement. Schaefer's original model was based on sampling without replacement while in salmon survey conditions, sampling occurs with replacement.

Jolly-Seber model (as described by Boydstun 1994): $E = N_1 + D_1 + D_2... + D_j$

where:

N_1 = Number of carcasses in the population in period 1, the first period of spawning and dying, and
D_i = number of carcasses that joined the population between periods *i* and *i*+1, with j as the last survey period.

Flow measurements for each day surveyed were obtained from the Keswick gauge operated by the U.S. Geological Survey. Water temperature (grab sample) and water visibility (Secchi depth) were measured daily by the survey crew.

RESULTS

A total of 5,652 carcasses was observed (Table 2). Mean weekly flow was 6,700 cfs at the onset of the survey, then gradually decreased to 6,000 cfs in period 3 before stabilizing at 6,200 cfs from period 5 through period 9. Flow then increased during periods 10 and 11 to a high of 8,100 cfs and then decreased to 6,800 cfs in period 12 (Table 2, Figure 2). Average weekly temperature narrowly ranged from 52 ˚F to 53 ˚F throughout the survey (Table 2, Figure 2). Water clarity (Secchi depth) ranged from 7 ft in period 8 (23–25 November) up to 12 ft in periods 3 and 12 (Table 2, Figure 2).
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Temporal Distribution

The number of observed carcasses steadily increased from period 1 through period 5 when the total weekly carcass count peaked at 809. After peaking in period 5, the numbers of carcasses fluctuated from a low of 304 in period 10 to a high of 791 in period 7 (Table 2 and Figure 3).

Spatial Distribution

The spatial distribution of all observed carcasses was 30% in Reach 1, 37% in Reach 2, 23% in Reach 3, and 10% in Reach 4 (Table 3 and Figure 4).

Size Distribution

A total of 1,137 carcasses was measured (Table 4). Mean size was 78.9 cm FL (range: 35–110 cm FL, SD = 13.9). Male salmon (n = 571) averaged 77.3 cm FL (range: 35–110 cm FL, SD = 17.9) (Figure 5). Female salmon (n = 566) averaged 80.5 cm FL (range: 45–98 cm FL) (Figure 6). The weekly mean size of males ranged from 64.7 to 89.6 cm FL (Figure 7). Weekly mean size of females ranged from 74.9 to 83.1 cm FL (Table 4 and Figure 8).

Length-frequency distributions were used to define a general size criterion distinguishing grilse (2-year-old salmon) and adults (>2-year-old salmon) for each sex (Figures 5 and 6). Male grilse (n = 246) were defined as salmon $\leq$71 cm FL, and female grilse (n = 19) were defined as salmon $\leq$66 cm FL (Table 5). Male grilse averaged 58.8 cm FL (range: 35–71 cm FL, SD = 17.9); male adults (n = 325) averaged 91.3 cm FL (range: 72–110 cm FL, SD = 8.6). Female grilse averaged 60.3 cm FL (range: 45–66 cm FL, SD = 5.8); female adults (n = 547) averaged 81.2 FL (range: 67–98 cm FL, SD = 6.7).

Grilse comprised 23% (265) of the 1,137 measured carcasses (Table 6). The greatest number of grilse (64) was observed during the last survey period (13–16 December) (Figure 9). Adults comprised 77% (872) of the measured carcasses. The greatest number of adults (163) was observed during Period 4 (18–21 October).

Table 2. General survey information for the upper Sacramento River fall-run chinook salmon escapement survey, September–December 1999.

Period	Dates	Flows (cfs)[1/]	Secchi depth (ft)[2/]	Water temperature (°F)[2/]	Carcass count[3/]		
					Fresh	Decayed	Total
1	Sep 27–30	6,700	9	52	21	9	30
2	Oct 4–7	6,400	10	53	76	90	166
3	Oct 12–15	6,000	12	53	143	235	378
4	Oct 18–21	6,000	11	53	194	498	692
5	Oct 25–28	6,200	9	53	178	631	809
6	Nov 1–4	6,200	11	53	123	594	717
7	Nov 8–12	6,200	9	53	95	696	791
8	Nov 15–18	6,200	7	52	49	368	417
9	Nov 22–24	6,200	10	52	62	305	367
10	Nov 29–Dec 2	7,800	8	52	62	242	304
11	Dec 6–10	8,100	11	52	106	342	448
12	Dec 13–16	6,800	12	52	118	415	533
				Totals	1,227	4,425	5,652

1/ Weekly average discharge (during the days sampled) measured at Keswick Dam by U.S. Bureau of Reclamation.
2/ Weekly average of daily measurements taken by survey crews.
3/ Includes both adults and grilse.

Table 3. Distribution by reach of carcasses (adults and grilse) observed during the upper Sacramento River fall-run chinook salmon escapement survey, September–December 1999.

Period	Reach 1 (River mile 298.5–295)		Reach 2 (River mile 295–292)		Reach 3 (River mile 292–284)		Reach 4 (River mile 284–273)	
	M[1/]	C[2/]	M	C	M	C	M	C
1	11	0	15	0	3	0	1	0
2	42	0	51	3	48	7	15	0
3	115	0	158	3	70	4	27	1
4	177	3	204	5	169	9	114	11
5	206	6	321	19	181	18	54	4
6	143	16	202	29	170	30	111	16
7	144	45	238	138	120	39	47	20
8	75	27	113	55	78	33	31	5
9	58	31	85	46	66	36	30	15
10	99	40	52	31	48	18	13	3
11	0	234	0	117	0	77	0	20
12	0	234	0	199	0	93	0	7
Totals	1,070	636	1,439	645	953	364	443	102
%	30		37		23		10	

1/ Number of carcasses tagged.
2/ Number of untagged carcasses chopped.

Table 4. Size and sex statistics for fresh fall-run chinook salmon carcasses measured during the upper Sacramento River escapement survey, September–December 1999.

Period	All salmon			Male salmon			Female salmon		
	Number measured	Length (FL in cm)		Number measured	Length (FL in cm)		Number measured	Length (FL in cm)	
		Mean	Range		Mean	Range		Mean	Range
1	21	78.7	45–103	13	81.1	45–103	8	74.9	55–86
2	65	78.7	46–105	37	80.0	46–105	28	77.0	52–93
3	123	81.6	53–102	56	85.2	53–102	67	78.6	62–98
4	180	84.9	49–110	85	89.6	49–110	95	80.7	60–97
5	169	80.5	49–103	67	79.7	49–103	102	81.0	69–98
6	120	80.3	48–107	48	81.1	48–107	72	79.8	59–96
7	89	77.9	35–105	37	73.5	35–105	52	81.0	66–98
8	47	80.2	47–103	22	77.5	47–103	25	82.6	64–94
9	61	77.1	45–105	34	74.3	45–105	27	80.8	60–97
10	60	76.7	44–103	36	72.6	44–103	24	82.8	65–97
11	84	70.1	37–101	55	64.7	37–101	29	80.4	45–97
12	118	71.8	45–104	81	66.5	45–104	37	83.1	50–97
Total (mean)	1,137	(78.9)	35–110	571	(77.3)	35–110	566	(80.5)	45–98

Table 5. Summary of adult and grilse sizes and numbers by sex for carcasses measured during the upper Sacramento River fall-run chinook salmon escapement survey, September–December 1999.

	Female		Male	
	Grilse	Adults	Grilse	Adults
Number	19	547	246	325
Mean FL (cm)	60.3	81.2	58.8	91.3
Range FL (cm)	45–66	67–98	35–71	72–110
Standard Deviation	5.8	6.7	17.9	8.6

Table 6. Age composition (grilse and adult) of carcasses measured during the upper Sacramento River fall-run chinook salmon escapement survey, September–December 1999.

	Adults		Grilse	
Period	Number	Percent	Number	Percent
1	17	81	4	19
2	54	83	11	17
3	115	93	8	7
4	163	91	17	9
5	147	87	22	13
6	100	83	20	17
7	67	75	22	25
8	36	77	11	23
9	41	61	20	39
10	37	62	23	38
11	41	49	43	51
12	54	46	64	54
Total(mean)	872	(77)	265	(23)

Sex Composition

Males comprised 37% (n = 325) of the fresh adult carcasses examined; females comprised 63% (n = 547) (Table 7). Males comprised 93% of the grilse (n = 246); females comprised 7% (n = 19). Females comprised 50% (n = 566) of the all fresh carcasses; males comprised 50% (n = 571). The female to male ratio for adult spawners was nearly 1.7:1 (547:325) (Table 7 and Figure 10). Females dominated the adult population after period 2. The grilse population was heavily dominated by males for the entire survey (Figure 11).

Spawning Success

There were 494 females examined for egg retention (Table 8): 463 (94%) had completely spawned, 10 (2%) had only partially spawned, and 21 (4%) had not spawned. At least 85% of the females checked each period had completely spawned.

