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 2000

by

Bill Snider,
Bob Reavis,
and
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Stream Evaluation Program
Technical Report No. 01-4
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2/ Stream Evaluation Program Technical Report No. 01-4

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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 2000 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 6th 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, Snider et al. 1999, and Snider et al. 2000). The survey was conducted from 2 October through 21 December 2000. It covered 25.5 miles of the Sacramento River, from Cottonwood Creek [river-mile (RM) 273] to Anderson-Cottonwood Irrigation District (ACID) dam (RM 298.5) located just 3.5 miles downstream of Keswick Dam (the upstream limit to anadromous fish migration).

Mean weekly flow ranged between 6,400 cubic feet per second (cfs) during the first survey period (2–5 October) and 4,600 cfs during the last survey period (18–21 December). Mean weekly water temperature varied between 53 °F and 55 °F (mode = 54 °F). Water visibility (Secchi depth) ranged from 12 ft to 20 ft.

A total of 8,188 fall-run carcasses was collected (1,847 fresh and 6,341 decayed); 1,654 fresh carcasses were measured, sexed, and aged. The peaks in the fresh carcass weekly counts (367 salmon) and total weekly carcass counts (1,127 salmon) occurred during period 4 (23–26 October). Thirty-eight percent of all fresh carcasses were collected during periods 3 and 4 (16–26 October), indicating that peak spawning occurred during periods 2 and 3.

Length frequency distributions were used to estimate the size distinguishing adults (>2 years old) from grilse (2 years old) by sex. Males >63 cm fork length (FL) and females >64 cm FL were classified as adults. Based upon these criteria, 97% of the population were adult salmon and 3% were grilse; 43% were adult males, 54% were adult females, 3% were male grilse, and <1% were female grilse.

We examined 882 females for egg retention: 850 (96%) had completely spawned, 17 (2%) still contained a substantial number of eggs, and 15 (2%) were unspawned.

The spawner population was estimated using both the Schaefer and the Jolly-Seber mark-recapture models. Per the Schaefer model, 1,458 fresh adult carcasses were marked and 630 (43%) were subsequently recaptured, yielding an escapement estimate of 19,959 total salmon (19,360 adult and 599 grilse). Per the Jolly-Seber model, 5,608 fresh and decayed carcasses were marked and 2,288 (41%) were subsequently recaptured, yielding an estimate of 14,938 total salmon (14,490 adults and 448 grilse). Both estimates are considerably less than the mean annual fall-run chinook salmon escapement between 1956 and 1999 (65,113 grilse and adults) estimated by counts made at Red Bluff Diversion Dam. Estimated escapement during the six carcass surveys (1995–2000) conducted during our investigations have ranged from 14,211 to 28,890 (mean = 22,113; SD = 5,719).

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 fall 2000 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, Snider et al. 1999, and Snider et al. 2000) 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 week-to-week) 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 ≥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 (F. Fisher, California Department of Fish and Game, personal communication and F. Meyer, California Department of Fish and Game, personal communication). 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 a, b); 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 made at RBDD and aerial redd surveys. The dam's gates are now typically open between mid-September and mid-May of the following year improving fish passage but eliminating direct counts at the ladders as much as 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 are 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 (Fig.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 for the upper Sacramento River upstream of Cottonwood Creek.

To determine egg-retention rate, 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 2000 spawner escapement surveys began immediately following the initial observation of spawning activity and were then conducted weekly from 2 October through 21 December 2000. The 25.5-mile-long stream segment from ACID dam (RM 298.5) downstream to the mouth of Cottonwood Creek (RM 273.0; Fig. 1) was divided into four reaches (Table 1). Each reach was surveyed one day per week.

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)

Table 1. Location of reaches surveyed during the upper Sacramento River fall-run chinook salmon escapement survey, October–December 2000.

Reach	Location	River mile (length in miles)
1	ACID Dam[1/] to Cypress St. Bridge	298.5–295.0 (3.5)
2	Cypress St. Bridge to Bonnyview Bridge	295.0–292.0 (3.0)
3	Bonnyview Bridge to North St. Bridge	292.0–284.0 (8.0)
4	North St. Bridge to Cottonwood Creek	284.0–273.0 (11.0)

1/ Surveys were conducted upstream to Keswick Dam prior to 30 October. Access to the section between Keswick and ACID dams was eliminated after this date.

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 number 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 calculate the escapement estimates (E) are as follows:

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

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, for each survey day. Water temperature (grab sample) and water visibility (Secchi depth) were measured daily by the survey crew.

RESULTS AND DISCUSSION

A total of 8,188 carcasses was observed (Table 2). Weekly average flow was 6,400 cubic feet per second (cfs) at the start of the survey, then gradually decreased to 5,300 cfs in period 4; increased to 5,500 cfs in period 9; and then decreased to 4,600 cfs in period 12 (Table 2, Fig.2). Average weekly temperature narrowly ranged between 53 ^{o}F and 56 ^{o}F throughout the survey (Table 2, Fig. 2). Water clarity (Secchi depth) ranged from 12 ft in period 11 (23–25 November) up to 20 ft in period 4 (23–26 October) (Table 2, Fig. 2)

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Temporal Distribution

The number of observed carcasses steadily increased from period 1(100) through period 4 (1,494) (Table 2 and Fig. 3). After peaking in period 4, the numbers of carcasses decreased to 458 in period 9, 599 in period 11 and 593 in period 12.

Spatial Distribution

The spatial distribution of all observed carcasses was 36% in reach 1, 37% in reach 2, 18% in reach 3, and 9% in reach 4 (Table 3 and Fig. 4).

Size Distribution

A total of 1,654 carcasses was measured (Table 4). Mean size was 83.5 cm FL. Size ranged from 40 to 112 cm FL. Male salmon (n = 748) averaged 86.8 cm FL (range: 40–112 cm FL) (Fig. 5). Female salmon (n = 906) averaged 80.8 cm FL (range: 50–105 cm FL) (Fig. 6). The weekly mean size for males ranged from 83.1 to 91.0 cm FL (Fig. 7). Weekly mean size for females ranged from 79.7 to 83.2 cm FL (Table 4 and Fig. 8).

Length-frequency distributions were used to define a general size criterion distinguishing grilse (2-year-old salmon) from adults (>2-year-old salmon) for each sex (Figs. 5 and 6). Male grilse (n = 44) were defined as salmon $\leq$63 cm FL, and female grilse (n = 5) were defined as salmon $\leq$65 cm FL (Table 5). Male grilse averaged 56.3 cm FL (range: 40–63 cm FL, SD = 5.8); male adults (n = 704) averaged 86.8 cm FL (range: 64–112 cm FL, SD = 9.9). Female grilse averaged 58.6 cm FL (range: 50–64 cm FL, SD = 6.2); female adults (n = 901) averaged 80.8 FL (range: 66–105 cm FL, SD = 6.3).

Grilse comprised 49 (3%) of the 1,654 carcasses measured (Table 6). The greatest numbers of grilse (10) were observed the survey period 4 (Fig. 9). Adults comprised 1,605 (97%) of the measured

carcasses. The greatest numbers of adults (258 and 243) were observed during periods 3 and 4, respectively.

Sex Composition

Males comprised 44% (n = 704) of the fresh adult carcasses examined, while females comprised 56% (n = 901) (Table 7). Males comprised 90% of the grilse (n = 44); females comprised 10% (n = 5). Females comprised 55% (n = 906) of the all fresh carcasses; males comprised 45% (n = 748). The female to male ratio for adult spawners was 1.3:1 (901:704) (Table 7 and Fig. 10). Females predominated during survey periods 2–8 and period 10, while males comprised the greater portions in periods 1, 9, 11, and 12. The grilse population was heavily dominated by males for the entire survey (Fig. 11).

Spawning Success

There were 882 females examined for egg retention (Table 8). Of these, 850 (96%) had completely spawned, 17 (2%) had only partially spawned, and 15 (2%) had not spawned. At least 89% of the females checked each survey period had completely spawned.

Table 2. General survey information for the upper Sacramento River fall-run chinook salmon escapement survey, October–December 2000.

Survey period	Dates	Flows (cfs)[1/]	Secchi depth (ft)[2/]	Water temperature (^{O}F)[2/]	Carcass count[3/]		
					Fresh	Decayed	Total
1	Oct 2–5	6,400	17	54	45	55	100
2	Oct 10–13	6,300	17	54	148	203	351
3	Oct 16–19	6,100	17	54	329	611	940
4	Oct 23–26	5,300	20	55	367	1,127	1,494
5	Oct 30–Nov 2	5,300	15	54	163	860	1,023
6	Nov 6–9	5,400	14	56	108	766	874
7	Nov 13–16	5,400	14	53	95	628	723
8	Nov 20–22	5,400	13	54	106	408	514
9	Nov 27–30	5,500	13	54	103	355	458
10	Dec 4–7	5,100	16	54	107	412	519
11	Dec 11–14	4,900	12	53	139	460	599
12	Dec 18–21	4,600	13	54	137	456	593
				Totals	1,847	6,341	8,188

1/ Weekly average discharge during days sampled as 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, October–December 2000.

