CALIFORNIA DEPARTMENT OF FISH AND GAME
HABITAT CONSERVATION DIVISION
Native Anadromous Fish and Watershed Branch
Stream Evaluation Program

Sacramento River
Fall-Run Chinook Salmon Escapement Survey
October–December 2001

by

Bill Snider
Bob Reavis
and
James Lyons

Prepared under the direction of
Larry Week, Chief
Native Anadromous Fish and Watershed Branch

December 2002

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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 Sacramento River during fall 2001 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 7th 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, Snider et al. 2000 and Snider et al. 2001). The survey was conducted from 1 October through 20 December 2001. It covered 25.5 miles of the Sacramento River, from Cottonwood Creek [river-mile (RM) 273] to Anderson-Cottonwood Irrigation District (ACID) Dam, located at RM 298.5 just 3.5 miles downstream of Keswick Dam. (Keswick Dam is the upstream limit to anadromous fish migration).

Mean weekly flow generally decreased from 7,600 cubic feet per second (cfs) during the first survey period (1–4 October) to 3,800 cfs during the last survey period (17–20 December). Mean weekly water temperature varied between 53 °F and 57 °F (mode = 57 °F). Water visibility (Secchi depth) ranged from 6 ft to 24 ft.

A total of 7,785 fall-run carcasses was collected (1,466 fresh and 6,319 decayed); 1,277 fresh carcasses were measured, sexed, and aged. Fresh carcass weekly counts (270 salmon) and total weekly carcass counts (1,402 salmon) peaked during weeks 4 and 5 (22 October–1 November); spawning peaked during weeks 2 and 3 (9–18 October).

Size criteria distinguishing adults (>2 years old) from grilse (2 years old) by sex were estimated using length frequency distributions. Males >76 cm fork length (FL) and females >64 cm FL were classified as adults. Based upon these criteria, 89% of the population were adult salmon and 11% were grilse; 33% were adult males, 56% were adult females, 10% were male grilse, and <1% were female grilse.

We examined 712 females for egg retention: 683 (96%) had completely spawned, 8 (1%) still contained a substantial number of eggs, and 21 (3%) were unspawned.

Spawner population estimates were made using both the Schaefer and the Jolly-Seber mark-recapture models, as part of the evaluation of the relationships among different methods. Per the Schaefer model, 1,085 fresh adult carcasses were marked and 291 (27%) were subsequently recaptured, yielding an escapement estimate of 29,102 total salmon (26,025 adults and 3,077 grilse). Per the Jolly-Seber model, 4,612 fresh and decayed carcasses were marked and 1,056 (23%) were subsequently recaptured, yielding an estimate of 20,694 total salmon (18,506 adults and 2,188 grilse). Both estimates are considerably less than the mean annual fall-run Chinook salmon escapement between 1956 and 2000 (65,606 grilse and adults) estimated by counts made at Red Bluff Diversion Dam. Escapement estimates during the six carcass survey years (1995–2001) of our investigation have ranged from 14,211 to 29,102 (mean = 22,884; SD = 5,028) based on the Schaefer model, and from

8,559 to 20,694 (mean = 16,714; SD = 4,163) based on the Jolly-Seber model. The Jolly-Seber model results represent the best estimate of the spawner population.

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 Sacramento River during fall 2001 to estimate spawner abundance and distribution. Ultimately, the spawner population information will be used to better determine flow and other habitat needs of Chinook salmon in the Sacramento River.

A primary charge of STEP - to improve understanding of the relationships between salmon and habitat in the 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 subsequent 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 from 1995 through 2001 (Snider et al. 1997, Snider et al. 1998a, Snider et al. 1998b, Snider et al. 1999, Snider et al. 2000, and Snider et al. 2001) in the Sacramento River.

The models used during the 2001 fall-run spawner survey were Schaefer (1951) and Jolly-Seber (Seber 1982). The Schaefer model was first used in the Central Valley in 1973 to estimate escapement in the Yuba River (Taylor 1974). A modified Schaefer model was first used in 1975 to estimate Yuba River escapement (Hoopaugh 1977) and later described by Hoopaugh (1978). Based on Law's (1994) analysis, the Schaefer model will overestimate escapement when carcass "survival" (carry-over from week-to-week) and catch rates are equivalent to those typically observed in Central Valley tributaries.

The Jolly-Seber model was first used to estimate escapement in the Central Valley in 1988. Also based on Law's (1994) analysis, the Jolly-Seber model will slightly underestimate Central Valley spawner escapement. It is more accurate when model assumptions are met and catch rates are $\geq$10% (Boydstun 1994, Law 1994). Law (1994) also states that both models could produce low estimates if the basic assumption of equal mixing of tagged carcasses with all carcasses is violated. Poor mixing can result in the released carcasses constituting a subpopulation with different probability of recapture than the other, yet uncollected carcasses.

Historical Background

The history of efforts to enumerate spawner escapement in the 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 Sacramento River (Fry 1961).

- **1956–1968** The DFG estimated escapement using carcass counts without mark-recapture and aerial redd counts. Experienced personnel estimated the proportion of the spawner population represented by observed carcasses based upon survey conditions (e.g., visibility) and previous years' experience and expanded the "carcass 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 eight 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 closed and fish must pass through the ladders to migrate above the diversion dam.

Objectives

The objectives of the continuing Sacramento River fall-run Chinook salmon escapement surveys are:

- To assess the utility of carcass, mark-and-recapture surveys to characterize and estimate fall-run Chinook salmon spawning populations in the Sacramento River.

- To provide information on spawner population attributes, including population size and composition, spawning distribution, and prespawning mortalities for assessment of relationships between spawning behavior and success and habitat conditions.

- To estimate the spawner population within the identified study reach to allow evaluation of the relationships between spawner population and resultant populations of emigrating fall-run Chinook salmon.

METHODS

The 2001 spawner escapement survey began immediately following the initial observation of spawning activity. It was conducted weekly from 1 October through 20 December 2001. The 25.5-mile-long survey area, 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. During Weeks 6, 8, and 10 some survey reaches were not surveyed due to lack of personnel.

Table 1. Location of reaches surveyed during the Sacramento River fall-run Chinook salmon escapement survey, October–December 2001.

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 (River mile 302) prior to 30 October. Access to the section between Keswick and ACID dams was eliminated after this date.

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 week 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 allow mixing with untagged carcasses and simulate original mixing conditions. Data collected included number tagged, number chopped, and number recovered.

All carcasses were 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, 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. Location (reach) of the collected carcasses was also recorded.

Escapement estimates were calculated by applying fresh carcass data only to the Schaefer model estimate, and both fresh and decayed carcass data to the Jolly-Seber model. These approaches are consistent with the standard protocols that have been used on most Central Valley streams,

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

Schaefer model (as described by Hoopaugh 1978): $E = N_{ij} = R_{ij}(T_i C_j / R_i R_j) - T_i$

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 (Hoopaugh 1978). 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 were obtained for each survey period from the Keswick gauge operated by the U.S. Geological Survey. Water temperature (grab sample) and water visibility (Secchi depth) were measured each survey day by the survey crew.

RESULTS

A total of 7,785 carcasses was observed (Table 2). Mean weekly flow was 7,600 cubic feet per second (cfs) at the start of the survey, then gradually decreased to 5,300 cfs in week 3, increased to 5,900 cfs in week 4, and then decreased to 3,800 cfs in week 10 (Table 2, Fig.2). Mean weekly temperatures narrowly ranged between 53 ^{o}F and 57 ^{o}F throughout the survey (Table 2, Fig. 2). Temperatures were low early (54 ^{o}F in week 1), increased as flow decreased maintaining at 57 ^{o}F from week 4–8, before declining to the lowest observed temperature during week 12. Visibility through the water column (Secchi depth) ranged from 6 ft in weeks 10 and 12, to 24 ft in week 2 (Table 2, Fig. 2). Results were affected by partial surveys conducted in weeks 6, 8, and 10 when lack of personnel precluded surveys in one or two reaches (typically the lower, less populated reaches).