Population Estimates

Only fresh carcass data were used to calculate the Schaefer estimate. A total of 835 fresh adult carcasses was tagged and 287 (34%) were subsequently recaptured. Both fresh and decayed carcass data were used to calculate the Jolly-Seber estimate. A total of 3,412 fresh and decayed adult carcasses was tagged, and 1,077 (32%) were subsequently recaptured.

An estimate of 14,031 adult spawners was calculated using the Schaefer model (Tables 9 and 10). Since adults made up 76.7% of the total escapement based on measured carcasses (Table 6), a total escapement estimate of 18,295 spawners (adults and grilse) was calculated by dividing the adult estimate by 0.767. An adult escapement estimate of 10,598 was calculated using the Jolly-Seber model (Table 11). This estimate was similarly expanded by dividing by 0.767 resulting in a total escapement estimate of 13,818 spawners.

The 1999 salmon spawner population estimates for the upper Sacramento River (from Cottonwood Creek to ACID Dam) are as follows:

	Schaefer model	Jolly-Seber model
Total estimate	18,295	13,818
Adult estimate	14,031	10,598
Grilse estimate	4,264	3,220

The estimated 1999 escapement (18,295) is considerably less than the 1956–1999 average (65,492) for the section of stream from RBDD to Keswick Dam (Table 12 and Figure 12). .

Table 7. Sex composition of fall-run chinook salmon grilse and adult carcasses measured during the upper Sacramento River escapement survey, September–December 1999.

Period	Adults				Grilse*			
	Male		Female		Male		Female	
	Number	%	Number	%	Number	%	Number	%
1	10	59	7	41	3	75	1	25
2	29	54	25	46	8	73	3	27
3	49	43	66	57	7	88	1	12
4	73	45	90	55	12	71	5	29
5	45	31	102	69	22	100	0	0
6	29	29	71	71	19	95	1	5
7	16	24	51	76	21	95	1	5
8	12	33	24	67	10	91	1	9
9	15	37	26	63	19	95	1	5
10	15	41	22	59	21	91	2	9
11	14	34	27	66	41	95	2	5
12	18	33	36	67	63	98	1	2
Total (mean)	325	(37)	547	(63)	246	(93)	19	(7)

* Based on length-frequency distributions, male adults are defined as salmon >71 cm FL and female grilse as salmon > 66 cm FL.

Table 8. Spawning completion (egg retention) summary for female fall-run chinook salmon carcasses measured during the upper Sacramento River escapement survey, September–December 1999.

Period	No. females measured	No. females checked for egg retention	Number spawned (%)	Number partially spawned (%)	Number unspawned (%)
1	8	8	8(100)	0(0)	0(0)
2	28	22	21(95)	1(5)	0(0)
3	67	59	57(96)	1(2)	1(2)
4	95	89	76(85)	4(5)	9(10)
5	102	100	99(99)	0(0)	1(1)
6	72	63	60(95)	1(2)	2(3)
7	52	50	47(94)	0(0)	3(6)
8	25	21	18(86)	2(9)	1(5)
9	27	22	19(86)	1(5)	2(9)
10	24	22	20(91)	0(0)	2(9)
11	29	14	14(100)	0(0)	0(0)
12	37	24	24(100)	0(0)	0(0)
Total (mean)	566	494	463(94)	10(2)	21(4)

Table 9. Weekly summary of tagging and recapture of fresh adult chinook salmon carcasses during the upper Sacramento River escapement survey, September–December 1999.

Schaefer model capture-recapture data matrix

Period of recovery (j)	Period of tagging$_{(i)}$										Tags recovered $R_{(j)}$	Carcasses counted $C_{(j)}$	Ratio $C_{(j)}/R_{(j)}$
	1	2	3	4	5	6	7	8	9	10			
2	4										4	176*	44.00
3		18									18	368	20.44
4		3	39								42	688	16.38
5		3	11	37							51	784	15.37
6		1	8	14	28						51	689	13.51
7			2	9	13	23					47	714	15.19
8				2	4	6	10				22	370	16.82
9					1	5	3	8			17	315	18.53
10						1	5	3	12		21	248	11.81
11									1	7	8	309	38.63
12									4	2	6	320	53.33
$R_{(i)}$	4	25	60	62	46	35	18	11	17	9	<- Tagged fish recovered		
$T_{(i)}$	17	65	134	173	158	104	66	35	46	37	<- Total fish tagged		
$T_{(i)}/R_{(i)}$	4.25	2.60	2.23	2.79	3.43	2.97	3.67	3.18	2.71	4.11	<- Ratio		

* Included carcasses observed during Period 1.

Table 10. Upper Sacramento River adult fall-run chinook salmon population estimate using the Schaefer model based on tagging fresh carcasses with all captured untagged carcasses removed, September–December 1999.

Population estimate

Period of recovery $_{(j)}$	Period of tagging $_{(i)}$										Totals
	1	2	3	4	5	6	7	8	9	10	
2	748										748
3		957									957
4		128	1,427								1,555
5		120	378	1,587							2,085
6		35	241	528	1,299						2,104
7			68	382	678	1,038					2,166
8				94	231	300	617				1,241
9					64	275	204	472			1,014
10						35	217	113	383		748
11									105	1,112	1,216
12									577	439	1,016
Subtotals	748	1,240	2,114	2,290	2,272	1,648	1,037	584	1,065	1,550	14,849
Tags		-65	-134	-173	-158	-104	-66	-35	-46	-37	-818
									Population estimate -		14,031

Table 11. Weekly summary of tagging and recapture of both fresh and decayed adult chinook salmon carcasses during the upper Sacramento River escapement survey, September–December 1999.

Jolly-Seber capture-recapture data matrix

Tagging period	Number tagged	Carcasses examined	Recaptures of fish marked in period										Tags recovered
			1	2	3	4	5	6	7	8	9	10	
1	25	25											
2	139	151	4										4
3	342	382	2	30									32
4	620	748		8	94								102
5	691	891		5	26	127							158
6	553	836		4	14	41	139						198
7	461	892			6	23	68	128					225
8	240	489				3	19	24	95				141
9	187	402					2	16	30	56			104
10	254	296						4	10	15	40		69
11	0	333									4	28	32
12	0	326									8	4	12
Totals	3,512	5,771	6	47	140	194	228	172	135	71	52	32	1,077

Adult population estimate = 10,598
Total population estimate = 13,818 (includes 3,220 grilse)

Table 12. Annual fall-run chinook salmon escapement estimates (adults and grilse) for upper Sacramento River from Red Bluff Diversion Dam to Keswick Dam, 1956–1998[1/].

Year	Totals	Year	Totals[2/]
1956	84,716	1978	32,235
1957	47,300	1979	47,758
1958	99,300	1980	21,961
1959	249,600	1981	26,261
1960	210,000	1982	17,731
1961	134,700	1983	26,226
1962	115,500	1984	36,898
1963	135,200	1985	51,647
1964	140,500	1986	67,958
1965	98,900	1987	76,039
1966	107,900	1988	65,204
1967	78,100	1989	48,512
1968	95,600	1990	32,225
1969	114,600	1991	19,272
1970	65,950	1992	26,912
1971	52,247	1993	33,923
1972	33,559	1994	31,017
1973	40,424	1995	28,030(26,548)[3/]
1974	45,590	1996	30,194(28,890)
1975	52,248	1997	95,505(26,191)
1976	43,612	1998	4,824(14,211)
1977	15,784	1999	48,418(18,295)

Annual average for 1953 through 1999 period = 65,492[4/]

1/ RBDD ladder count estimates for the years 1995 through 1999 were used in the calculation. Escapement estimates for years 1956 through 1968 were based on a combination of carcass counts and aerial redd counts. Estimates for years 1968 through 1985 were based on ladder counts made at RBDD during the entire run. Estimates for years after 1985 were based on ladder counts made at RBDD during a portion of the run.

2/ Estimate based on carcass tagging studies.

3/ Estimates in parenthesis are based on carcass survey results.

4/ Average was calculated using annual escapements estimates from the RBDD counts for 1995–1999.

Coded-wire Tag Recoveries

We collected 15 adipose-fin clipped carcasses indicating that these fish possessed a coded-wire tag (CWT). Nine of these fish still contained a CWT (Table 13). Only three of the tagged fish were from CNFH, the closest hatchery and the closest point of release to the survey area. Five tagged fish were from Feather River Hatchery that had been released in at two different locations including three released into the lower Sacramento River at Miller Park (RM 47) and two released into the Delta near Rodeo. Most of the tagged fish were observed earlier in the survey. Three of these fish were from the 1995 brood year (4-years old), 5 from the 1996 brood year and 1(grilse) from the 1997 brood year.

DISCUSSION

Carcass surveys have been annually conducted on the Sacramento River since 1995 to acquire data on the river's fall-run chinook spawning population. Our purpose was to determine if this method would provide reliable information on abundance and age and sex composition of the spawner population, temporal and spatial distribution of spawning and pre spawning mortality (egg retention), and if these data in combination with results of other investigations (e.g., redd surveys and RBDD fish counts) could be used to identify any influences of flow, temperature, channel morphology, or other habitat conditions on the functioning of the river's fall-run population. Results obtained during the five survey years (1995–1999) have been very consistent. It appears that this approach can provide the targeted information needed to improve our understanding of the dynamics of the river's fall-run population, and ultimately its relationship with manageable habitat conditions.