Survey period	Reach 1 (RM 298.5-295.0)		Reach 2 (RM 295.0-292.0)		Reach 3 (RM 292.0-284.0)		Reach 4 (RM 284.0-273.0)	
	M[1/]	C[2/]	M	C	M	C	M	C
1	27	2	32	1	19	5	12	2
2	101	3	131	3	67	7	36	4
3	228	2	354	23	212	10	111	0
4	361	11	625	29	259	51	139	19
5	321	37	336	44	200	34	40	11
6	266	53	281	99	69	49	38	19
7	170	67	154	102	69	81	48	32
8	163	31	129	41	41	21	53	36
9	136	69	98	34	43	6	50	22
10	177	83	109	21	49	13	45	22
11	0	320	0	220	0	52	0	7
12	0	295	0	171	0	102	0	25
Total	1,950	973	2,249	788	1028	431	572	199
% by reach	36		37		18		9	

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, October–December 2000.

Survey 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	50	83.8	50–107	29	86.7	50–107	21	79.8	66–92
2	149	85.6	55–107	70	91.0	55–107	79	80.9	64–97
3	264	85.7	54–107	112	89.1	54–107	152	83.2	66–100
4	253	82.9	53–106	90	88.4	53–106	163	79.8	54–95
5	163	83.0	50–107	58	90.0	62–107	105	79.7	50–98
6	102	81.6	45–108	37	84.5	45–108	65	79.9	67–99
7	94	82.7	40–105	38	86.8	40–105	56	79.8	69–102
8	102	84.3	55–105	52	88.2	55–105	50	80.2	69–98
9	105	83.8	41–105	60	84.4	41–104	45	83.0	73–105
10	100	83.2	45–104	40	85.4	45–104	60	81.6	68–102
11	139	82.0	49–112	84	83.1	49–112	55	80.3	72–92
12	133	82.9	50–110	78	84.5	50–110	55	80.8	70–92
Total (mean)	1,654	(83.6)	40–112	748	(87.1)	40–112	906	(80.8)	50–105

Population Estimates

Only fresh carcass data were used to calculate the Schaefer estimate. A total of 1,458 fresh adult carcasses was tagged and 630 (43%) were subsequently recaptured. Both fresh and decayed carcass data were used to calculate the Jolly-Seber estimate. A total of 5,608 fresh and decayed adult carcasses was tagged and 2,288 (41%) were subsequently recaptured.

An estimate of 19,360 adult spawners was calculated using the Schaefer model (Tables 9 and 10). Since adults made up 97% of the total escapement, based on measured carcasses (Table 6), a total escapement estimate of 19,959 spawners (adults and grilse) was calculated by dividing the adult estimate by 0.97. An adult escapement estimate of 14,490 was calculated using the Jolly-Seber model (Table 11). This estimate was similarly expanded by dividing it by 0.97 resulting in a total escapement estimate of 14,938 spawners.

The 2000 population estimates for salmon spawning in the upper Sacramento River from Cottonwood Creek to ACID Dam are as follows:

	Schaefer model	Jolly-Seber model
Total estimate	19,959	14,938
Adult estimate	19,360	14,490
Grilse estimate	599	448

The estimated 2000 escapement (19,951) is considerably less than the 1956–1999 average estimate (65,113) for the reach between Keswick Dam and RBDD (Table 12 and Fig. 12). Since most fall-run chinook salmon spawn between Cottonwood Creek and ACID dam, with very little spawning taking place upstream of ACID dam, the inclusion of the uppermost 3.5 miles of river (ACID dam to Keswick Dam) would have added little to the survey.

Coded-wire Tag Recoveries

We collected nine adipose-fin clipped carcasses indicating that these fish possessed a coded-wire tag (CWT). Five of these fish contained a CWT (Table 13). All tagged fish were from Feather River Hatchery. Four had been released into the Sacramento River (one at Fremont Weir, one at Yolo Bypass, one at the City of West Sacramento, and one at Benicia). One had been released at Stewart Road in the San Joaquin River system. The recovered salmon ranged in age from 2 to 5 years old.

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, October–December 2000.

	Female		Male	
	Grilse	Adults	Grilse	Adults
Number	5	901	44	704
Mean FL (cm)	58.6	80.8	56.3	86.8
Range FL (cm)	50–64	66–105	40–63	64–112
SD	6.2	6.3	5.8	9.9

Table 6. Age composition (grilse and adult) of carcasses measured during the upper Sacramento River fall-run chinook salmon escapement survey, October–December 2000.

	Adults		Grilse[1/]	
Survey period	Number	Percent	Number	Percent
1	46	92	4	8
2	146	98	3	2
3	258	98	6	2
4	243	96	10	4
5	161	99	2	1
6	98	96	4	4
7	91	97	3	3
8	99	97	3	3
9	98	93	7	7
10	98	98	2	2
11	135	97	4	3
12	132	99	1	1
Total(mean)	1605	(96.7)	49	(3.3)

1/ Based on length-frequency distributions, male grilse are defined as salmon $\leq$63 cm FL and female grilse as salmon $\leq$65 cm FL.

Table 7. Sex composition of fall-run chinook salmon grilse and adult carcasses measured during the upper Sacramento River escapement survey, October–December 2000.

Survey period	Adults				Grilse[1/]			
	Male		Female		Male		Female	
	Number	%	Number	%	Number	%	Number	%
1	25	54	21	46	4	100	0	0
2	68	47	78	53	2	67	1	33
3	106	41	152	59	6	100	0	0
4	83	34	160	66	7	70	3	30
5	57	31	104	69	1	50	1	50
6	33	34	65	66	4	100	0	0
7	35	38	56	62	3	100	0	0
8	49	49	50	51	3	100	0	0
9	53	54	45	46	7	100	0	0
10	38	39	60	61	2	100	0	0
11	80	59	55	41	4	100	0	0
12	77	58	55	42	1	100	0	0
Total (mean)	704	(44.8)	901	(55.2)	44	(90.6)	5	(9.4)

1/ Based on length-frequency distributions, male grilse are defined as salmon ≤63 cm FL and female grilse as salmon ≤65 cm FL.

Table 8. Spawning completion (egg retention) summary for female fall-run chinook salmon carcasses measured during the upper Sacramento River escapement survey, October–December 2000.

Survey period	No. females measured	No. females checked for egg retention	Number spawned (%)	Number partially spawned (%)	Number unspawned (%)
1	21	18	17(94)	1(6)	0(0)
2	79	78	69(89)	5(6)	4(5)
3	152	143	138(97)	1(<1)	4(3)
4	163	159	156(98)	1(1)	2(1)
5	105	105	105(100)	0(0)	0(0)
6	65	61	60(98)	1(2)	0(0)
7	56	56	52(93)	2(4)	2(4)
8	50	47	45(96)	1(2)	1(2)
9	45	45	45(100)	0(0)	0(0)
10	60	60	58(97)	2(3)	0(0)
11	55	55	53(96)	1(2)	1(2)
12	55	55	52(95)	2(3)	1(2)
Total (mean)	906	882	850(96)	17(2)	15(2)

Table 9. Summary of tagging and recapture data for fresh adult chinook salmon carcasses collected during the upper Sacramento River escapement survey, October–December 2000.

Schaefer model capture-recapture data matrix

Period of recovery (j)	Period of tagging$_{(i)}$ 1	2	3	4	5	6	7	8	9	10	Tags recovered $R_{(j)}$	Carcasses counted $C_{(j)}$	Ratio $C_{(j)}/R_{(j)}$
2	12										12	443[1/]	36.92
3	4	31									35	952	27.24
4	2	19	149								170	1,618	9.52
5		4	22	88							114	1,116	9.79
6		1	11	34	34						80	919	11.49
7				14	19	33					65	753	11.58
8					14	7	20				41	536	13.07
9						3	8	22			33	470	14.24
10						3	6	5	24		38	541	14.24
11						1	1	5	7	20	34	598	17.59
12									1	6	7	580	82.86
$R_{(i)}$	18	55	182	135	67	47	35	32	32	26	<- Tagged fish recovered		
$T_{(i)}$	42	145	311	346	157	97	89	99	86	86	<- Total fish tagged		
$T_{(i)}/R_{(i)}$	2.33	2.64	1.71	2.56	2.34	2.06	2.54	3.09	2.69	3.31	<- Ratio		

1/ 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, October–December 2000.

Population estimate

Period of recovery$_{(j)}$	Period of tagging $_{(i)}$										
	1	2	3	4	5	6	7	8	9	10	Totals
2	1,034										1,034
3	254	2,223									2,477
4	44	477	2,423								2,944
5		103	368	2,208							2,679
6		30	216	1,001	915						2,162
7				386	516	789					1,691
8					429	189	665				1,283
9						88	290	969			1,347
10						88	217	220	918		1,443
11						35	45	272	331	1,164	1,847
12									577	1,644	2,221
Subtotals	1,332	2,833	3,007	3,595	1,860	1,190	1,217	1,462	1,472	2,808	21,128
Tags		-145	-311	-346	-157	-97	-89	-99	-86	-86	-1,416
										Adult population estimate -	19,712

Table 11. Summary of tagging and recapture data for both fresh and decayed adult chinook salmon carcasses sampled during the upper Sacramento River escapement survey, October–December 2000.