Temporal Distribution

The number of carcasses observed steadily increased from week 1(196) through week 5 (1,402) (Table 2 and Fig. 3). After peaking in week 5, the numbers of carcasses decreased to 282 in week 8 (partial survey week), and then generally increased until the end of the survey (20 December).

These results indicate that spawning, typically preceding carcass availability by two weeks (Snider and Vyverberg 1995), occurred from mid September through mid December. Peak spawning occurred during mid October (weeks 2–3).

Table 2. General survey information for the Sacramento River fall-run Chinook salmon escapement survey, October–December 2001.

Survey week	Dates	Flows (cfs)[1/]	Secchi depth (ft)[2/]	Water temperature (^{O}F)[2/]	Carcass count[3/]		
					Fresh	Decayed	Total
1	Oct 1–4	7,600	22	54	92	104	196
2	Oct 9–12	5,700	24	54	101	246	347
3	Oct 15–18	5,300	22	55	236	555	791
4	Oct 22–25	5,900	22	57	270	872	1,142
5	Oct 29–Nov 1	5,800	18	57	247	1,155	1,402
6	Nov 7–9[4/]	5,100	19	57	85	608	693
7	Nov 14–16	4,600	10	57	54	561	615
8	Nov 19–20[4/]	4,300	16	57	28	254	282
9	Nov 26–29	3,900	12	56	74	457	531
10	Dec 3–4[4/]	3,800	6	54	41	288	329
11	Dec 10–13	3,800	12	54	119	507	626
12	Dec 17–20	3,800	6	53	119	712	831
				Totals	1,466	6,319	7,785

1/ Mean weekly discharge during days sampled as measured at Keswick Dam by U.S. Bureau of Reclamation.

2/ Mean weekly of daily measurements taken by survey crews.

3/ Includes both adults and grilse.

4/ Partial survey - some reaches not surveyed.

Spatial Distribution

Spawning distribution increased moving upstream. Most carcasses were observed in reaches 1 and 2 (34% and 32% respectively). Overall, the spatial distribution of all observed carcasses was 34% in reach 1, 32% in reach 2, 22% in reach 3, and 12% in reach 4 (Table 3 and Fig. 4).
Since carcasses tend to occur downstream of the spawning location, spawning distribution was likely even greater in the uppermost reaches than represented by the observed carcass distribution.

Size Distribution

A total of 1,277 carcasses was measured (Table 4). Mean size was 85.8 cm FL. Size ranged from 37 to 118 cm FL. Male salmon (n = 547) averaged 87.1 cm FL (range: 39-118 cm FL) (Fig. 5). Female salmon (n = 730) averaged 84.0 cm FL (range: 37–105 cm FL) (Fig. 6). The weekly mean size for males ranged from 85.3 to 97.3 cm FL (Fig. 7). Weekly mean size for females ranged from 78.4 to 90.1 cm FL (Table 4 and Fig. 8).

Analysis of the length-frequency distributions (Figs. 5 and 6) used to identify age-size criteria showed male grilse (n = 125) as salmon $\leq$76 cm FL, and female grilse (n = 10) as salmon $\leq$64 cm FL (Table 5). Male grilse averaged 62.2 cm FL (range: 39-76 cm FL, SD = 7.7); male adults (n = 422) averaged 95.9 cm FL (range: 77-118 cm FL, SD = 9.3). Female grilse averaged 57.9 cm FL (range: 37–64 cm FL, SD = 8.4); female adults (n = 720) averaged 84.4 FL (range: 65–105 cm FL, SD = 7.9).

Grilse comprised 11% (n = 135) of the 1,277 carcasses measured (Table 6). The highest number of grilse measured during any survey was 24 during week 4 (Fig. 9). Adults comprised 89% (n = 1,142) of the measured carcasses. The highest numbers of adults measured during any survey period were 194 and 210, during weeks 3 and 4, respectively.

Sex Composition

Males comprised 37% (n = 422) and females comprised 63% (n = 720) of the measured, fresh adult carcasses (Table 7). Males comprised 92% (n = 125) and females comprised 8% (n = 10) of the grilse. Females comprised 57% (n = 730) and males comprised 43% (n = 547) of all the measured fresh carcasses (33% male adults, 56% female adults, 10% male grilse and >1% female grilse) . The female to male ratio for adult spawners was 1.7:1 (720:422) (Table 7 and Fig. 10). Female adults predominated every week of the survey except Week 8. The grilse population was heavily dominated by males during the entire survey (Fig. 11).

Spawning Success

There were 712 females examined for egg retention (Table 8). Of these, 683 (96%) had completely spawned, eight (1%) had only partially spawned, and 21 (3%) had not spawned. At least 89% of the females checked each survey period had completely spawned.

Table 3. Distribution by reach of carcasses (adults and grilse) observed during the Sacramento River fall-run Chinook salmon escapement survey, October–December 2001.

Survey week	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	56	2	74	3	38	4	18	1
2	102	5	130	6	71	6	26	1
3	256	16	185	24	175	19	105	11
4	242	43	367	47	210	79	149	5
5	231	63	274	113	173	194	146	208
6	194	60	206	88	81	64	3/	3/
7	113	103	83	49	38	41	111	77
8	3/	3/	70	58	75	46	24	9
9	140	47	105	77	94	63	4	1
10	165	61	67	36	3/	3/	3/	3/
11	0	288	0	151	0	148	0	39
12	179[4]	305	153[4/]	91	45[4/]	43	12[4/]	3
Total	1,678	993	1,714	743	1,000	707	595	355
%	34		32		22		12	

1/ Number of carcasses tagged.
2/ Number of untagged carcasses chopped.
3/ Survey on conducted
4/ Carcasses were tagged for late-fall Chinook salmon run survey during the last survey week (12).

Table 4. Size and sex statistics for fresh fall-run Chinook salmon carcasses measured during the Sacramento River escapement survey, October–December 2001.

	All salmon			Male salmon			Female salmon		
		Length (FL in cm)			Length (FL in cm)			Length (FL in cm)	
Survey week	Number measured	Mean	Range	Number measured	Mean	Range	Number measured	Mean	Range
1	90	82.4	37-116	48	85.8	39-116	42	78.4	37-102
2	100	86.8	56-112	53	88.8	56-112	47	84.6	72-98
3	217	84.4	52-115	93	86.0	52-115	124	83.3	63-98
4	234	83.2	47-110	95	85.3	47-110	139	81.8	66-100
5	125	83.5	54-109	41	88.2	54-109	84	81.2	62-100
6	85	85.4	52-108	30	87.1	52-108	55	84.5	68-101
7	53	83.6	49-110	20	86.0	49-110	33	82.2	62-99
8	28	90.0	55–113	22	90.1	55–113	6	89.3	83-96
9	73	84.8	40–118	34	86.0	40-118	39	83.7	51-102
10	41	91.8	55-113	20	94.2	55-113	21	89.6	71-99
11	112	92.0	45-114	40	90.8	45-114	72	90.1	56-105
12	119	92.0	58-115	51	97.3	58-115	68	88.1	70–105
Total (mean)	1,277	(85.8)	37-118	547	(87.1)	39-118	730	(84.0)	37–105

Table 5. Summary of adult and grilse sizes and numbers by sex for carcasses measured during the Sacramento River fall-run Chinook salmon escapement survey, October–December 2001.

	Female		Male	
	Grilse	Adults	Grilse	Adults
Number	10	720	125	422
Mean FL (cm)	57.9	84.4	62.2	95.9
Range FL (cm)	37-64	65–105	39–76	77–118
SD	8.4	7.9	7.7	9.3

Table 6. Age composition (grilse and adult) of carcasses measured during the Sacramento River fall-run Chinook salmon escapement survey, October–December 2001.

	Adults		Grilse[1/]	
Survey week	Number	Percent	Number	Percent
1	74	82	16	18
2	89	89	11	11
3	194	89	23	11
4	210	90	24	10
5	116	93	9	7
6	74	87	11	13
7	47	89	6	11
8	24	86	4	14
9	62	85	11	15
10	37	98	4	2
11	102	91	10	9
12	113	95	6	5
Total (%)	1,142	(89)	135	(11)

1/ Based on length-frequency distributions, male grilse are defined as salmon $\leq$76 cm FL and female grilse as salmon $\leq$64 cm FL.