- Fall-run spawner escapement estimates have been very consistent during the four survey years (Table 14). The estimates for the first three years were essentially identical ranging from 25,890 to 26,246 salmon (mean=26,209, SD=268). Tag recovery rates were also nearly equal during the first three years (mean=32%. SD=0.82). The population estimate decreased in 1998 to 14,211 as did the recovery rate (24%). In 1999, the population estimate increased slightly to 18,295 (recovery rate = 34%).

- Escapement estimates were also made for the reach from RBDD to Keswick using fish counts made at RBDD and redd distribution data. Escapement estimates for this reach were similar to the carcass survey based estimates in 1995 (28,030 v. 26,546) and 1996 (30,184 v. 25,890), but were considerably different in 1997 (95,505 v. 26,191), 1998 (5,386 v. 14,211) and 1999 (48,418 v. 18,295).

Table 13. Summary of statistics for adipose-clipped (hatchery produced) carcasses observed during the upper Sacramento River fall-run chinook salmon escapement survey, September - December 1999.

Collection Data				Coded-wire tag data				
Date	Reach	Sex	FL (cm)	Tag code	Race	Brood year	Hatchery of origin	Release site
4 Oct	1	M	90	06-01-06-02-11	fall	96	FRH	Miller Park
6 Oct	2	M	77	lost half tag				
6 Oct	3	F	77	06-01-06-02-11	fall	96	FRH	Miller Park
6 Oct	3	F	78	no tag				
13 Oct	2	M	102	no tag				
13 Oct	2	F	67	06-01-06-02-11	fall	96	FRH	Miller Park
18 Oct	1	F	61	no tag				
19 Oct		F	89	06-01-14-05-07	fall	95	FRH	Rodeo
20 Oct	3	M	95	no tag				
21 Oct	4	M	56	05-01-02-06-11	fall	97	CNFH	CNFH
21 Oct	4	F	82	05-01-02-02-12	fall	96	CNFH	CNFH
21 Oct	4	M	95	no tag				
1 Nov	1	F	84	05-01-02-01-14	fall	95	CNFH	CNFH
3 Nov	3	M	99	06–29-38	fall	95	FRH	Rodeo
23 Nov	3	F	74	06-49-13	fall	96	MRH	Jersey Pt

Table 14. Comparison of results of carcass surveys conducted on the upper Sacramento River fall-run chinook salmon spawner population from 1995 through 1998.

	1995	1996	1997	1998	1999
Total estimate	26,546	25,890	26,191	14,211	18,295
% Adult	91	79	90	86	77
% Grilse	9	21	10	14	23
% Female adult	66.4	65.7	59	63.5	48
% Male adult	33.6	34.3	41	36.5	29
% Female all	62	54	55	63	2
% Male all	38	46	45	37	21
Tag recovery rate (%)	33	32	31	24	34
Spawning success	94	87	92	96	94
Reach 1 %	40	23	28	29	30
Reach 2 %	21	37	34	36	37
Reach 3 %	23	26	24	23	23
Reach 4 %	16	14	14	12	10
Peak carcass count period	6 (11/5–11)	5 (10/28–11/1)	5 (10/27–30)	6 (11/2–5)	5 (10/25–28)
Flow range	4,800-6,500	6,700-27,700	4,200-6,300	6,200-23,400	6,000-8,100
Temperature range	53-57	53-56	53-57	51-55	52-53
Male grilse size criteria (cm)	64	73	72	71	71
Female grilse size criteria (cm)	64	64	66	67	66

The RBDD count based estimate includes 31.5 miles not covered in the carcass survey (3.5 miles upstream of the carcass survey reach, from ACID to Keswick Dam, and 28 miles downstream from the survey reach from Cottonwood Creek to RBDD). Redd survey data, however, indicate that few salmon spawn upstream of ACID and downstream of Cottonwood Creek. The carcass survey results also indicate that spawning activity decreases moving downstream (Table 14). (The proportion of carcasses found in the lowermost 11 miles (43%) of the survey area has averaged about 12%). Comparison of the two estimates for 1995 and 1996 suggest that from 86 to 95% of spawning occurred within the carcass survey reach. A similar comparison among the 1997 and 1999 estimates suggests that only 27% to 37% of spawning occurred in the carcass survey reach. Since the 1998 carcass survey based estimate was nearly 3-fold the RBDD based estimate, no comparison could be made.

- Age composition of the spawner population varied from 91% to 77% adults (Table 14). There was no relationship observed between percent grilse and the estimated adult population for the subsequent year.

- Sex composition varied only slightly during the five survey years (Table 14). The percentage of female adults ranged from 59% (1997) to 66.4% (1995) (mean = 63.5, SD=2.6). The total percentage of female (grilse and adult) ranged from 50% (1999) to63% (1998) (mean=56.8, SD=5.0).

- Spatial spawning distribution (based upon location of fresh carcass collection) varied slightly within Reaches 1 and 2 and was fairly consistent in Reaches 3 and 4 (Table 14). The majority of spawning occurred within Reaches 1 and 2, accounting for at least 60% of all spawning (mean=63%, SD=2.6). Spawning within these two reaches has been predominantly in Reach 2, although nearly twice as much spawning was observed in Reach 1 versus 2 in 1995 (the only year when spawning was greater in Reach 1). Spawning within Reach 3 averaged 24%; (SD = 1.2); spawning in Reach 4 averaged 13% (SD = 2.0).

- Spawning consistently peaked during the last week of October and first week of November. Fresh and decayed carcasses were also observed during the first survey period (typically the first week of October) of each year.

- Spawning success, measured as percentage of completely spent female carcasses, ranged from 87% to 96%. The lowest spawning success was measured in 1996 when the overall population was highest; the highest success was measured in 1998 when overall population was lowest.

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FIGURES

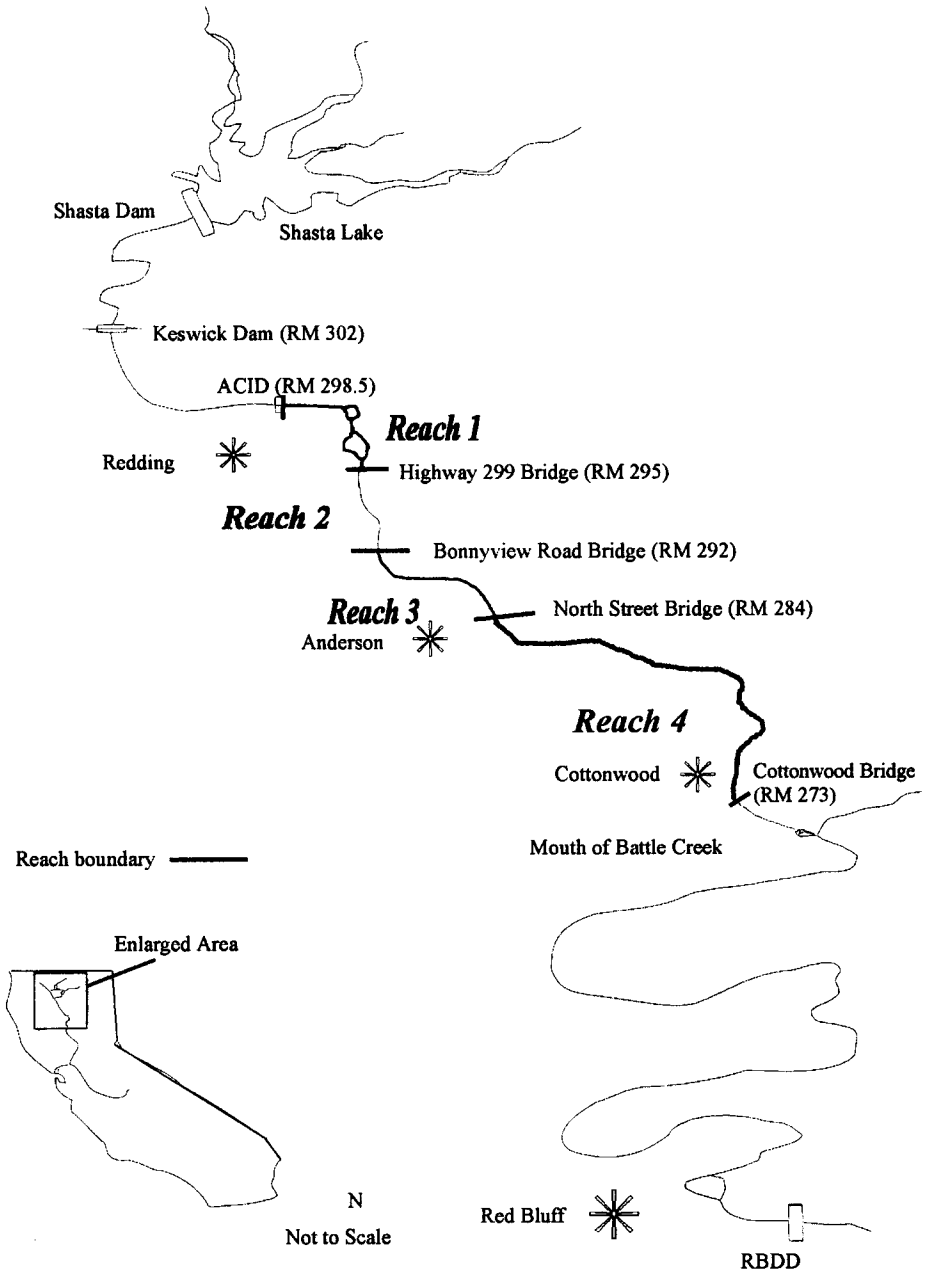

Figure 1. Location of upper Sacramento River fall-run Chinook salmon spawner escapement survey.