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	82	91											
2	324	362	22										22
3	883	1,019	7	95									102
4	1,343	1,852	4	39	361								404
5	879	1,413		11	60	340							411
6	631	1,159		2	15	99	204						320
7	415	993			2	28	69	206					305
8	369	691				5	23	45	120				193
9	312	590					3	12	35	103			153
10	370	605						5	6	26	65		102
11	0	692						1	1	12	18	96	128
12	0	600									2	25	27
Totals	5,608	10,067	33	147	438	472	299	269	162	141	85	121	

Adult population estimate = 14,490
Total population estimate = 14,932 (includes 442 grilse)

Table 12. Annual fall-run chinook salmon escapement estimates (adults and grilse) for upper Sacramento River from Red Bluff Diversion Dam (RBDD) to Keswick Dam, 1956–2000.

Year	Totals	Year	Totals[1/]
1956	84,716	1979	47,758
1957	47,300	1980	21,961
1958	99,300	1981	26,261
1959	249,600	1982	17,731
1960	210,000	1983	26,226
1961	134,700	1984	36,898
1962	115,500	1985	51,647
1963	135,200	1986	67,958
1964	140,500	1987	76,039
1965	98,900	1988	65,204
1966	107,900	1989	48,512
1967	78,100	1990	32,225
1968	95,600	1991	19,272
1969	114,600	1992	26,912
1970	65,950	1993	33,923
1971	52,247	1994	31,017
1972	33,559	1995	27,678(26,548)
1973	40,424	1996	71,206(25,890)
1974	45,590	1997	95,505(26,191)
1975	52,248	1998	4,824(14,211)
1976	43,612	1999	48,418(18,295)
1977	15,784	2000	87,793(19,951)
1978	32,235		
Annual average for 1956 through 2000 period = 65,113[2/]			

1/ 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/ Two estimates were calculated for 1995 through 2000. One estimate based on RBDD ladders counts and the other on a carcass tagging study. The average escapement estimate is based upon RBDD data.

Table 13. Summary of statistics for adipose-clipped (hatchery produced) carcasses observed during the upper Sacramento River fall-run chinook salmon escapement survey, October–December 2000.

Collection Data				Coded-wire tag data				
Date	Reach	Sex	FL (cm)	Tag code	Race	Brood year	Hatchery of origin	Release site
2 Oct	1	M	54	05-24-17	Fall	1998	Feather R H	West Sacramento
3 Oct	2	M	83	lost				
3 Oct	2	F	85	no tag				
3 Oct	2	F	89	lost				
3 Oct	2	M	82	06-01-06-06-10	Fall	1997	Feather R H	Benicia
3 Oct	2	F	81	lost				
5 Oct	4	M	90	06-01-06-04-11	Fall	1997	Feather R H	Fremont Weir
12 Oct	3	M	101	06-01-06-02-01	Fall	1995	Feather R H	San Joaquin River Stewart Road
23 Oct	1	M	63	06-01-06-07-01	Fall	1998	Feather R H	Yolo Bypass Road 16

DISCUSSION

Carcass surveys have been annually conducted on the Sacramento River since 1995 to acquire data on the river's fall-run chinook salmon 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 six survey years (1995–2000) have been very consistent. It appears that this approach can provide the 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 were very consistent during the first three survey years (Table 14). Estimates during these years were essentially identical ranging between 25,890 and 26,546 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%). The escapement estimate was slightly greater in 2000 at 19,951 and the recovery rate was the highest to date (43%).

- 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 generated estimates in 1995 (27,678 v. 26,548), but were considerably different in 1996 (71,206 v. 25,890), 1997 (95,505 v. 26,191), 1998 (4,824 v. 14,211), 1999 (48,418 v. 18,295), and 2000 (87,793 v. 19,951).

- The RBDD count-based estimates include 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 13%).

- Age composition of the spawner population has varied from 77% to 97% adults (Table 14). There does not appear to be any relationship between percent grilse and the estimated adult population for the subsequent years.

Table 14. Comparison of results from carcass surveys conducted on the upper Sacramento River fall-run chinook salmon spawner population from 1995 through 2000.

	1995	1996	1997	1998	1999	2000
Total estimate	26,546	25,890	26,191	14,211	18,295	19,959
% Adult	91	79	90	86	77	97
% Grilse	9	21	10	14	23	3
% Female adult	66	66	59	63	63	56
% Male adult	34	34	41	37	37	44
% Female all	62	54	55	63	50	55
% Male all	38	46	45	37	50	45
Tag recovery rate (%)	33	32	31	24	34	43
Spawning success	94	87	92	96	94	96
Reach 1 (%)	40	23	29	29	30	36
Reach 2 (%)	21	37	33	36	37	37
Reach 3 (%)	23	26	24	23	23	18
Reach 4 (%)	16	14	14	12	10	9
Peak carcass count period	6 (5–11 Nov)	5 (28 Oct–1 Nov)	5 (27–30 Oct)	6 (2–5 Nov)	5 (25–28 Oct)	4 (23–26 Oct)
Flow range	4,800–6,500	5,300–27,700	4,200–6,300	6,200–23,400	6,000–8,100	4,600–6,400
Temperature range (°F)	53–57	53–56	53–57	51–55	52–53	53–56
Male grilse size criteria (cm)	64	73	72	71	71	63
Female grilse size criteria (cm)	64	64	66	67	66	64

- Sex composition varied only slightly during the six survey years (Table 14). The percentage of female adults ranged from

56% (2000) to 66% (1995 and 1996) (mean = 65, SD = 4.4). The total percentage of female (grilse and adult) ranged from 50% in 1999 to 63% in 1998 (mean = 56.5, SD = 4.6).

- Spatial spawning distribution (based upon the location of fresh carcass collections) 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 over 67% of all spawning during the last 2 years and average 63.7%, (SD = 2.9) for the 6 years of the survey. 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). These two reaches make up 25% of the 25.5 miles surveyed. Spawning within reach 3 has averaged 23.6%; (SD = 1.1); spawning in reach 4 has averaged 12.6% (SD = 2.2).

- Spawning has consistently peaked during the last week of October and the 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 (14,211), and in 2000, when the population (19,951) was below the 6-year mean of 21,847.

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The California Department of Fish and Game recognizes the efforts of Corrie Carter, Chris Cox, James Lyons, Mike Spiker, and Todd Walter. Their efforts in the collection of field data are greatly appreciated. The data collection was funded by the FWS as a part of a cooperative agreement with the DFG as authorized by the CVPIA (PL 102-575).