Table 7. Sex composition of fall-run Chinook salmon grilse and adult carcasses measured during the Sacramento River escapement survey, October–December 2001.

Survey week	Adults				Grilse[1/]			
	Male		Female		Male		Female	
	Number	%	Number	%	Number	%	Number	%
1	36	49	38	51	12	75	4	25
2	42	47	47	53	11	100	0	0
3	71	37	123	63	22	96	1	4
4	71	34	139	66	24	100	0	0
5	34	29	82	71	7	78	2	22
6	19	26	55	74	11	100	0	0
7	15	32	32	68	5	83	1	17
8	18	75	6	25	4	100	0	0
9	24	39	38	61	10	91	1	9
10	16	43	21	57	4	100	0	0
11	31	30	71	70	9	90	1	10
12	45	40	68	60	6	100	0	0
Total (%)	422	(37)	720	(63)	125	(92)	10	(8)

1/ Based on length-frequency distributions, male grilse are defined as salmon ≤76 cm FL and female grilse as salmon ≤64 cm FL.

Table 8. Spawning completion (egg retention) summary for female fall-run Chinook salmon carcasses measured during the Sacramento River escapement survey, October–December 2001.

Survey week	No. females measured	No. females checked for egg retention	Number spawned (%)	Number partially spawned (%)	Number unspawned (%)
1	42	42	39(93)	0(0)	3(7)
2	47	45	45(100)	0(0)	0(0)
3	124	115	110(96)	3(3)	2(2)
4	139	136	135(99)	0(0)	1(1)
5	84	84	84(100)	0(0)	0(0)
6	55	55	54(98)	1(2)	0(0)
7	33	32	32(100)	0(0)	0(0)
8	6	5	5(100)	0(0)	0(0)
9	39	39	37(95)	0(0)	2(5)
10	21	21	19(90)	0(0)	2(10)
11	72	72	64(89)	3(4)	5(7)
12	68	66	59(89)	1(2)	6(9)
Total (mean)	730	712	683(96)	8(1)	21(3)

Population Estimates

Only fresh carcass data were used to calculate the Schaefer estimate. A total of 1,085 fresh adult carcasses was tagged and 291 (27%) were subsequently recaptured. Both fresh and decayed carcass data were used to calculate the Jolly-Seber estimate. A total of 4,612 fresh and decayed adult carcasses was tagged and 1,056 (23%) were subsequently recaptured.

An estimate of 26,025 adult spawners was calculated using the Schaefer model (Tables 9 and 10). Since adults made up 89% of the total escapement, based on measured carcasses (Table 6), a total escapement estimate of 29,102 spawners (adults and grilse) was calculated by dividing the adult estimate by 0.89. An adult escapement estimate of 18,506 was calculated using the Jolly-Seber model (Table 11). This estimate was similarly expanded by dividing it by 0.89 resulting in a total escapement estimate of 20,694 spawners.

The 2001 population estimates for salmon spawning in the Sacramento River from Cottonwood Creek to ACID Dam are as follows:

	Schaefer	Jolly-Seber
Adult estimate	26,025	18,506
Grilse estimate	3,077	2,188
Total estimate	29,102	20,694

The estimated 2001 escapement (29,102) is considerably less than the 1956–2000 average estimate (65,606) 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 estimate.

Coded-wire Tag Recoveries

We collected 38 adipose-fin clipped carcasses. A fin clip indicates the salmon was produced in a hatchery and originally received a coded-wire tag (CWT). Only 32 of the 38 marked salmon still possessed a CWT (Table 13). Twenty-four of these were from Feather River Hatchery (FRH); six from Coleman National Fish Hatchery; and two from Mokelumne River Fish Installation (MRFI). Nineteen of the 24 FRH produced salmon were from the 1998 brood year (BY 1998) and five from BY 1997; eight were spring run and 16 were fall run. Four of the six fish from CNH were from BY

Table 9. Summary of tagging and recapture data for fresh adult Chinook salmon carcasses collected during the Sacramento River escapement survey, October–December 2001.

Schaefer model capture-recapture data matrix

Week of recovery $_{(j)}$	Week 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	13										13	520[1/]	40.00
3	5	23									28	745	26.61
4	3	3	59								65	1,045	16.22
5	1	4	19	39							63	1,306	20.73
6		2	6	12	23						43	661	15.37
7			1	2	8	9					20	576	28.80
8					1	5	6				12	270	22.50
9					1	3	3	2			9	503	55.89
10						1			10		11	314	28.55
11								1	4	17	22	605	27.50
12									1	4	5	817	163.40
$R_{(i)}$	22	32	85	53	33	18	9	3	15	21	<- Tagged fish recovered		
$T_{(i)}$	77	92	214	233	217	78	47	25	65	37	<- Total fish tagged		
$T_{(i)}/R_{(i)}$	3.50	2.88	2.52	4.40	6.58	4.33	5.22	8.33	4.33	1.76	<- Ratio		

1/ Included carcasses observed during week 1.

Table 10. 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 2001.

Population estimate

Week of recovery $_{(j)}$	Week of tagging $_{(i)}$ 1	2	3	4	5	6	7	8	9	10	Totals
2	1,820										1,820
3	466	1,759									2,225
4	170	140	2,409								2,719
5	73	238	992	3,445							4,857
6		88	232	811	2,325						3,456
7			73	253	1,515	1,123					2,964
8					148	487	705				1,340
9					368	727	876	931			2,901
10						124			1,237		1,361
11								229	477	824	1,530
12									708	1,152	1,860
Subtotals	2,528	2,226	3,705	4,618	4,355	2,461	1,581	1,161	2,422	1,975	27,033
Tags		-92	-214	-233	-217	-78	-47	-25	-65	-37	-1,008
									Adult population estimate -		26,025

Table 11. Summary of tagging and recapture data for both fresh and decayed adult Chinook salmon carcasses sampled during the Sacramento River escapement survey, October–December 2001.

Jolly-Seber capture-recapture data matrix

Tagging week	Number tagged	Carcasses examined	Recaptures of fish marked in week										Tags recovered
			1	2	3	4	5	6	7	8	9	10	
1	161	170											
2	306	354	30										30
3	671	822	12	78									90
4	879	1,244	4	27	172								203
5	754	1,516	1	8	56	158							223
6	456	794		4	11	42	89						146
7	319	650			3	7	26	51					87
8	155	332				1	4	35	35				75
9	315	538					3	11	15	19			48
10	218	334						2	2	1	28		33
11	0	691								3	21	75	99
12	0	826							1		5	16	22
Totals	4,234	8,271	47	117	242	208	122	99	53	23	54	91	

Adult population estimate = 18,508
Total population estimate = 20,694 (includes 2,188 grilse)

Table 12. Annual fall-run Chinook salmon escapement estimates (adults and grilse) for Sacramento River from Red Bluff Diversion Dam (RBDD) to Keswick Dam, 1956–2001.

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[2/])
1973	40,424	1996	71,206(25,890[2/])
1974	45,590	1997	95,505(26,191[2/])
1975	52,248	1998	4,824(14,211[2/])
1976	43,612	1999	48,418(18,295[2/])
1977	15,784	2000	87,793(19,951[2/])
1978	32,235	2001	29,102
Annual average for 1956 through 2000 period = 65,606[3/]			

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/ Based on carcass tagging study. The average escapement estimate is based upon RBDD data.

3/ Estimates from RBDD counts were used to calculate average.

Table 13. Summary of statistics for adipose-clipped (hatchery produced) carcasses observed during the Sacramento River fall-run Chinook salmon escapement survey, October–December 2001.