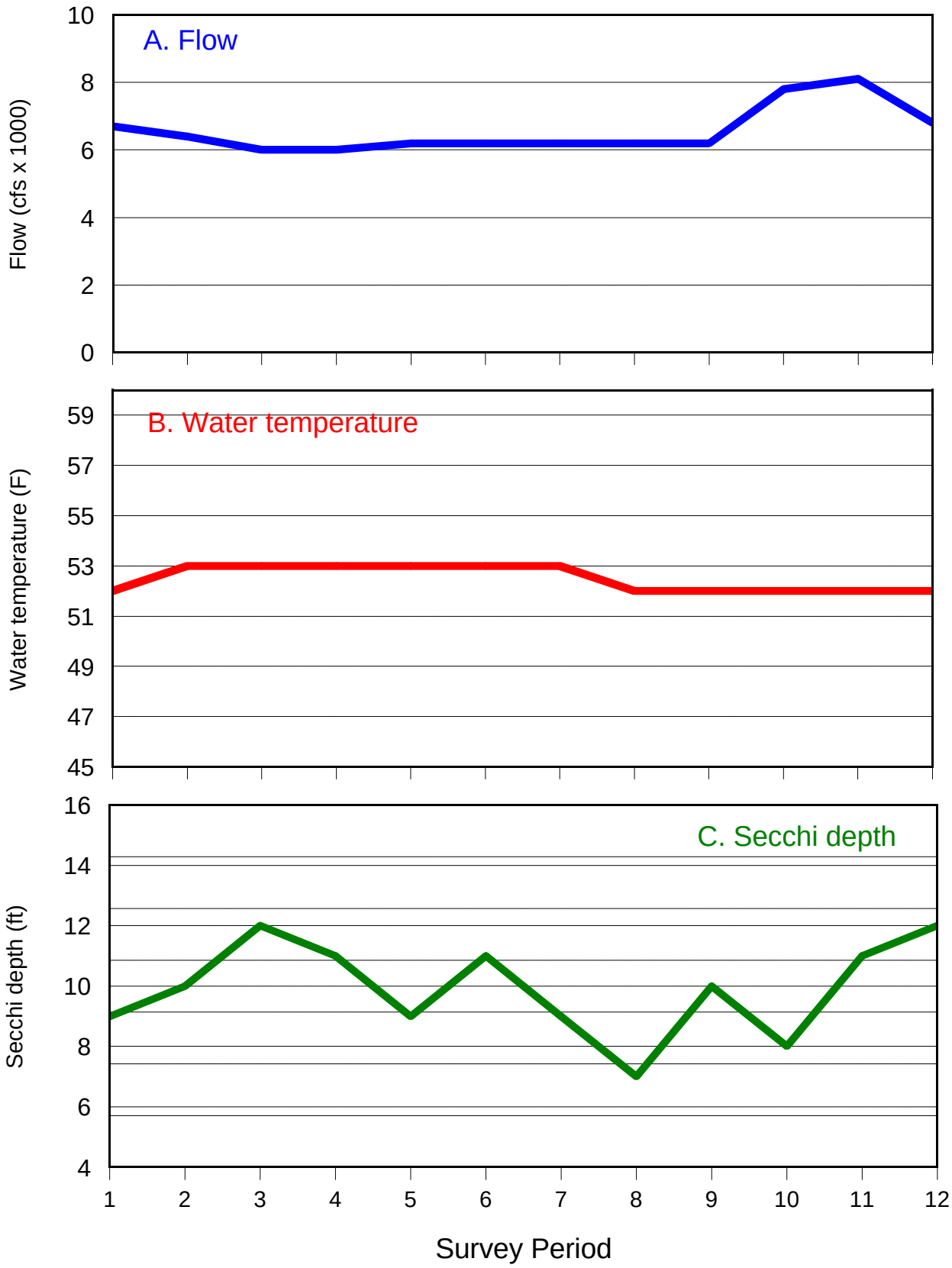

Figure 2. Mean daily flow at Keswick Dam (A), water temperature (B), and Secchi depth (C), measured during the upper Sacramento River fall-run chinook salmon spawner escapement survey, September--December 1999.

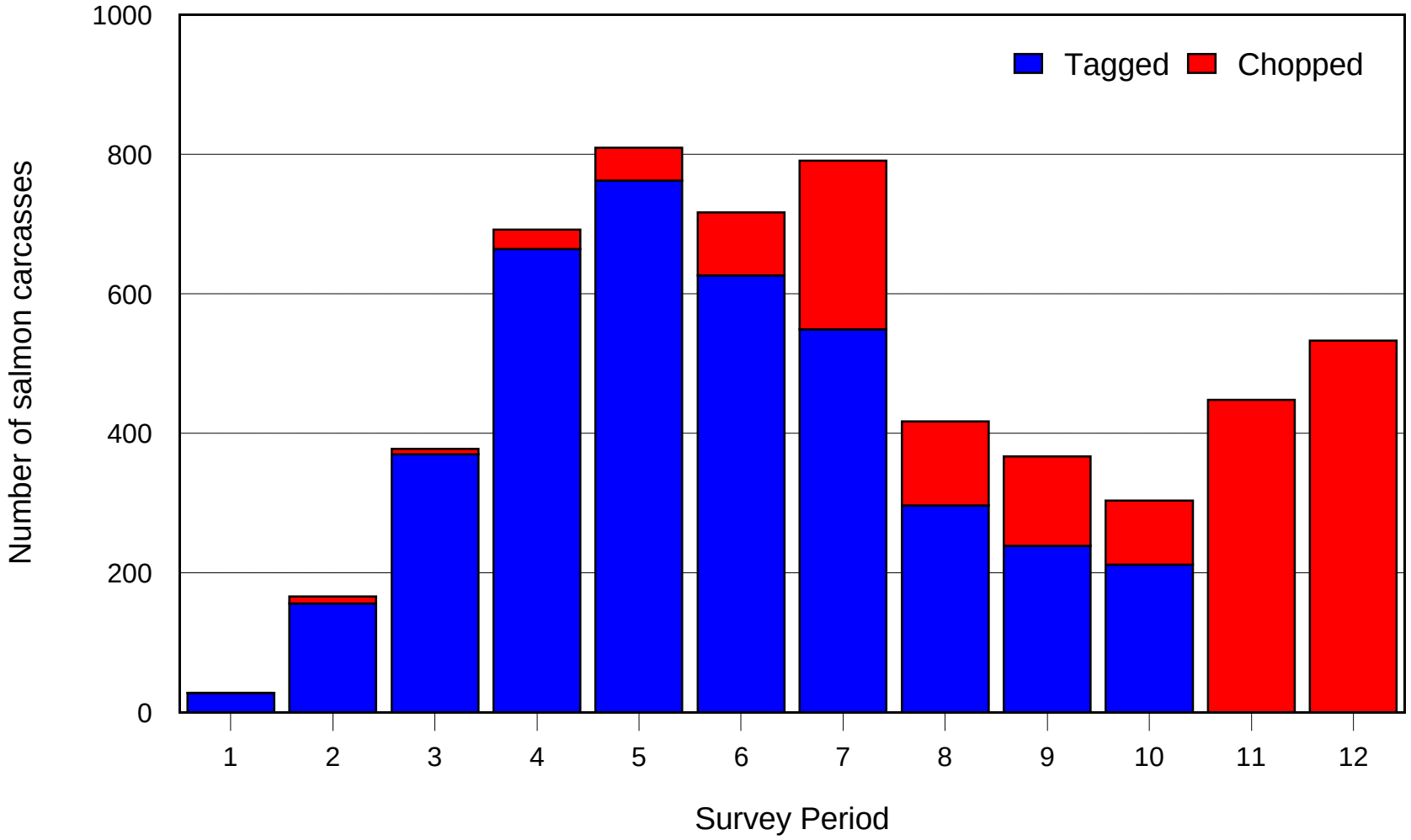

Figure 3. Weekly distribution of both fresh and decayed carcasses (adult and grilse) observed during the upper Sacramento River fall-run chinook salmon spawner escapement survey, September--December 1999.