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FIGURES

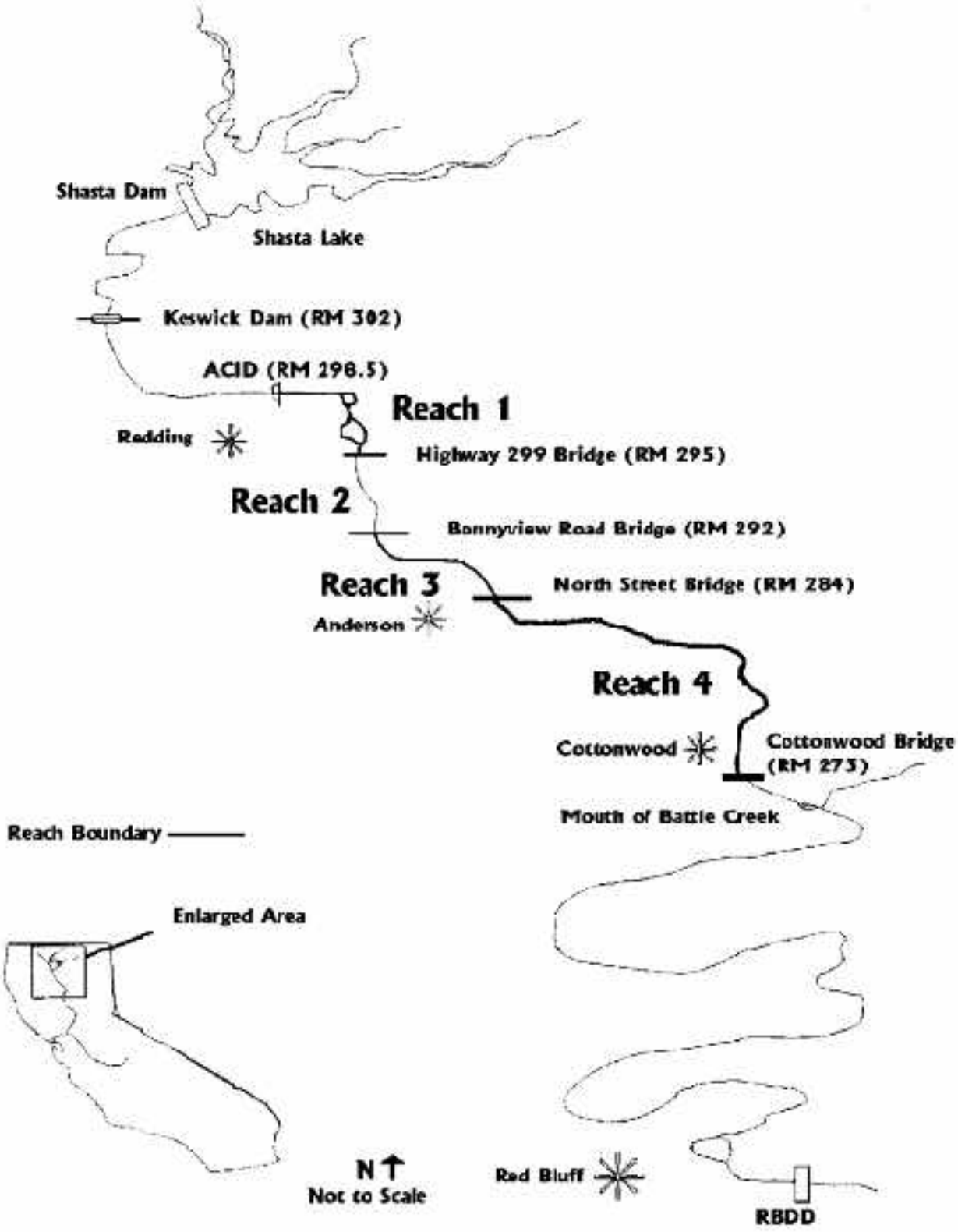

Figure 1. Upper Sacramento RIver fall-run Chinook salmon spawner escapement survey location, including reach designations, September - December 2000.

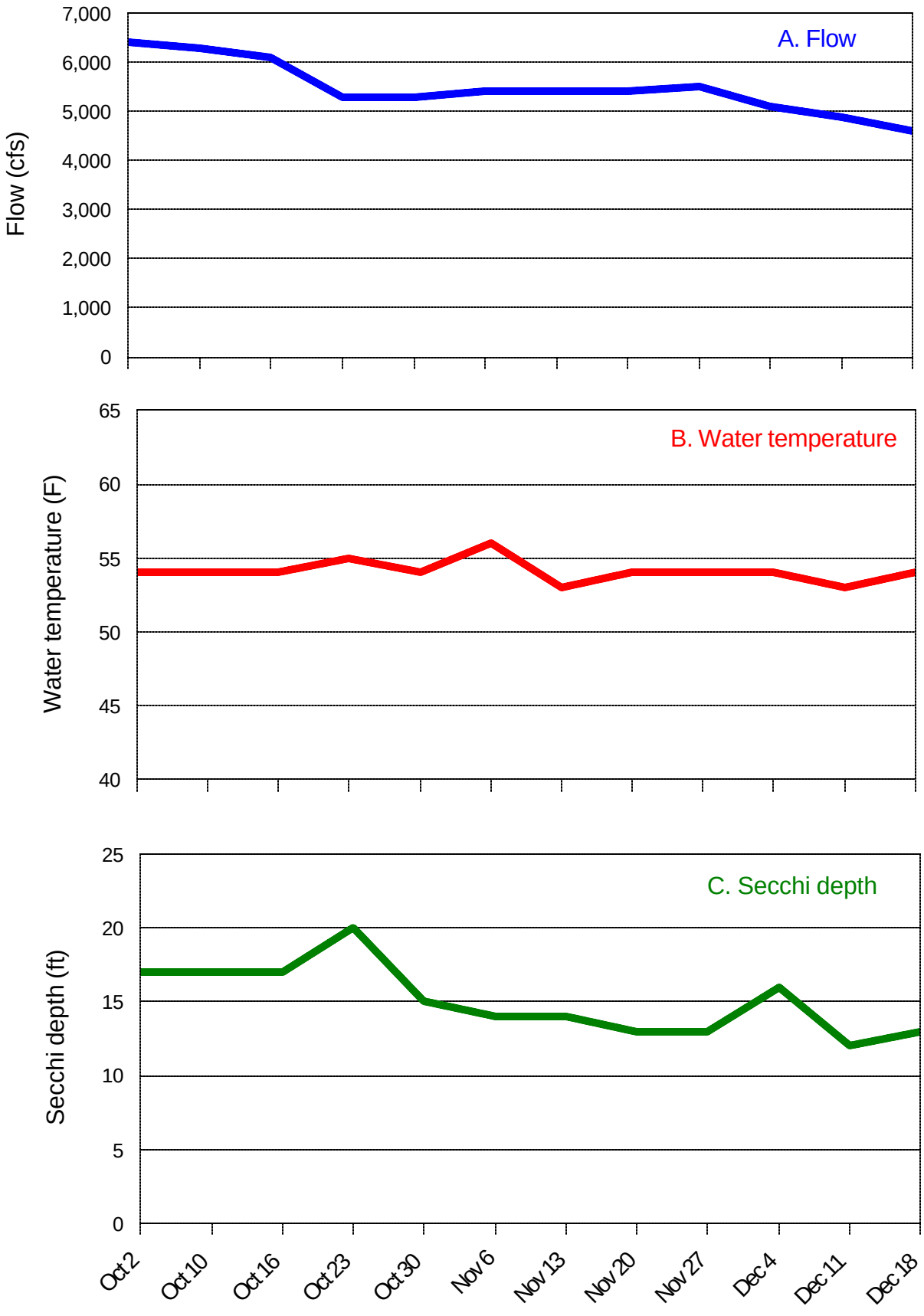

Figure 2. Mean daily flow at Keswick Dam (A), water temperature (B), and Secchi depth (C), measured during the upper Sacramento River fall-run chinook salmon spawner escapement survey, October - December 2000.

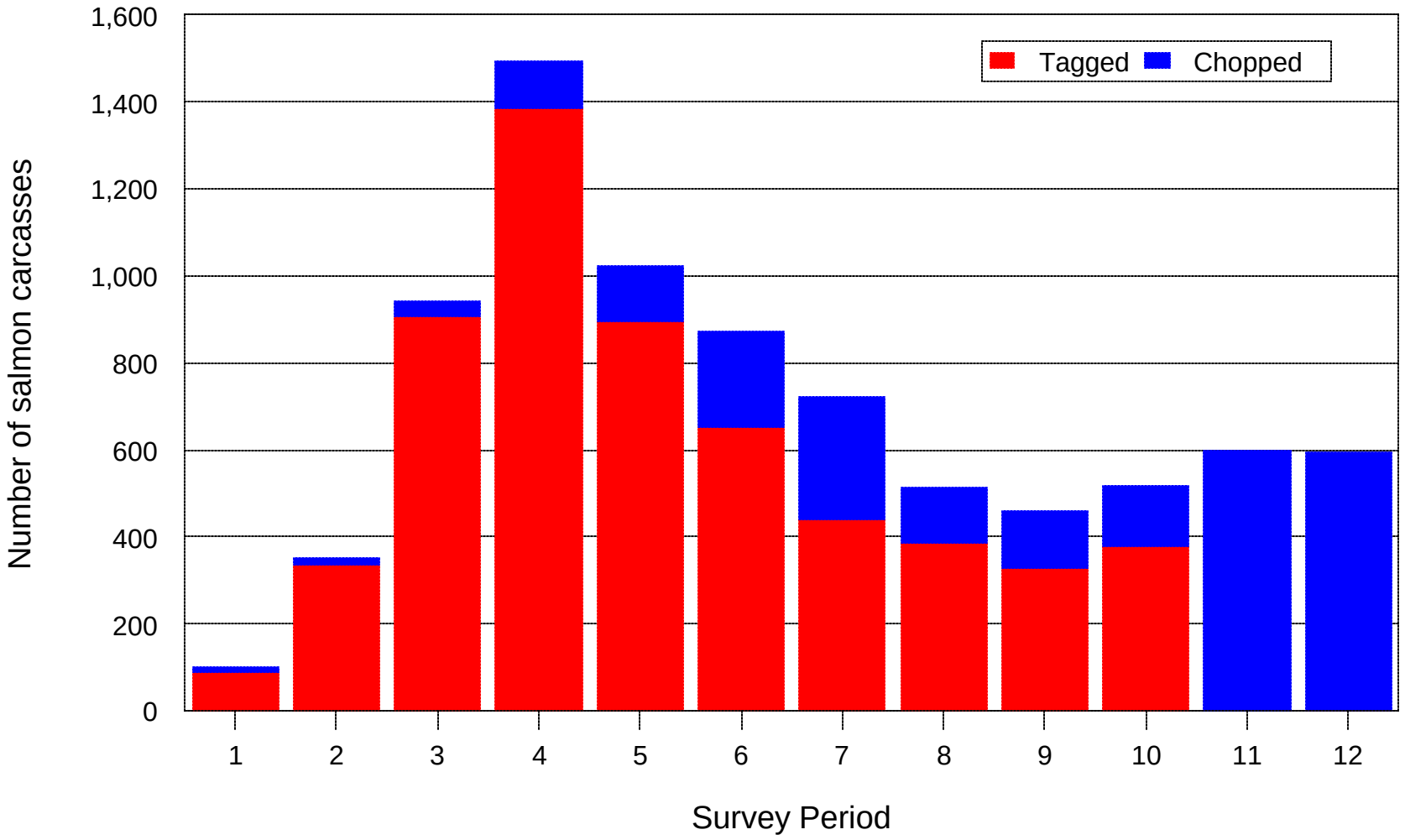

Figure 3. Weekly distribution of both fresh and decayed carcasses (adult and grilse) observed during the upper Sacramento River fall-run chinook salmon spawner escapement survey, October - December 2000.