Collection Data				Coded-wire tag data				
Date	Reach	Sex	FL (cm)	Tag code	Race	Brood year	Hatchery of origin	Release site
1 Oct	1	F	37	no tag				
1 Oct	1	F	89	no tag				
1 Oct	1	F	82	no tag				
1 Oct	1	M	91	06-01-06-09-01	Spring	1998	Feather R H	Crochett
1 Oct	1	F	82	06-01-06-09-06	Spring	1998	Feather R H	Crockett
2 Oct	2	M	90	06-01-06-09-02	Spring	1998	Feather R H	Crockett
2 Oct	2	F	79	06-01-06-06-06	Spring	1997	Feather R H	Carquinez Strait
3 Oct	3	F	91	06-01-06-09-01	Spring	1998	Feather R H	Crockett
3 Oct	3	F	82	06-01-06-06-04	Spring	1997	Feather R H	Carquinez Strait
3 Oct	3	F	89	06-01-06-06-14	Fall	1997	Feather R H	Gridley
4 Oct	4	F	77	no tag				
9 Oct	1	F	83	06-01-06-06-05	Spring	1997	Feather R H	Carquinez Strait
10 Oct	2	F	92	06-01-06-06-05	Spring	1997	Feather R H	Carquinez Strait
10 Oct	2	F	88	06-26-31	Fall	1998	Feather R H	Crockett
10 Oct	2	M	94	06-01-06-07-04	Fall	1998	Feather R H	Yolo Bypass-HWY 16
12 Oct	4	M	97	06-01-06-07-04	Fall	1998	Feather R H	Yolo Bypass-HWY 16
15 Oct	1	M	92	06-26-32	Fall	1998	Feather R H	Crockett
15 Oct	1	F	79	06-26-34	Fall	1998	Feather R H	Crockett
16 Oct*	2	F	74	06-26-34	Fall	1998	Feather R H	Crockett
16 Oct	2	M	78	05-23-26	Fall	1998	Feather R H	Port Chicago
16 Oct	2	M	106	05-01-02-06-14	Fall	1997	Coleman F H	Coleman F H
17 Oct	3	M	101	05-01-02-06-14	Fall	1997	Coleman F H	Coleman F H
17 Oct	3	M	62	06-26-62	Fall	1998	MRFI	Mouth of Mok. River
17 Oct	3	F	73	05-01-02-08-01	Fall	1998	Feather R H	Georgiana Slough

Table 13. Summary of statistics for adipose-clipped (hatchery produced) carcasses observed during the Sacramento River fall-run Chinook salmon escapement survey, October–December 2001 (con't).

Collection Data				Coded-wire tag data				
Date	Reach	Sex	FL (cm)	Tag code	Race	Brood year	Hatchery of origin	Release site
18 Oct	4	F	72	06-49-16	Fall	1998	MRFI	New Hope Landing
18 Oct	4	F	82	05-01-02-07-12	Fall	1998	Feather R H	Georgianna Slough
18 Oct	4	F	81	05-01-02-07-01	Fall	1997	Coleman F H	Coleman F H
22 Oct	1	F	76	06-26-31	Fall	1998	Feather R H	Crockett
22 Oct	1	F	83	05-01-02-10-08	Fall	1998	Coleman F H	Coleman F H
22 Oct	1	M	81	06-26-34	Fall	1998	Feather R H	Crockett
23 Oct	2	F	72	06-26-34	Fall	1998	Feather R H	Crockett
23 Oct	2	F	76	06-26-33	Fall	1998	Feather R H	Crockett
24 Oct	3	M	89	06-26-33	Fall	1998	Feather R H	Crockett
24 Oct	3	M	86	no tag				
24 Oct	3	F	89	no tag				
30 Oct	2	M	88	06-26-33	Fall	1998	Feather R H	Crockett
13 Nov	4	F	89	05-01-02-04-09	Fall	1998	Coleman F H	below Red Bluff Dam
17 Dec	1	M	68	05-52-07	Late Fall	1997	Coleman F H	Coleman F H

* Head was taken from decayed carcass

1997 and two were from BY 1998; five of the fish were fall run and one was a late-fall run. Both fish from the MRFI were fall run from BY 1998.

Of the 1,277 fresh carcasses examined for marks, 37 had an adipose-fin mark and CWTs were recovered from 31. (A CWT. of FRH. origin was taken from a decayed carcass.) All of the fresh, adipose-clipped carcasses were either 3- or 4-year-old adult fish. Five of the six marked carcasses without a CWT exceeded 76 cm FL and appeared to be adults. The sixth carcass measured 37 cm FL and was likely a grilse. Based upon these findings, 3.1% of the adult spawner population (36 of 1,142 fresh adult carcasses) were hatchery produced, and 0.7% of the grilse population (1 of 135 fresh grilse carcasses) were hatchery produced.

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 seven survey years (1995–2001) have been very consistent. It appears that this approach can provide the information needed to improve our understanding 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 only ranged from 31% to 33% 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%). In 2001 the estimate was 29,102 (highest to date) and recovery rate was 27% (second lowest to date).

- Escapement estimates were also made for the reach from RBDD to Keswick Dam using fish counts made at RBDD and redd distribution data. Escapement estimates for this reach were similar to the carcass survey generated Schaefer or Jolly-Seber produced estimates in 1995 (27,678 v. 26,548), but were considerably different in 1996 (71,206 v. 25,890/ 18,942), 1997 (95,505 v. 26,191/20,544), 1998 (4,824 v. 14,211/8,559), 1999 (48,418 v. 18,295/13,818), and 2000 (87,793 v. 19,951/14,938). No estimate was made for 2001 based on RBDD counts. Mean RBDD estimates during the six years of concurrent carcass surveys was 55,904

while the Schaefer produced estimates averaged 22,884 and the Jolly-Seber produced estimates averaged 16,714.

- 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 Dam 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 Dam 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%).

- Age composition of the spawner population has varied from 77% (1999) to 97% (2000) adults (Table 14). There does not appear to be any relationship between percent grilse and the estimated adult population for the subsequent years.

- Sex composition varied only slightly during the seven survey years (Table 14). The percentage of female adults ranged from 56% (2000) to 66% (1995 and 1996) (mean = 62, SD = 3.6). The total percentage of female (grilse and adult) ranged from 50% in 1999 to 63% in 1998 (mean = 57, SD = 4.6).

- Spatial spawning distribution (based upon the location of fresh carcass collections) varied 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 66% of all spawning during 2001 and averaged 65%, (SD = 4.5) for the 7 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 except 2001 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%; (SD = 2.4); spawning in reach 4 has averaged 12% (SD = 2.4).

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

- Spawning success, measured as percentage of completely spent female carcasses, ranged from 87% (in 1996) to 96% (in 1998, 2000, and 2001) (mean=94, SD=3.3).

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Table 14. Comparison of results from carcass surveys conducted from 1995 through 2001 on Sacramento River fall-run Chinook salmon spawner populations.

	1995	1996	1997	1998	1999	2000	2001
Total estimate	26,546	25,890	26,191	14,211	18,295	19,959	29,102
% adult	91	79	90	86	77	97	89
% Grilse	9	21	10	14	23	3	11
% Female adult	66	66	59	63	63	56	63
% Male adult	34	34	41	37	37	44	37
% Female all	62	54	55	63	50	55	57
% Male all	38	46	45	37	50	45	43
Tag recovery rate (%)	33	32	31	24	34	43	27
Spawning success	94	87	92	96	94	96	96
Reach 1 (%)	40	23	29	29	30	36	34
Reach 2 (%)	21	37	33	36	37	37	32
Reach 3 (%)	23	26	24	23	23	18	22
Reach 4 (%)	16	14	14	12	10	9	12
Peak carcass count period	5-11 Nov	28 Oct-1 Nov	27-30 Oct	2-5 Nov	25-28 Oct	23-26 Oct	29 Oct-1Nov
Flow range (cfs)	4,800-6,500	5,300-27,700	4,200-6,300	6,200-23,400	6,000-8,100	4,600-6,400	3,800-7,600
Temperature range (^{o}F)	53-57	53-56	53-57	51-55	52-53	53-56	53-57
Male grilse criteria (cm)	64	73	72	71	71	63	76
Female grilse criteria (cm)	64	64	66	67	66	64	64