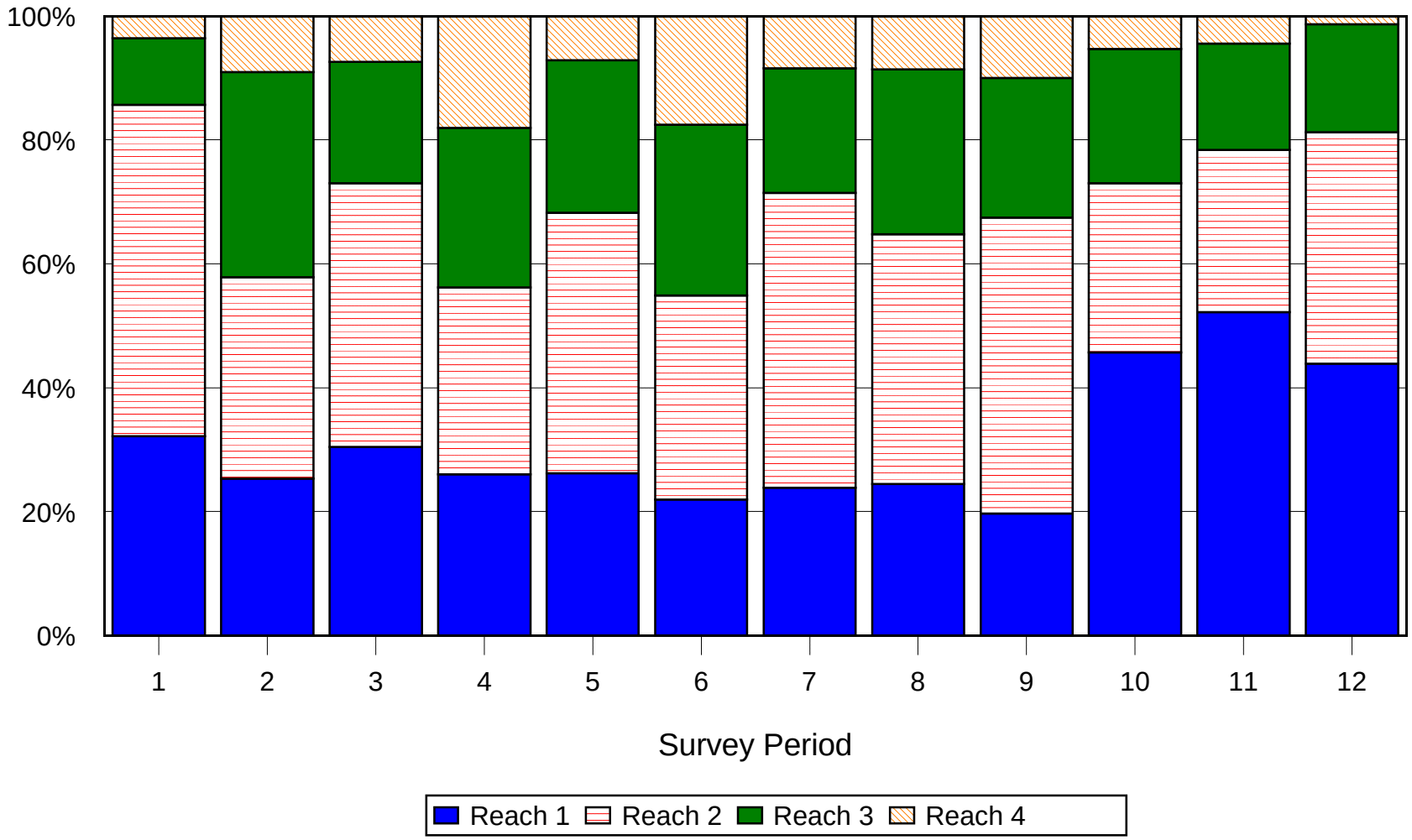

Figure 4. Weekly distribution (%) by reach of both fresh and decayed carcasses observed during the upper Sacramento River fall-run chinook salmon spawner escapement survey, September - December 1999.

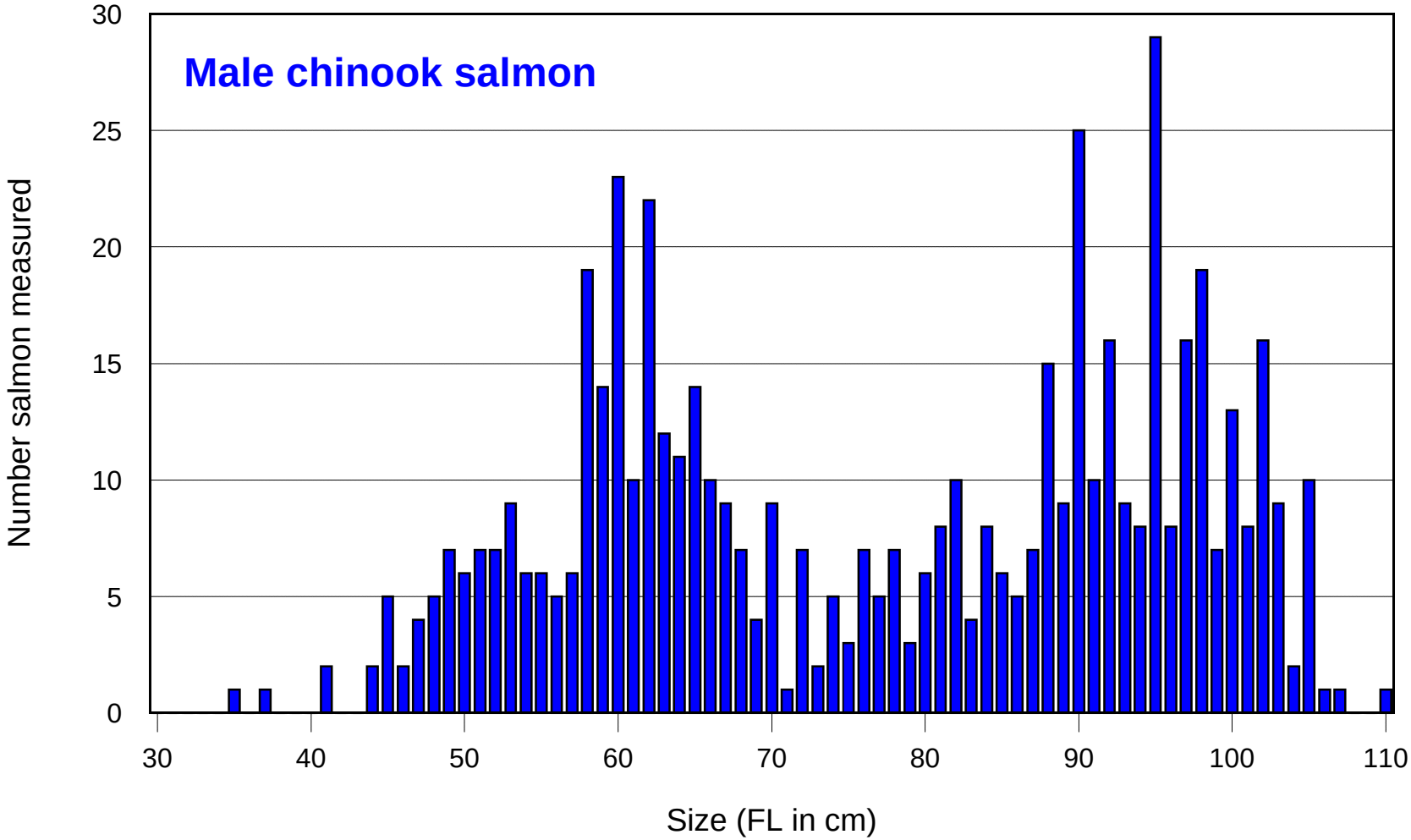

Figure 5. Size (FL in cm) distribution of male chinook salmon carcasses measured during the upper Sacramento River fall-run spawner escapement survey, September - December 1999.