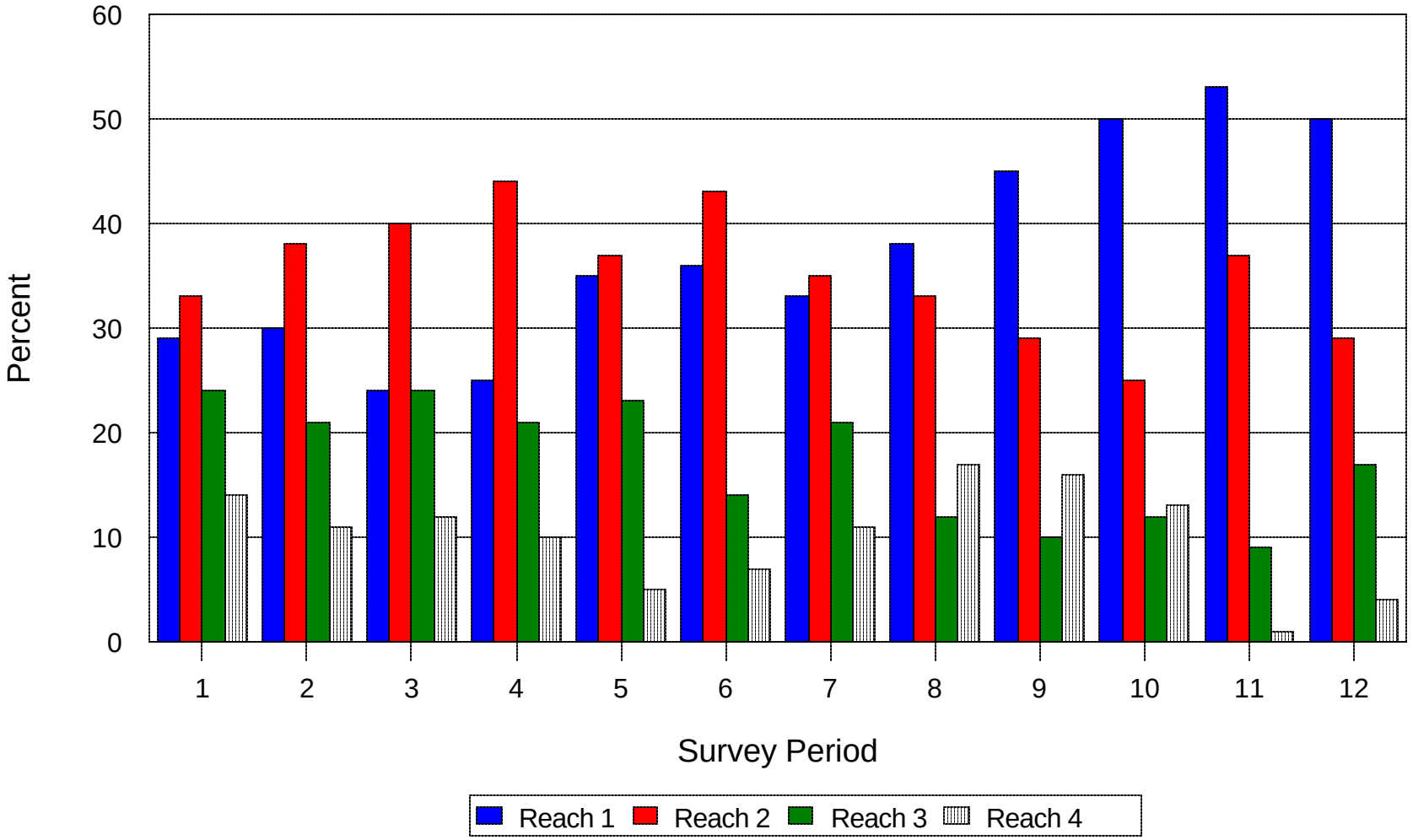

Figure 4. Weekly distribution (%) by reach of both fresh and decayed carcasses observed during the upper Sacramento River fall-run chinook salmon spawner escapement survey, October - December 2000.

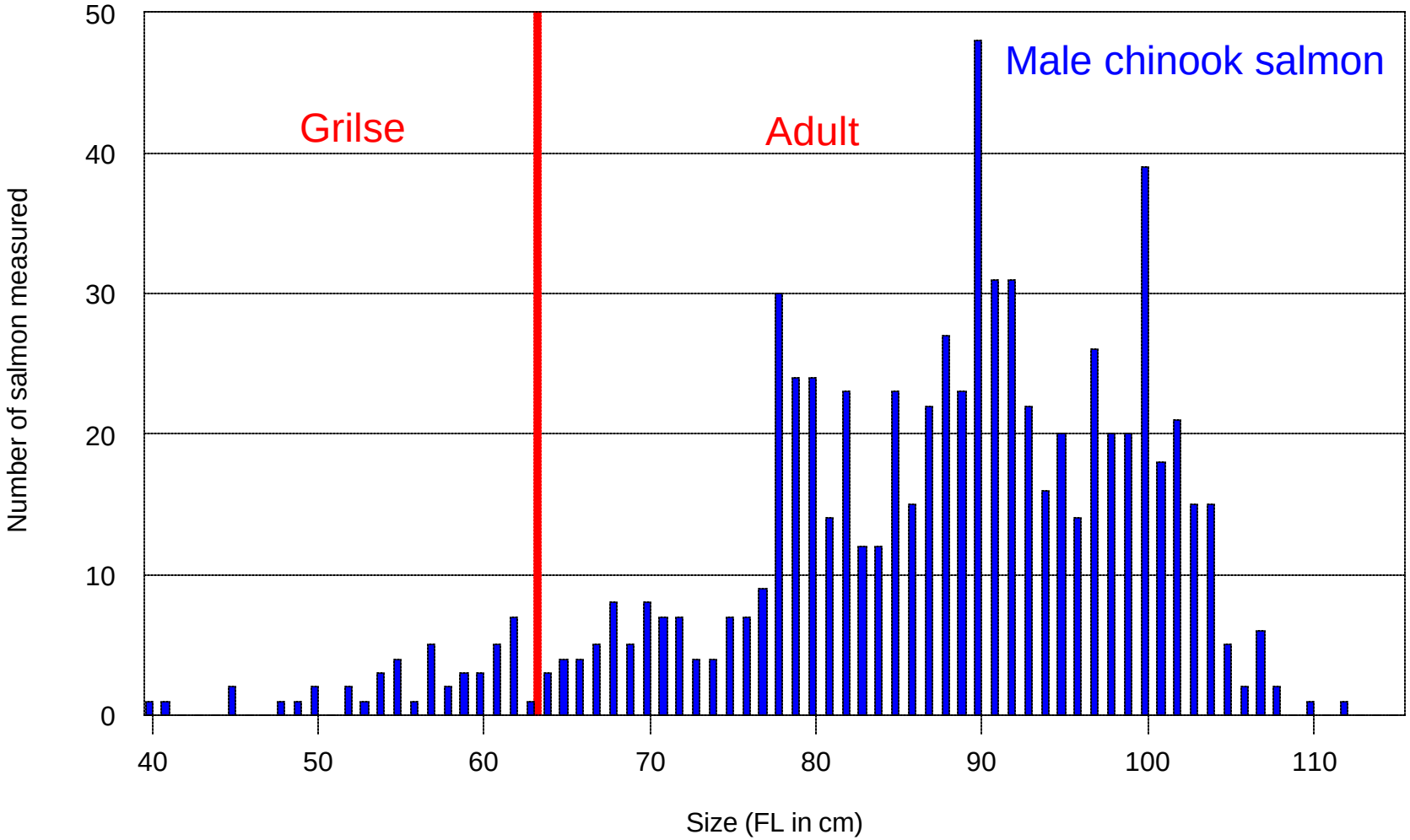

Figure 5. Size (FL in cm) distribution of male carcasses measured during the upper Sacramento River fall-run chinook salmon spawner escapement survey, October - December 2000.