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FIGURES

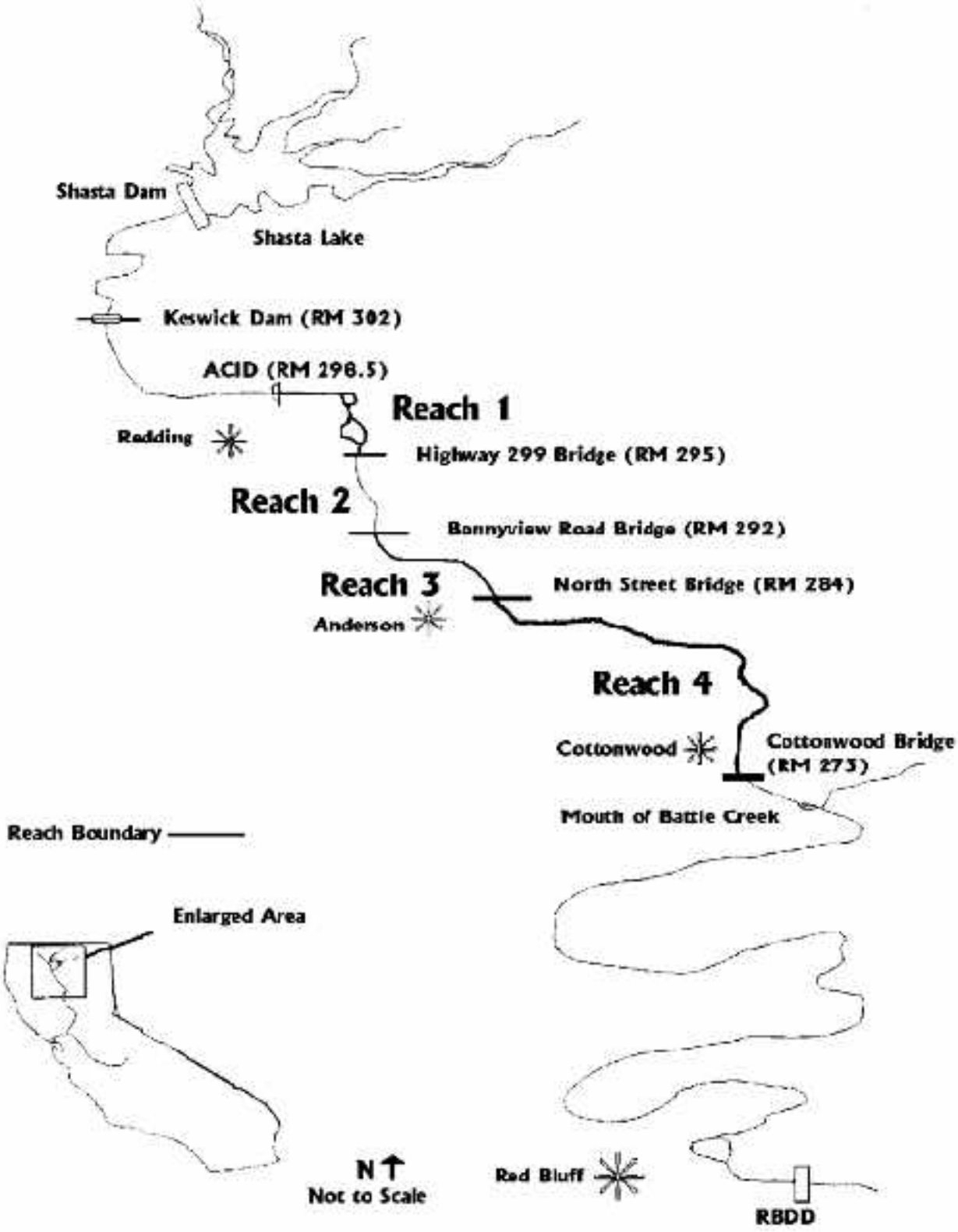

Figure 1. Upper Sacramento RIver fall-run Chinook salmon spawner escapement survey location, including reach designations, September - December 2001.

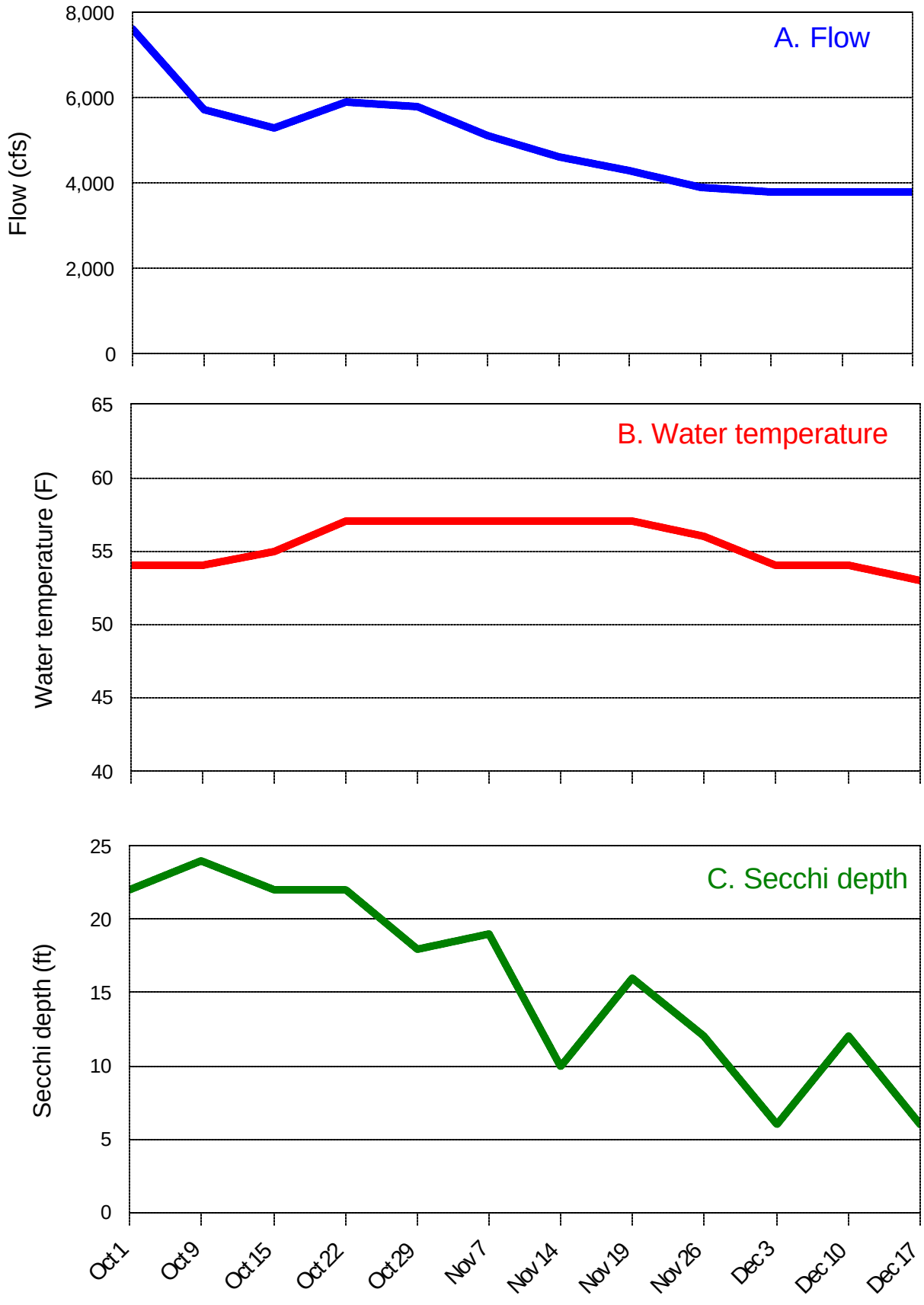

Figure 2. Mean daily flow at Keswick Dam (A), water temperature (B), and Secchi depth (C), measured during the Sacramento River fall-run Chinook salmon spawner escapement survey, October - December 2001.