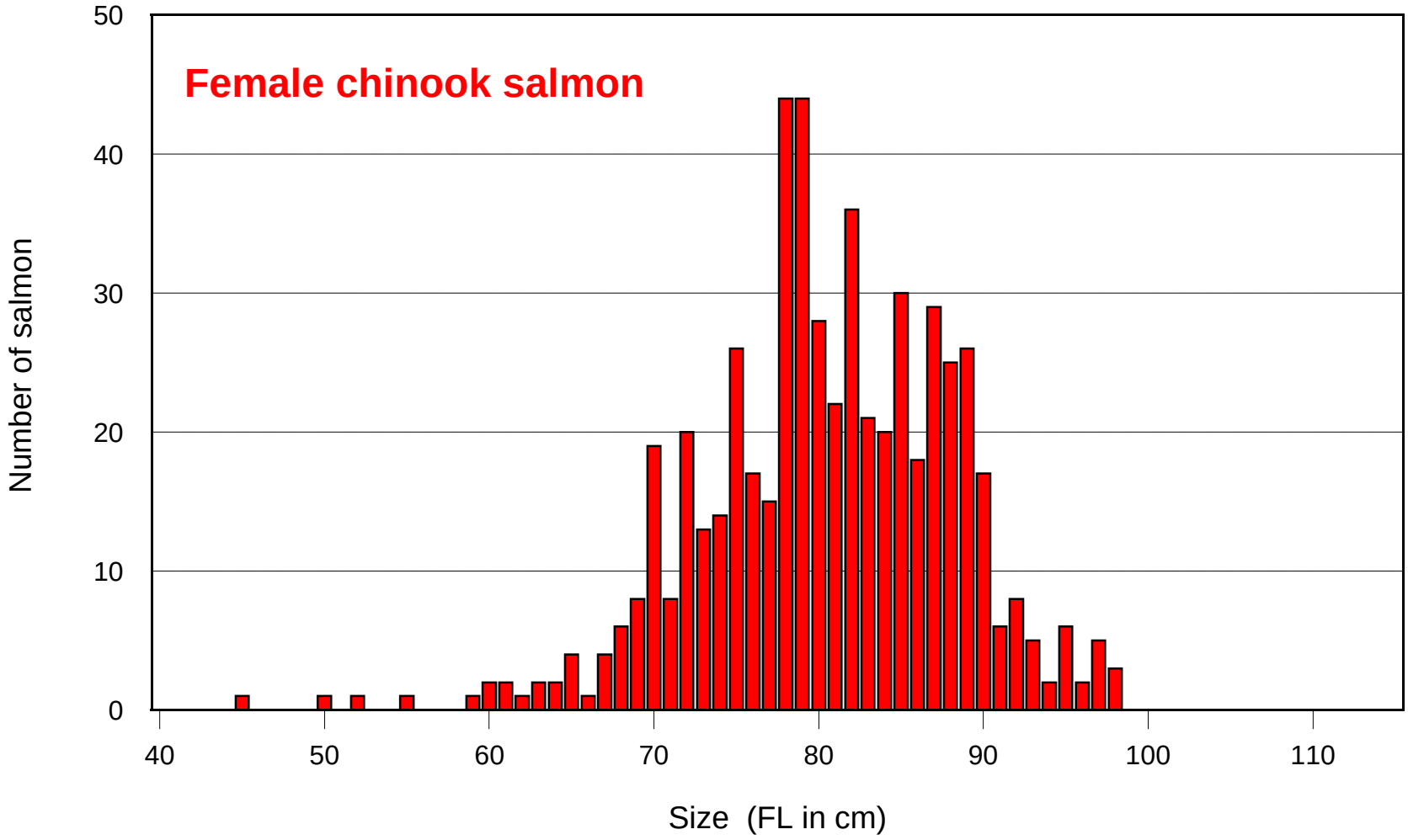

Figure 6. Size (FL in cm) distribution of female chinook salmon carcasses measured during the upper Sacramento River fall-run spawner escapement survey, September - December 1999.

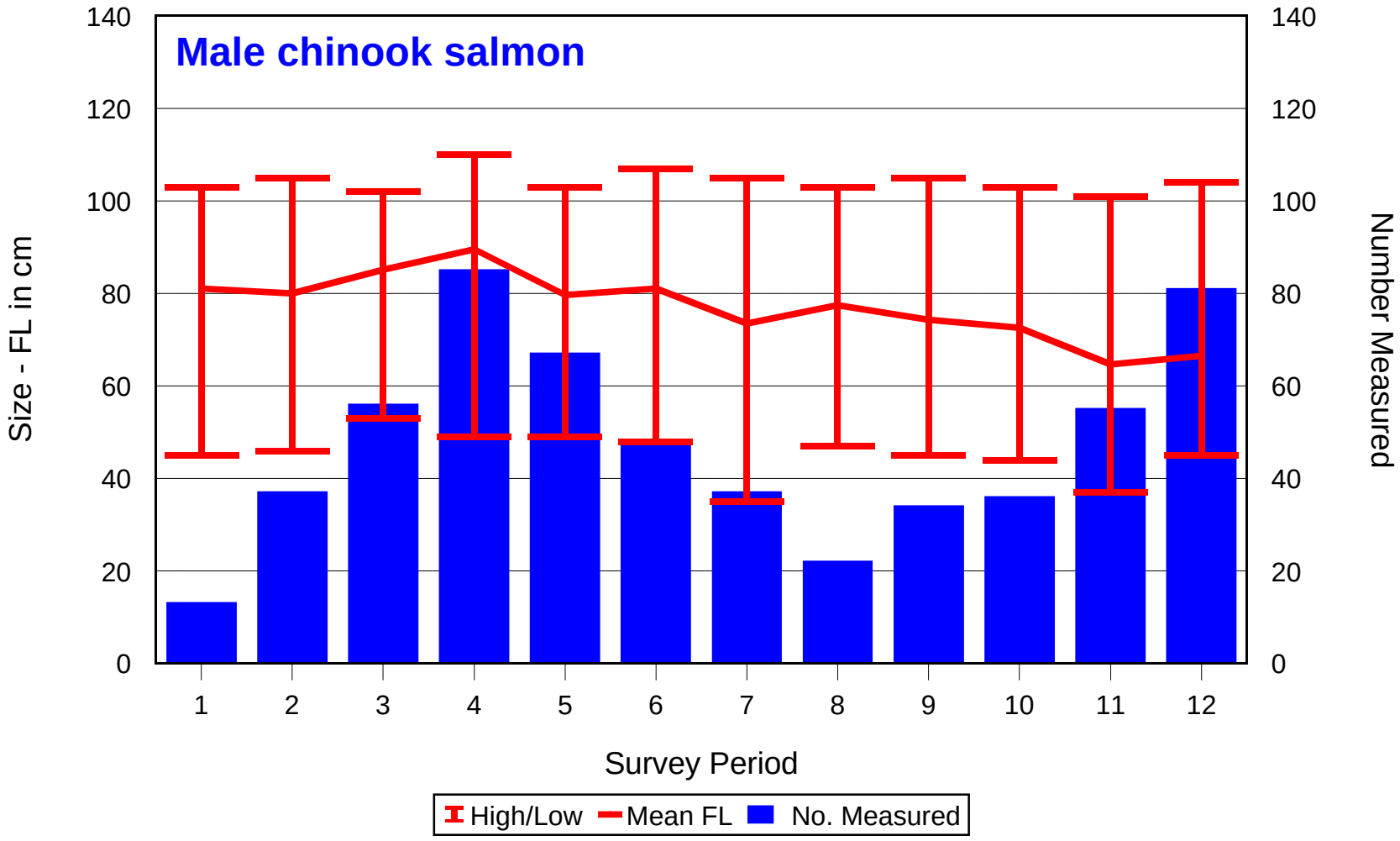

Figure 7. Weekly mean size, size range, and number of male chinook salmon measured during the upper Sacramento River fall-run chinook salmon spawner escapement survey, September - December 1999.