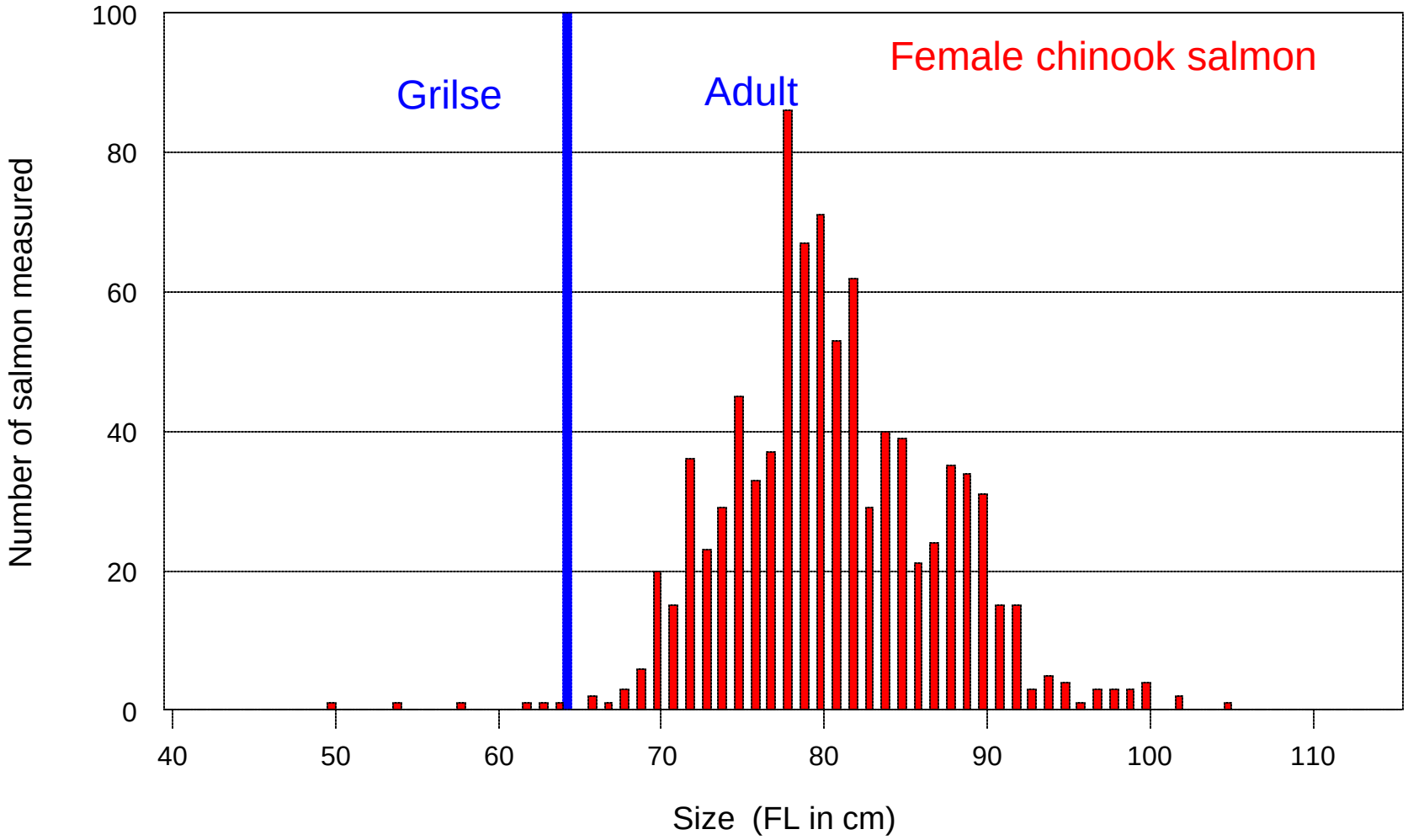

Figure 6. Size (FL in cm) distribution of female carcasses measured during the upper Sacramento River fall-run chinook salmon spawner escapement survey, October - December 2000.

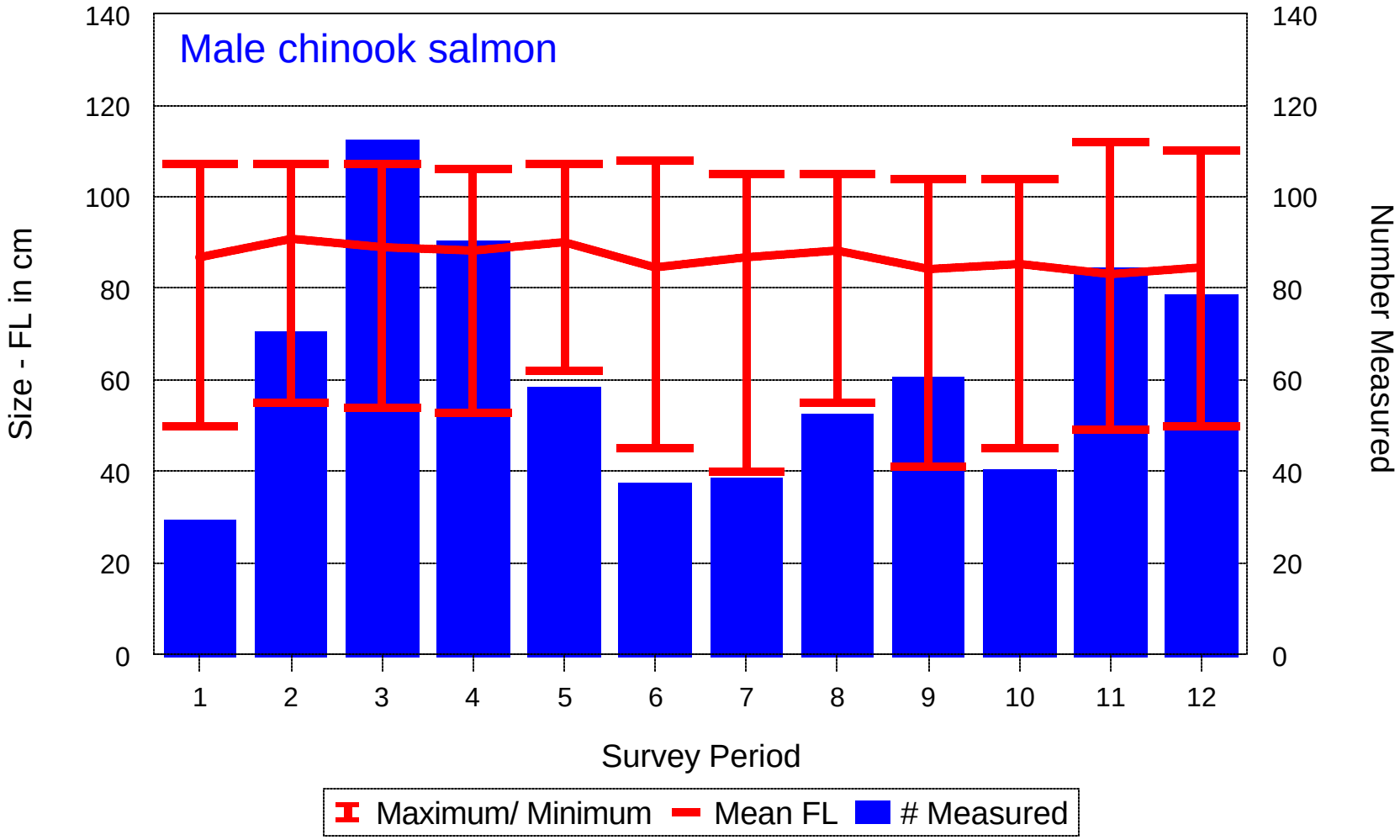

Figure 7. Weekly mean size, size range, and number of male chinook salmon measured during the upper Sacramento River fall-run chinook salmon spawner escapement survey, October - December 2000.