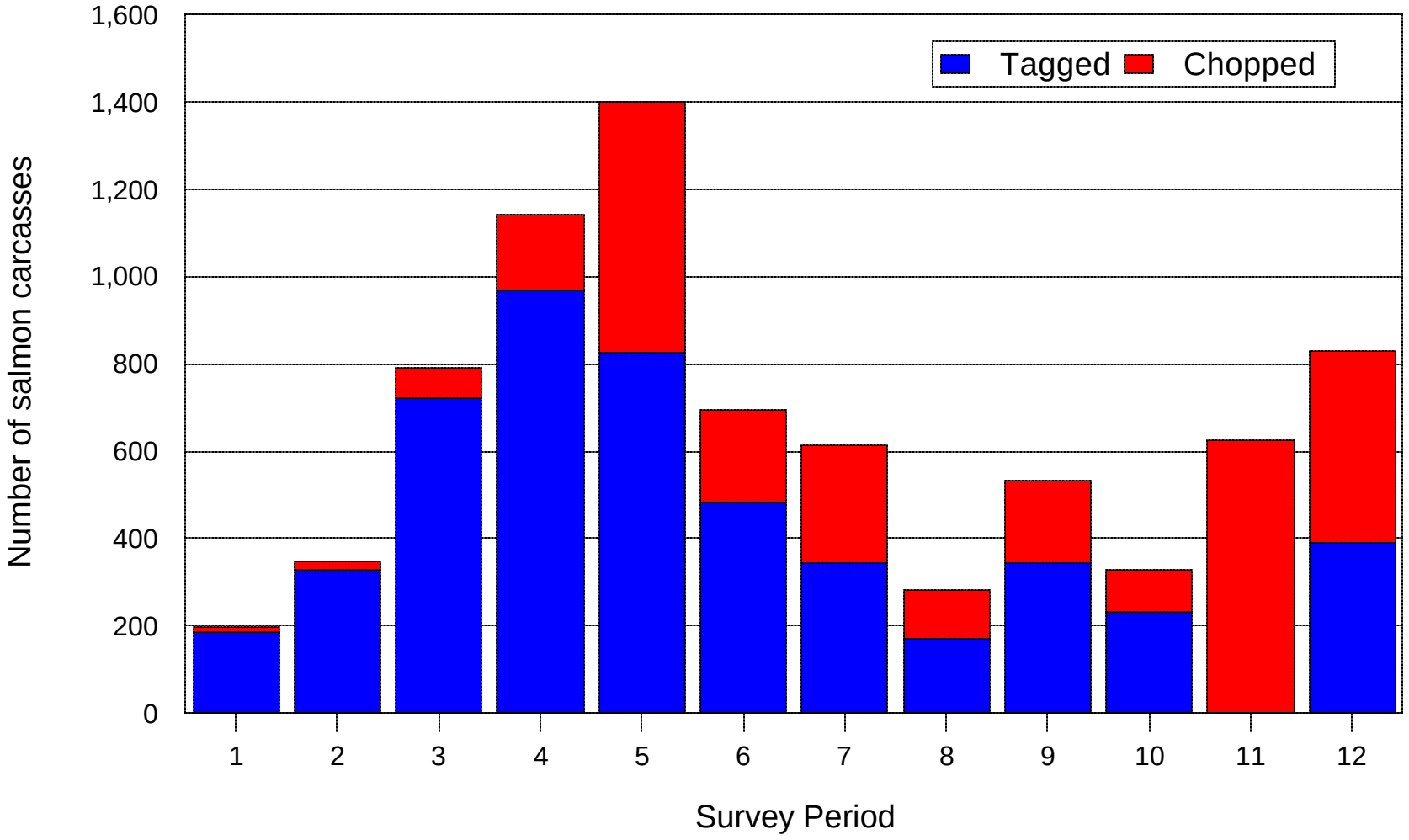

Figure 3. Weekly distribution of both fresh and decayed, adult and grilse carcasses observed during the upper Sacramento River fall-run chinook salmon spawner escapement survey, October - December 2001. Carcasses were tagged during last fall-run survey for subsequent late-fall-run Chinook Salmon escapement survey.

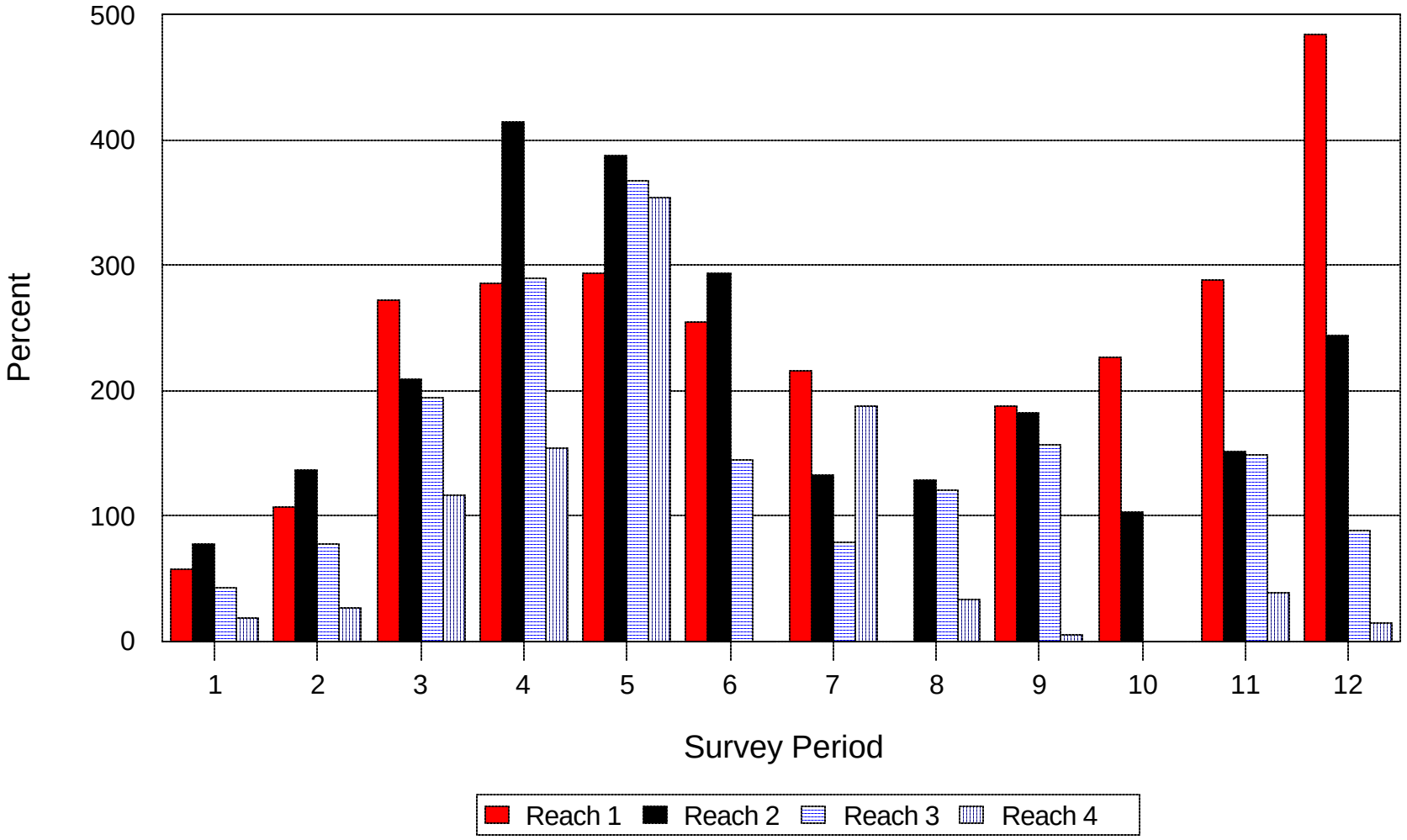

Figure 4. Weekly spatial distribution (% by reach) of both fresh and decayed carcasses observed during the Sacramento River fall-run Chinook salmon spawner escapement survey, October - December 2001.