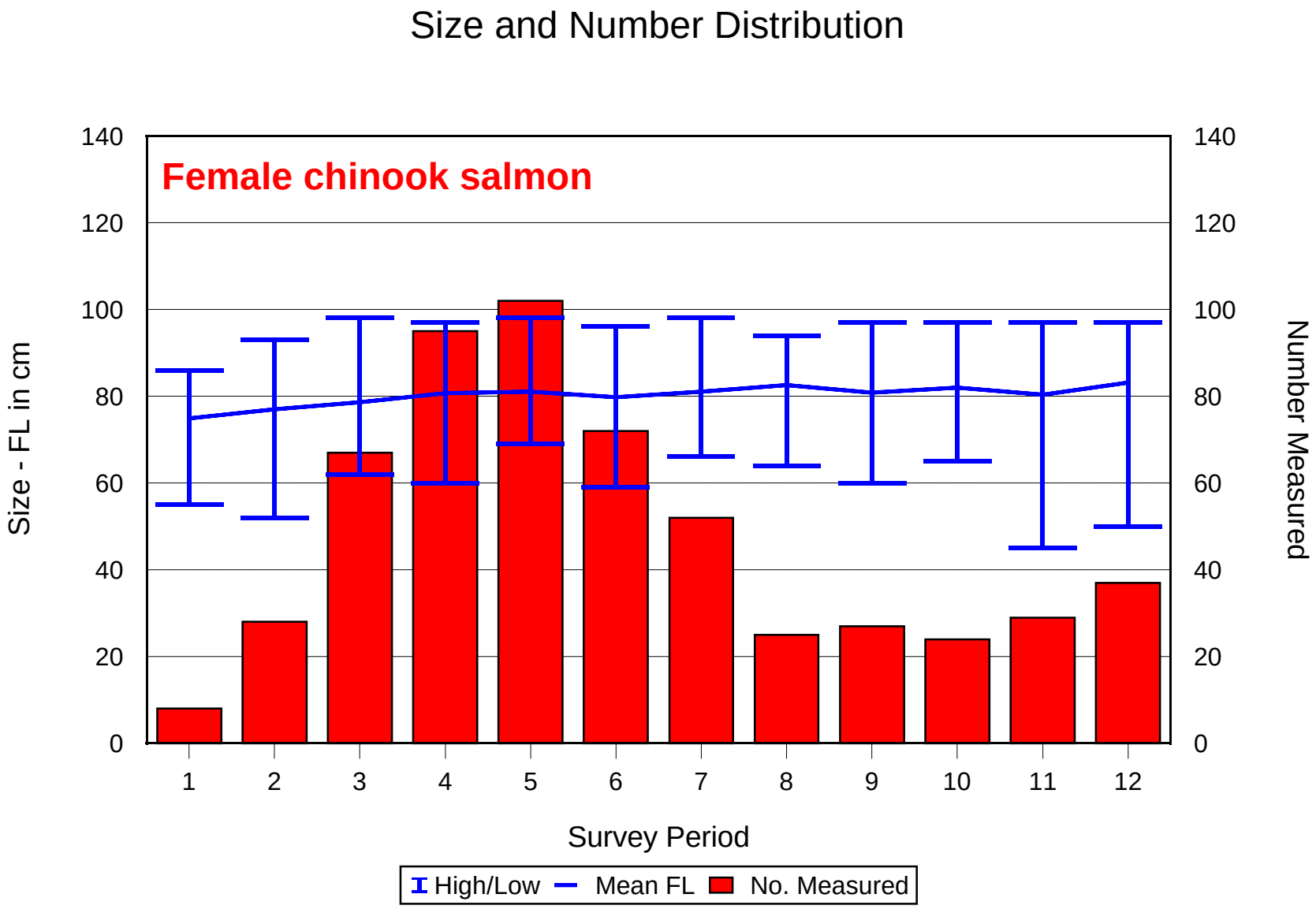

Figure 8. Weekly mean size, size range, and number of female chinook salmon measured during the upper Sacramento River fall-run chinook salmon spawner escapement survey, September - December 1999.

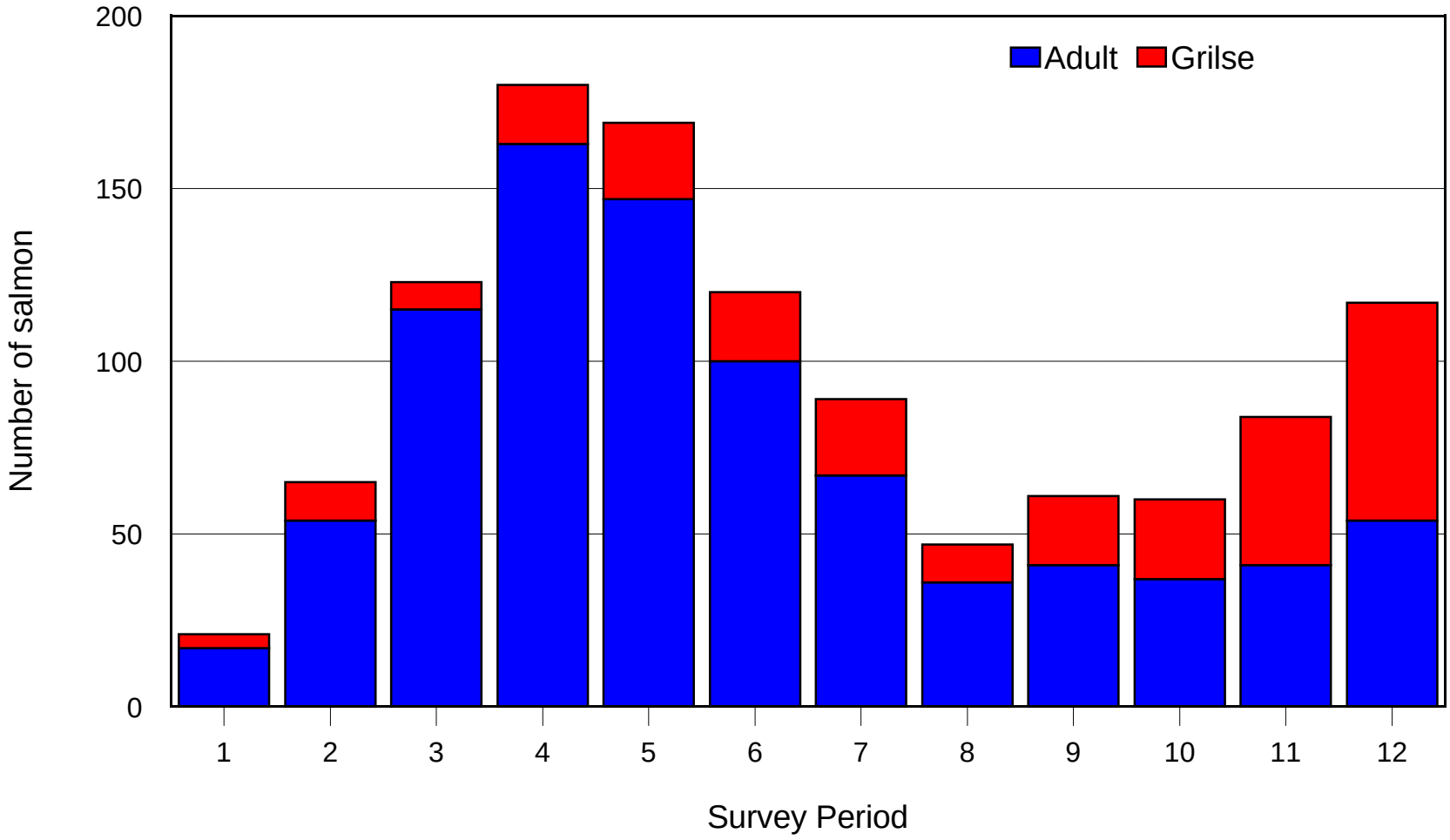

Figure 9. Adult and grilse compostion of chinook salmon measured during the upper Sacramento River fall-run chinook salmon spawner escapement survey, September - December 1999.

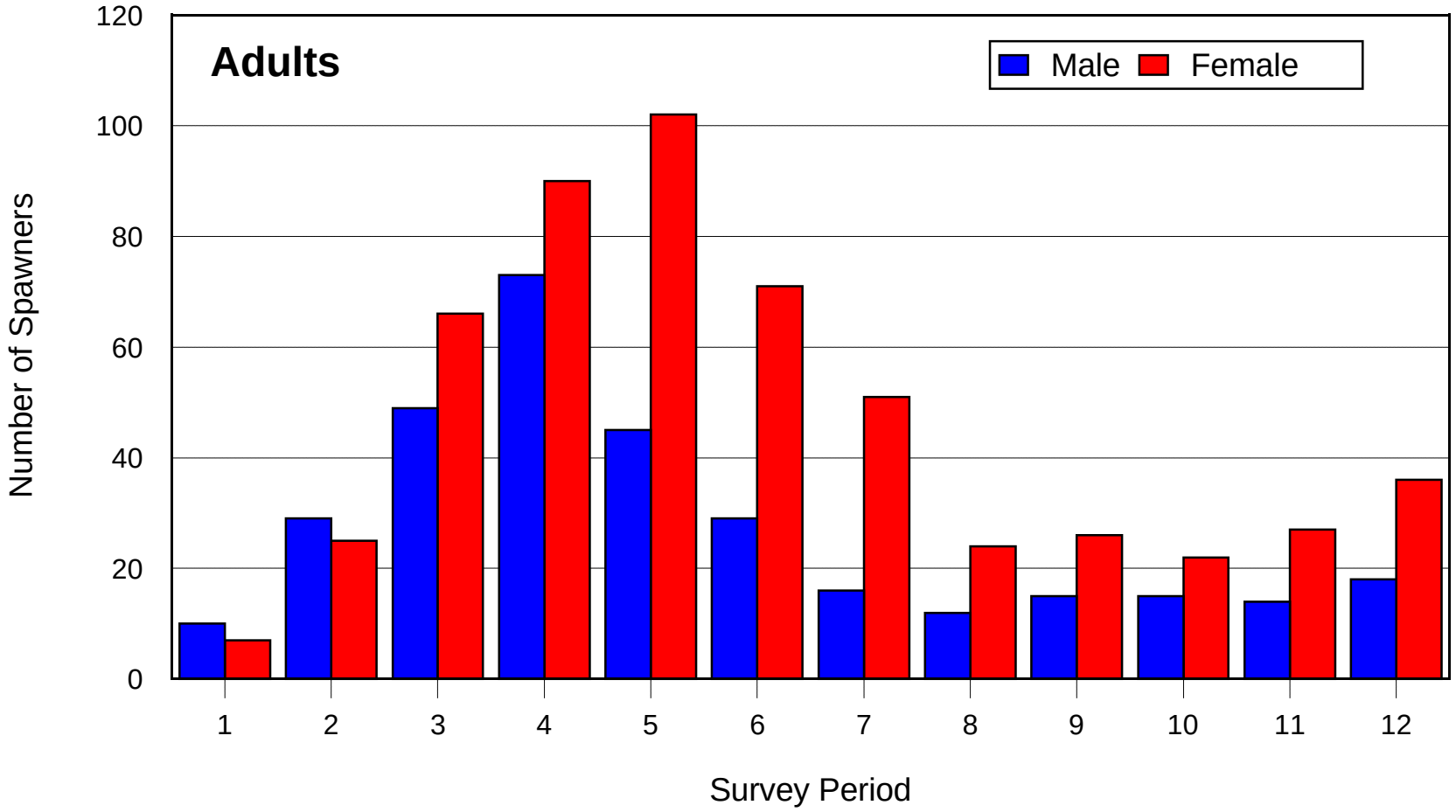

Figure 10. Weekly gender (sex) distribution of adult-sized chinook salmon measured during the upper Sacramento River fall-run chinook salmon spawner escapement survey, September--December 1999.