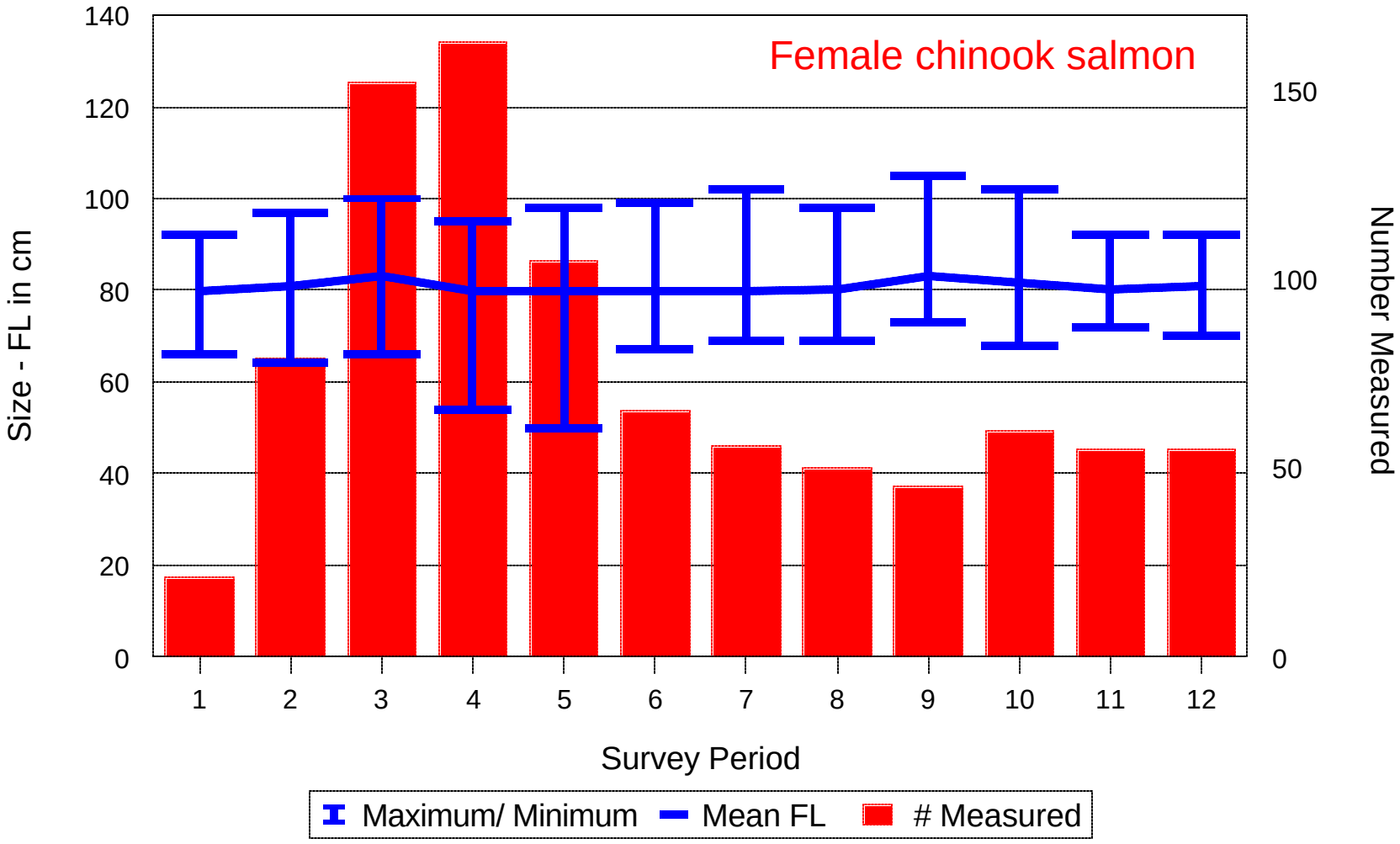

Figure 8. Weekly mean size, size range, and number of female chinook salmon measured during the upper Sacramento River fall-run chinook salmon spawner escapement survey, October - December 2000.

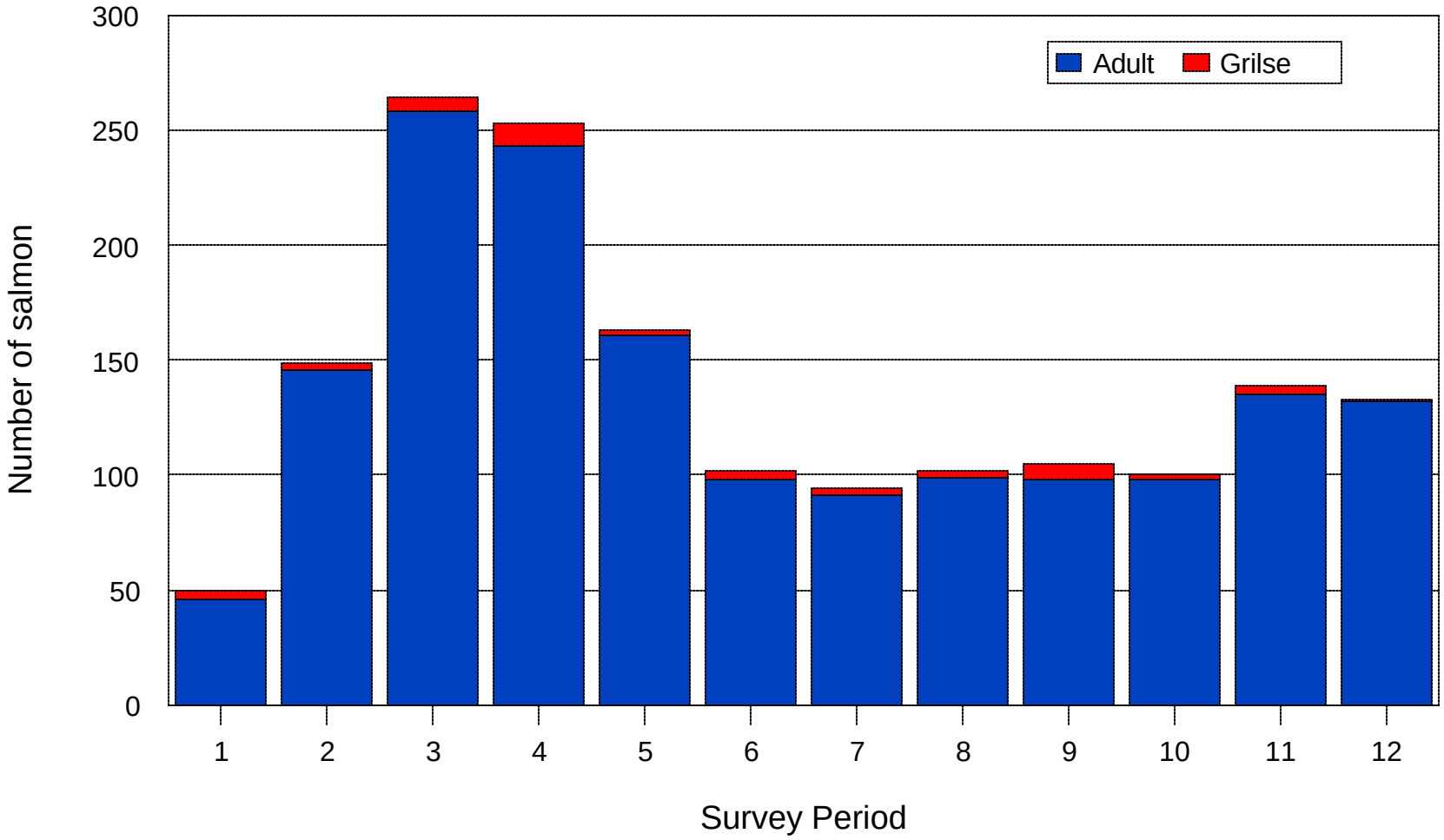

Figure 9. Adult and grilse composition of chinook salmon measured during the upper Sacramento River fall-run chinook salmon spawner escapement survey, October - December 2000.

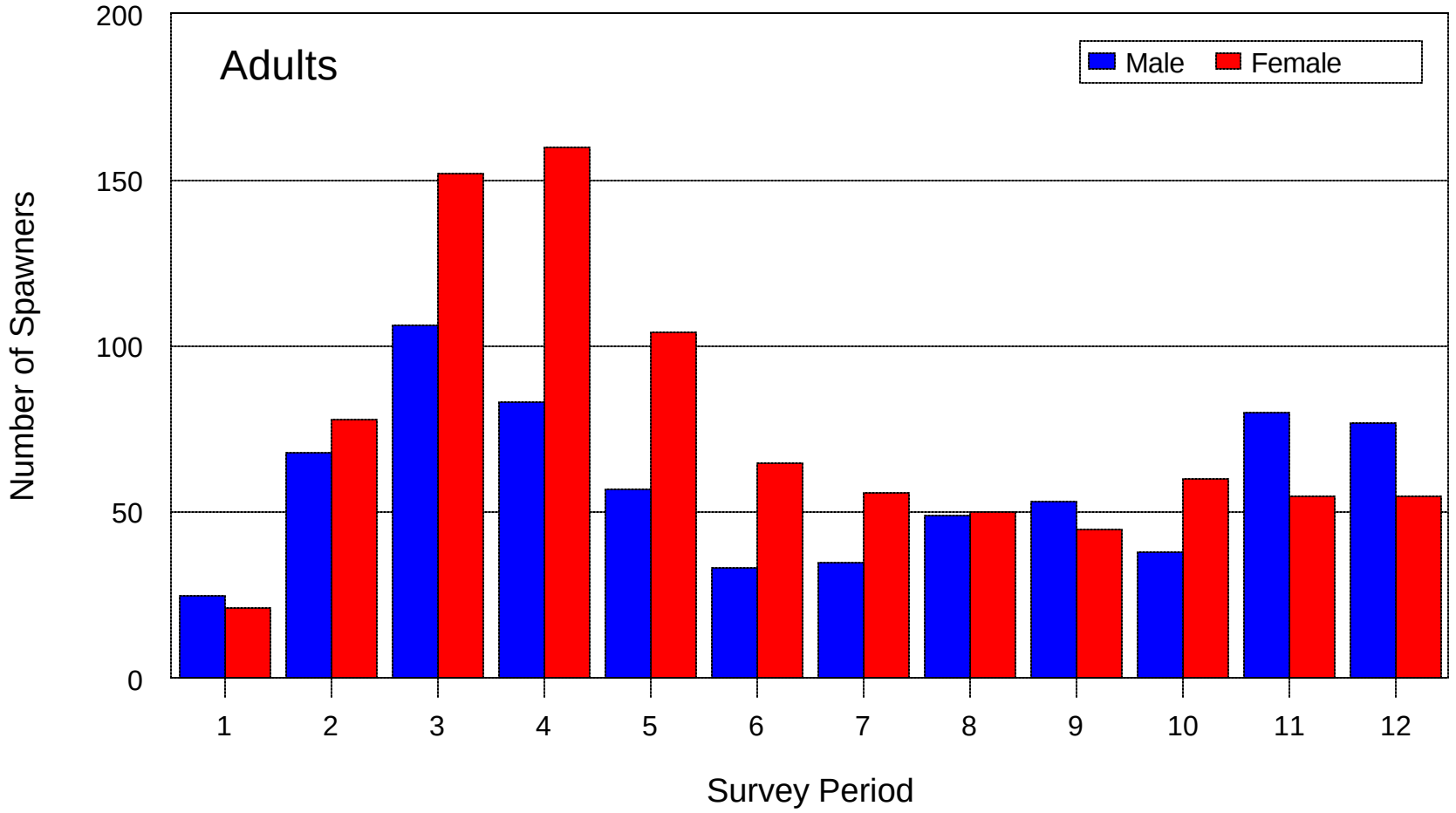

Figure 10. Weekly gender (sex) distribution of adult-sized chinook salmon measured during the upper Sacramento River fall-run chinook salmon spawner escapement survey, October - December 2000.