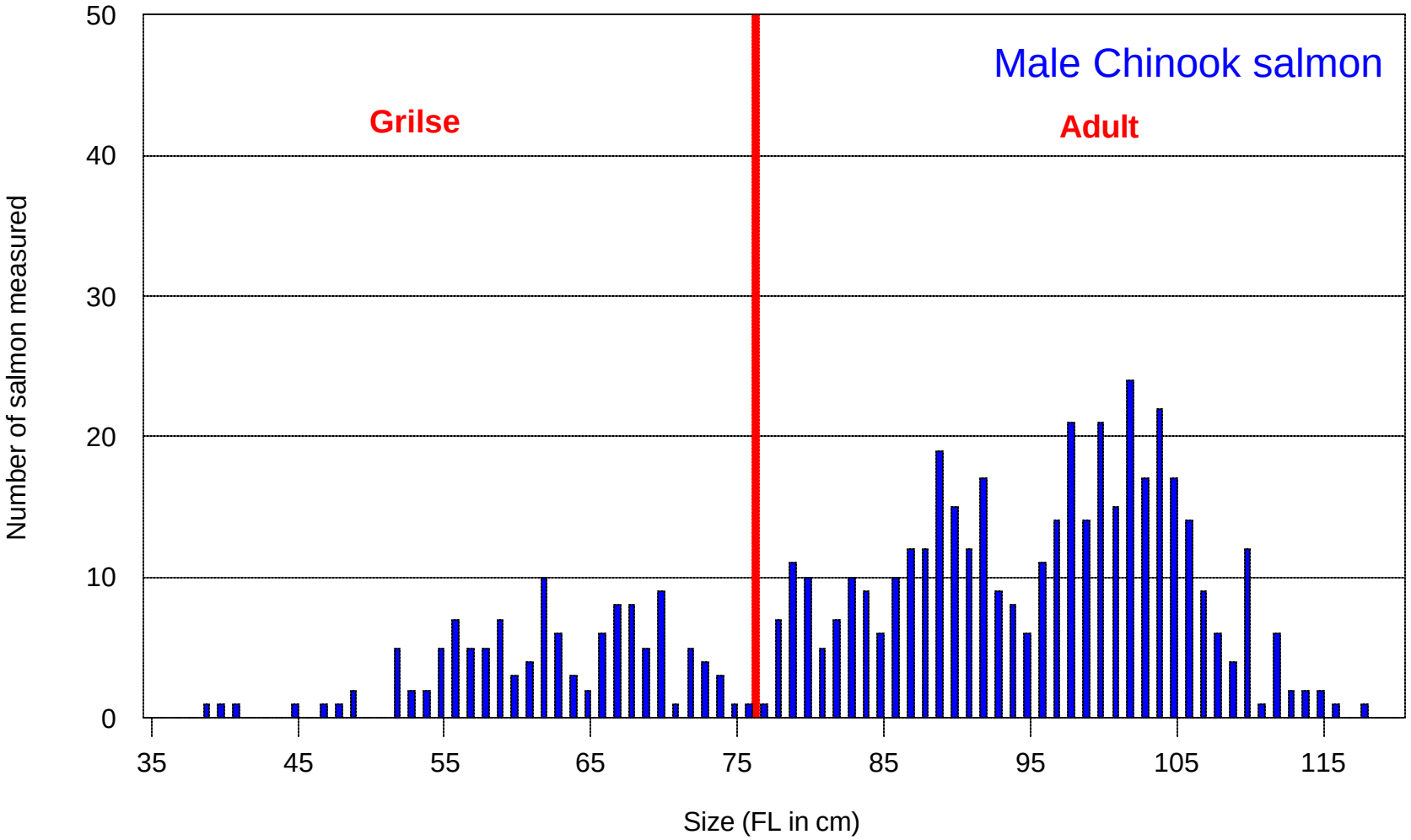

Figure 5. Size (FL in cm) distribution of fresh, male carcasses measured during the Sacramento River fall-run Chinook salmon spawner escapement survey, October - December 2001.

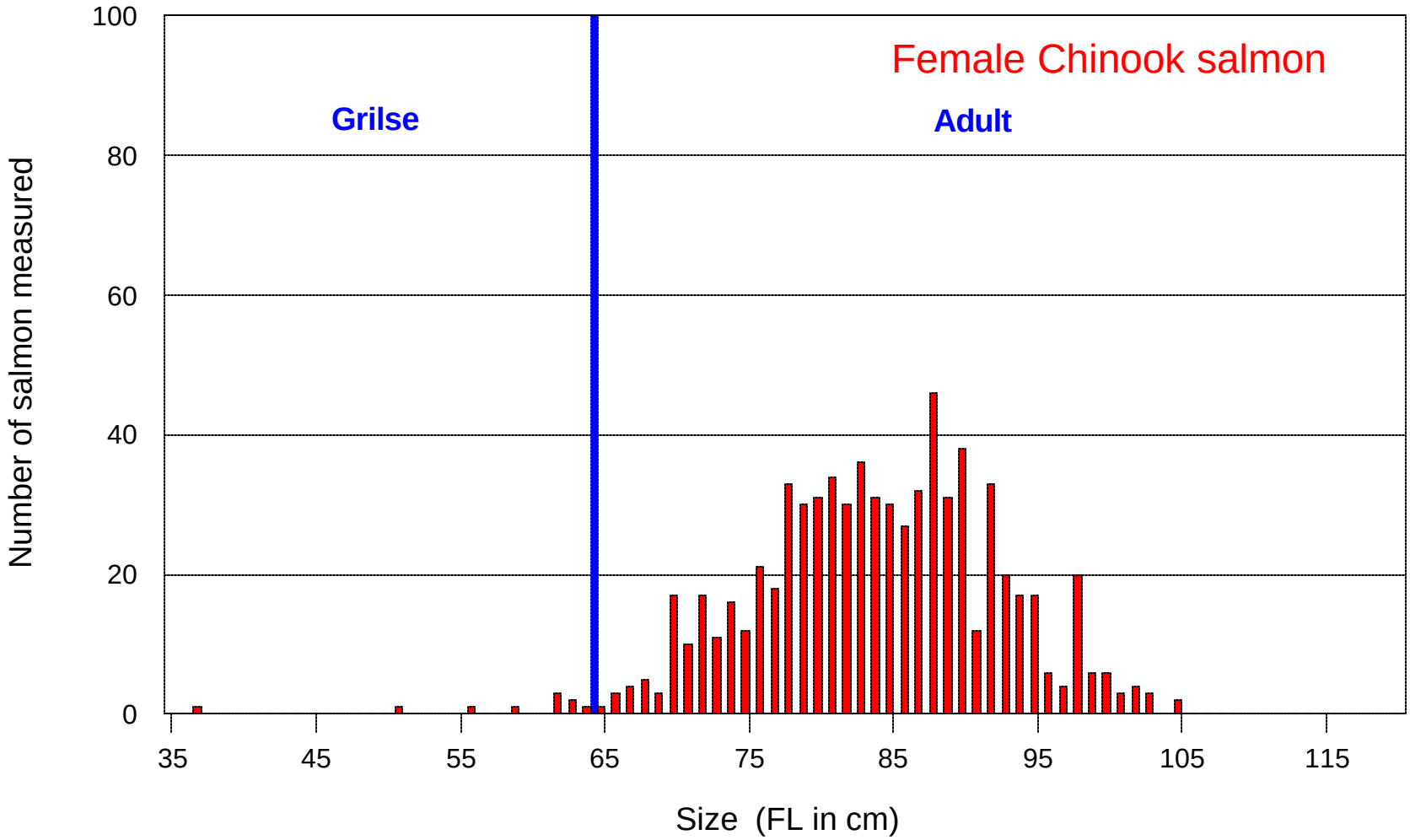

Figure 6. Size (FL in cm) distribution of fresh, female carcasses measured during the Sacramento River fall-run Chinook salmon spawner escapement survey, October - December 2001.