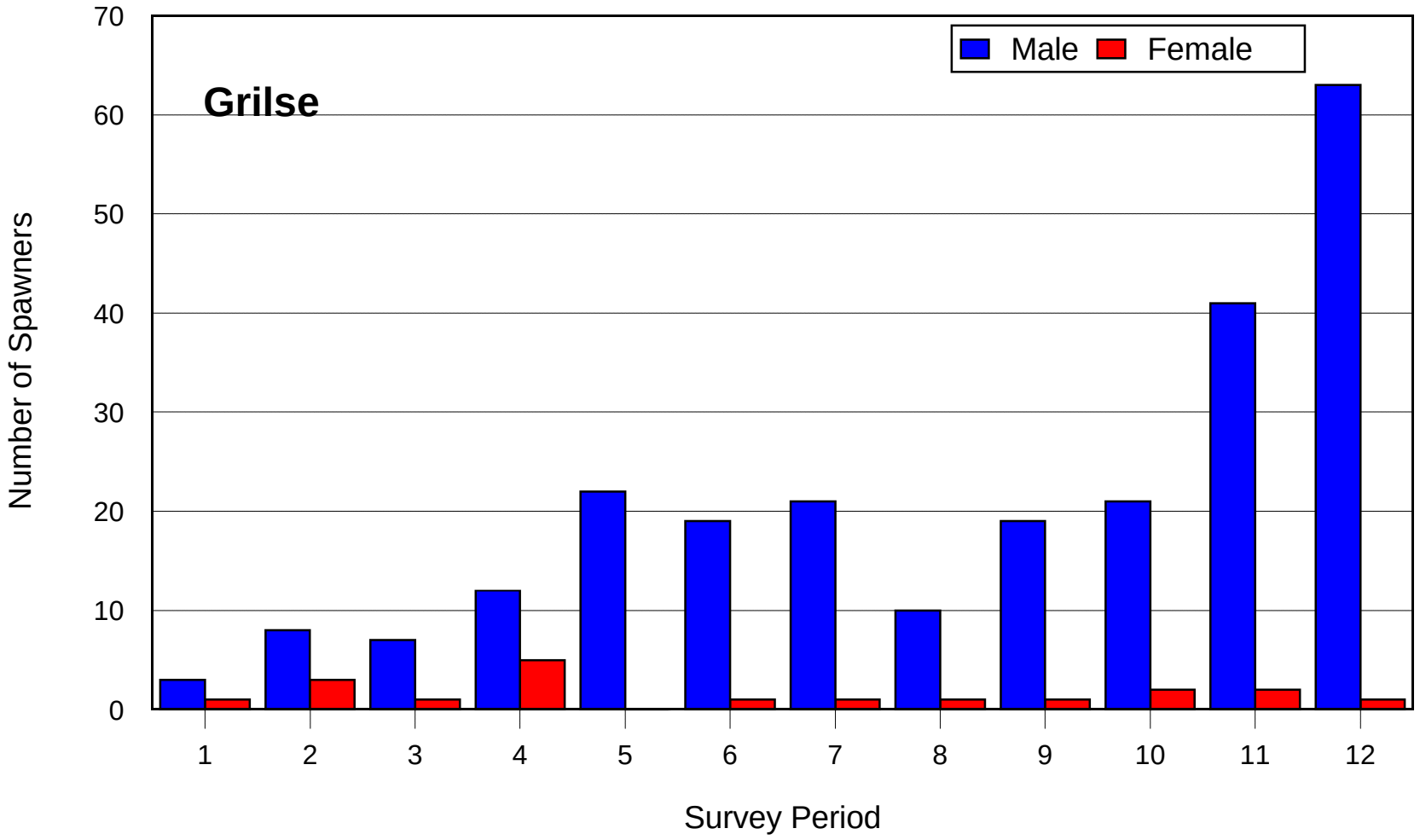

Figure 11. Weekly gender (sex) distribution of grilse-sized chinook salmon measured during the upper Sacramento River fall-run spawner escapement survey, September--December 1999.

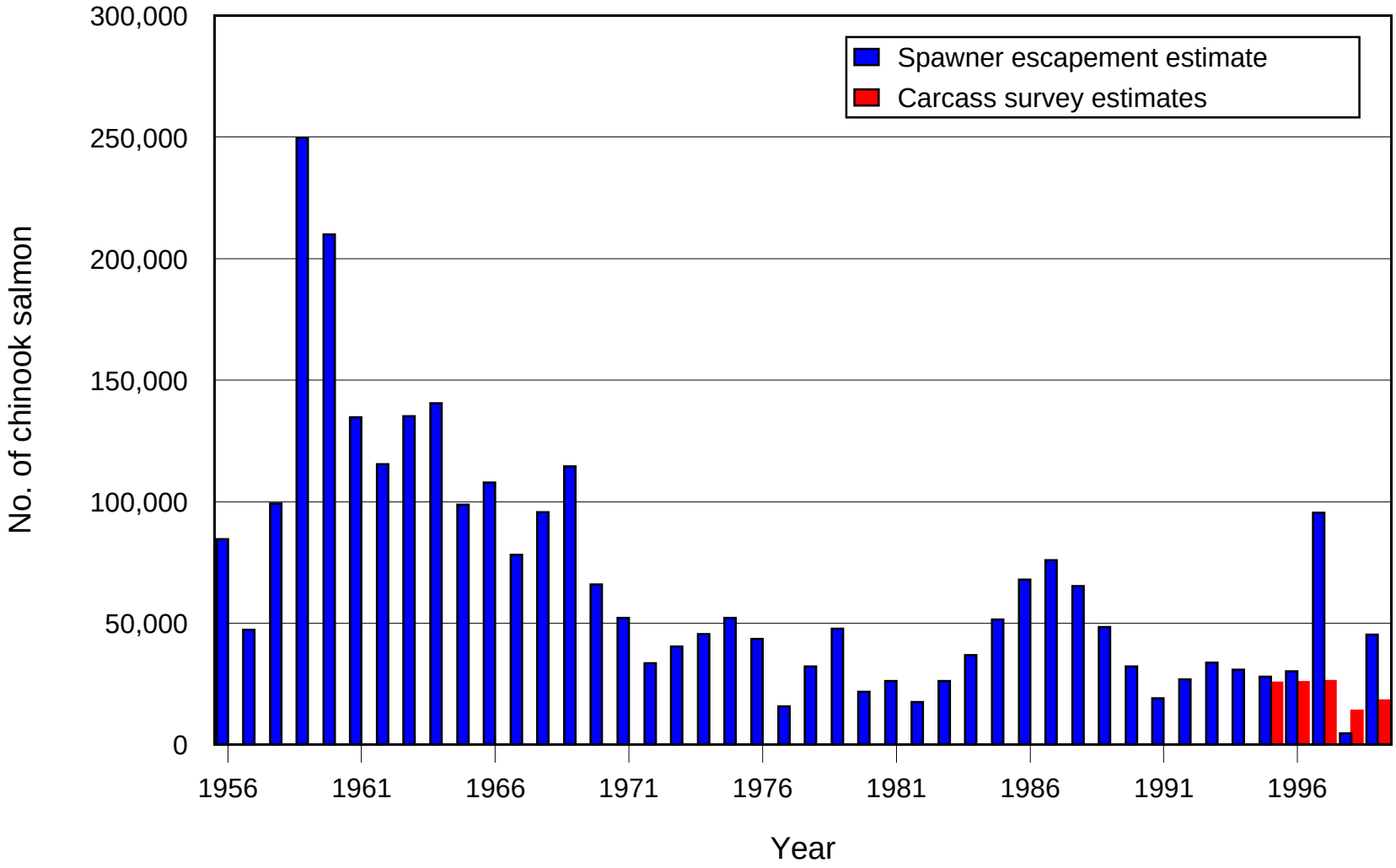

Figure 12. Summary of chinook salmon escapement (adults and grilse) in the mainstem Sacramento River from Keswick Dam downstream to Red Bluff Diversion Dam excluding tributaries (1956--1999).