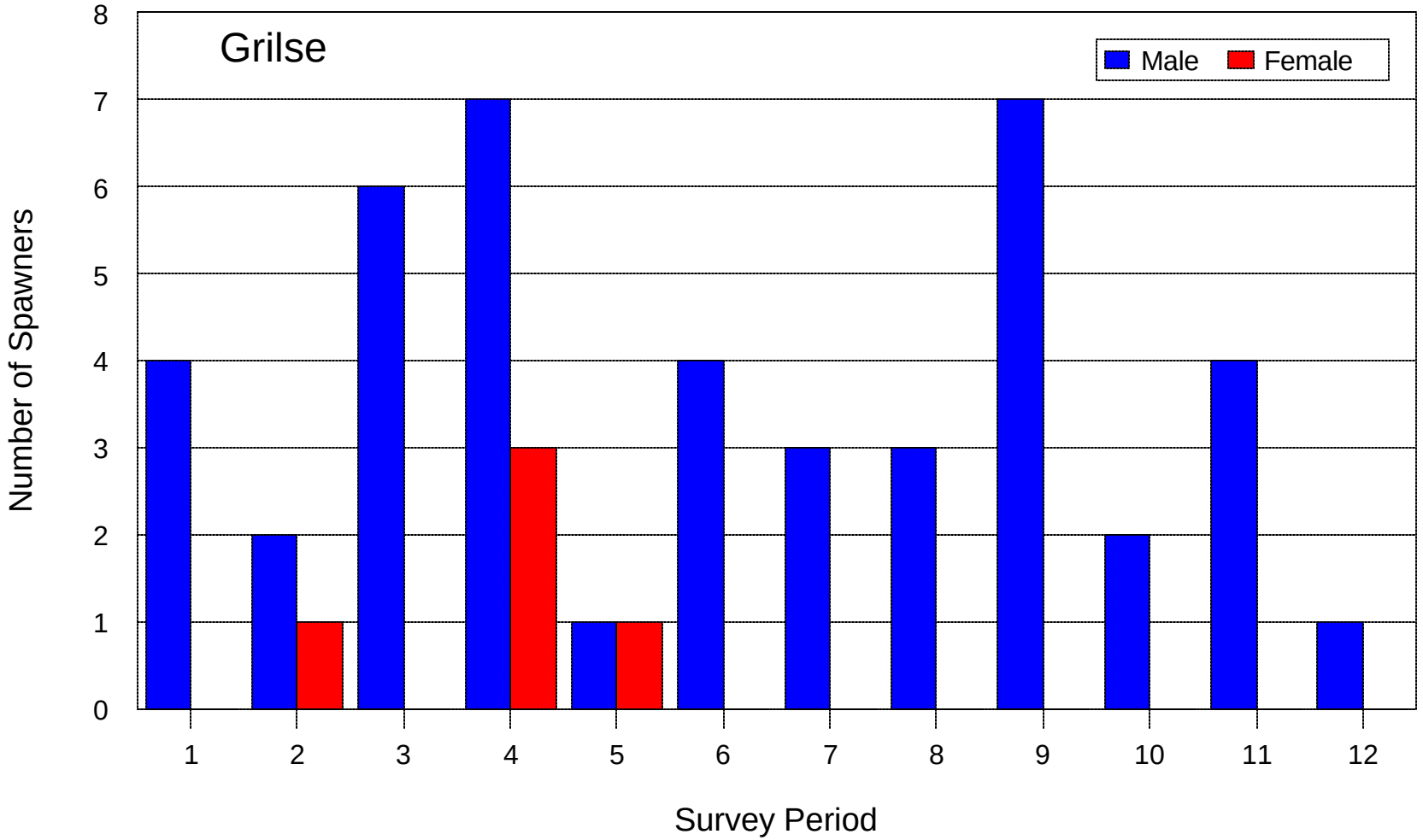

Figure 11. Weekly gender (sex) distribution of grilse-sized chinook salmon measured during the upper Sacramento River fall-run spawner escapement survey, October - December 2000.

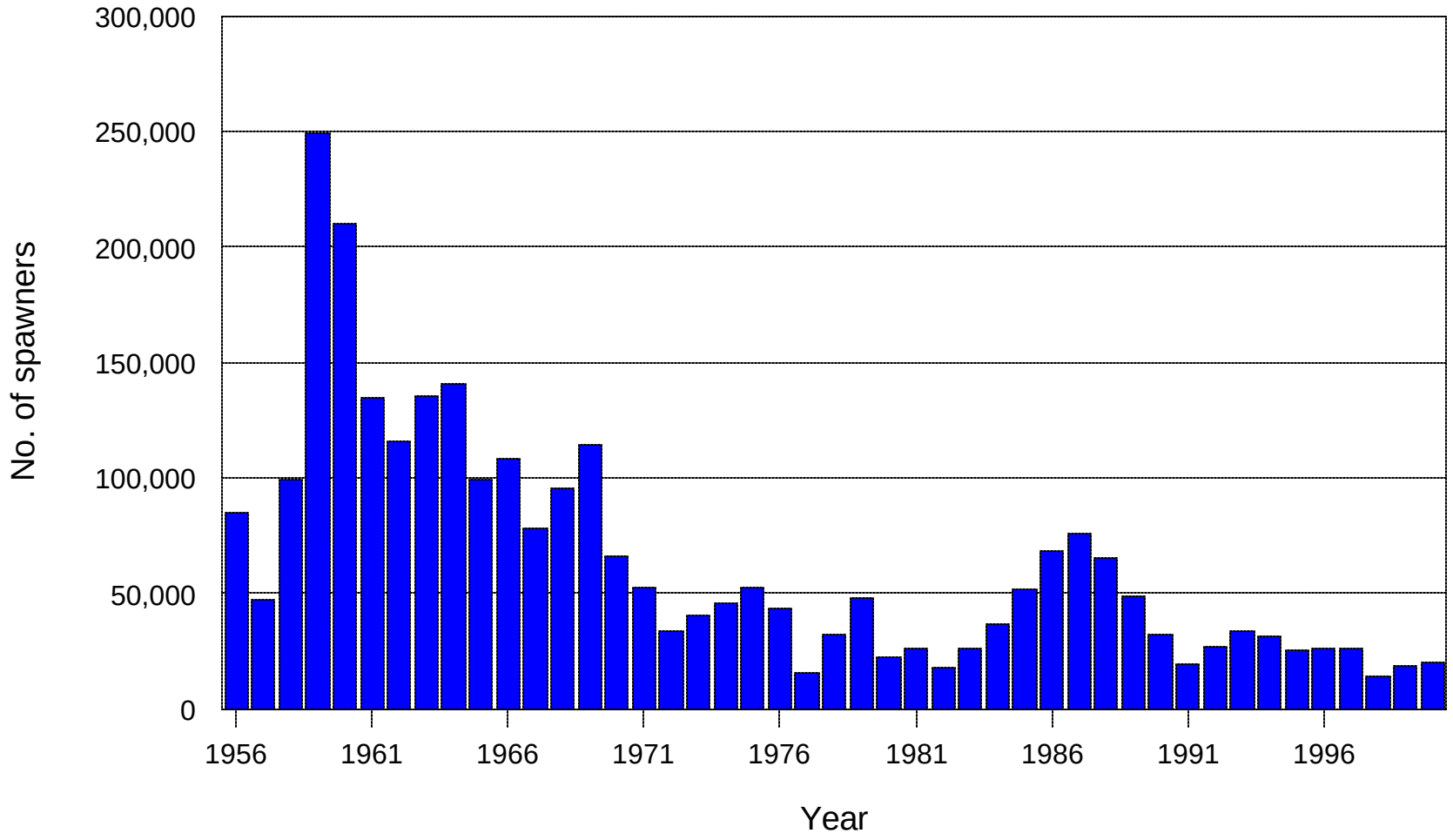

Figure 12. Summary of chinook salmon escapement estimates (adults and grilse) made on the mainstem Sacramento River from Keswick Dam downstream to Red Bluff Diversion Dam excluding tributaries (1956 - 2000).