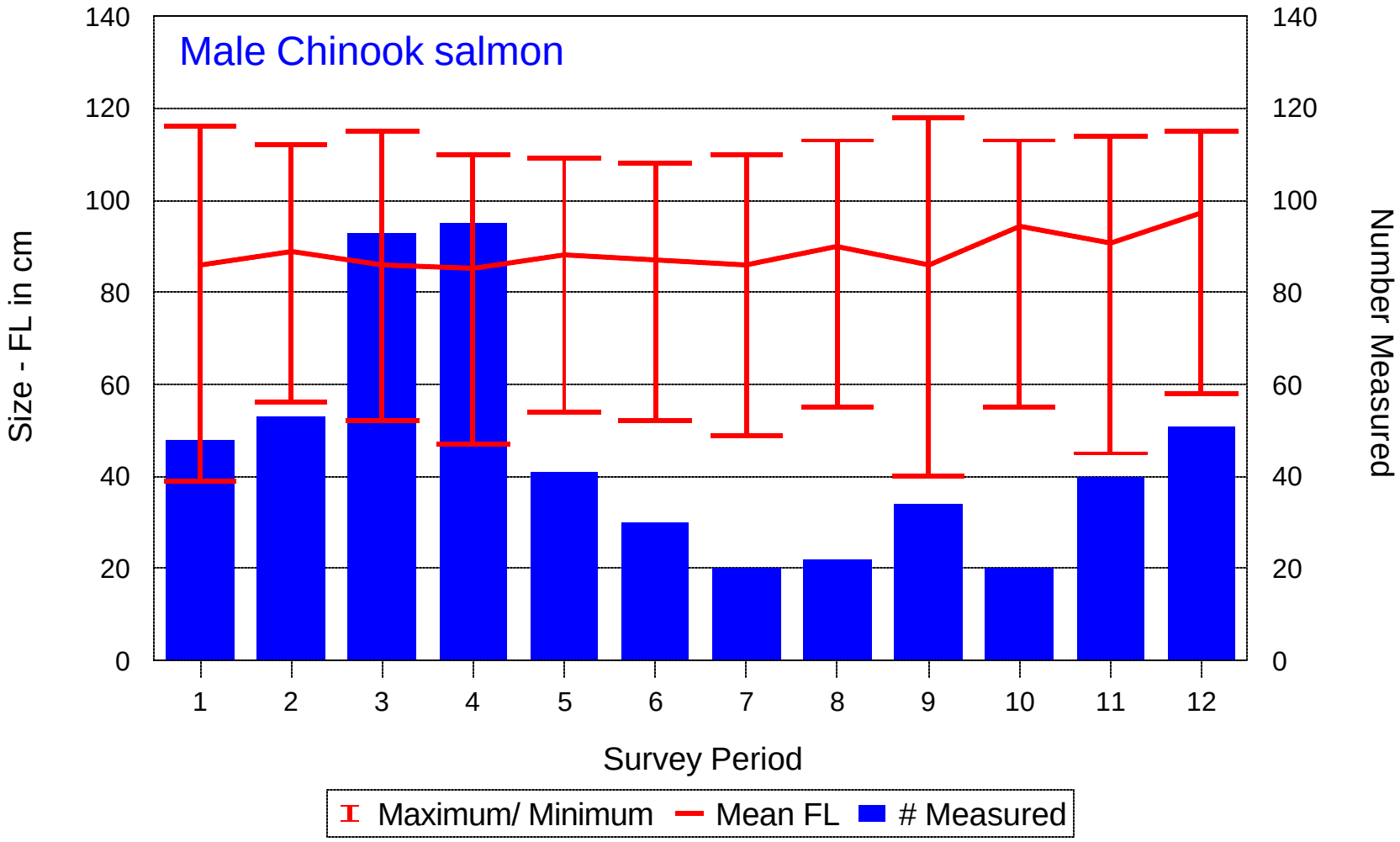

Figure 7. Weekly mean size (FL in cm), size range, and number of male chinook salmon measured during the Sacramento River fall-run Chinook salmon spawner escapement survey, October - December 2001.

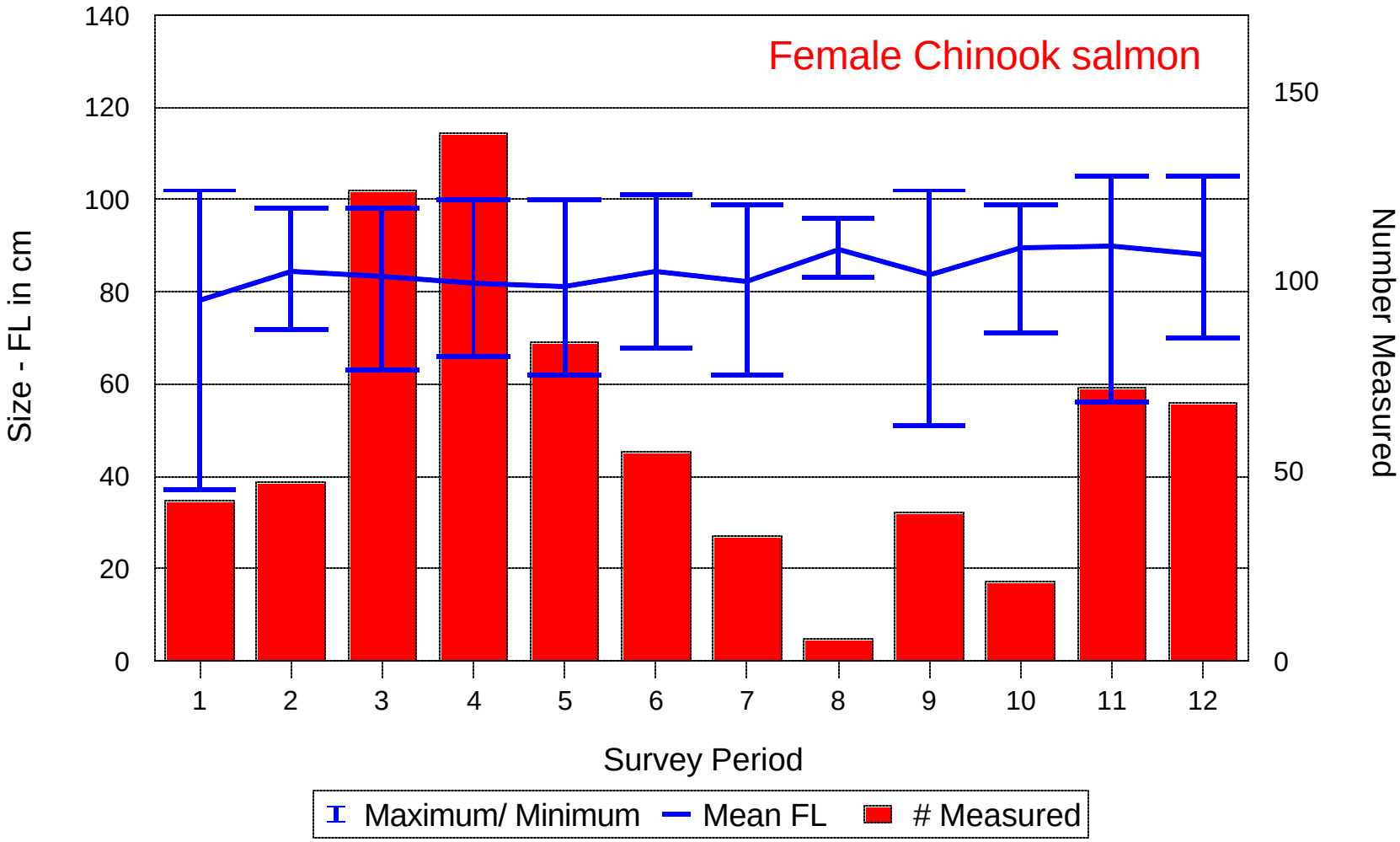

Figure 8. Weekly mean size (FL in cm), size range, and number of female Chinook salmon measured during the Sacramento River fall-run Chinook salmon spawner escapement survey, October - December 2001.

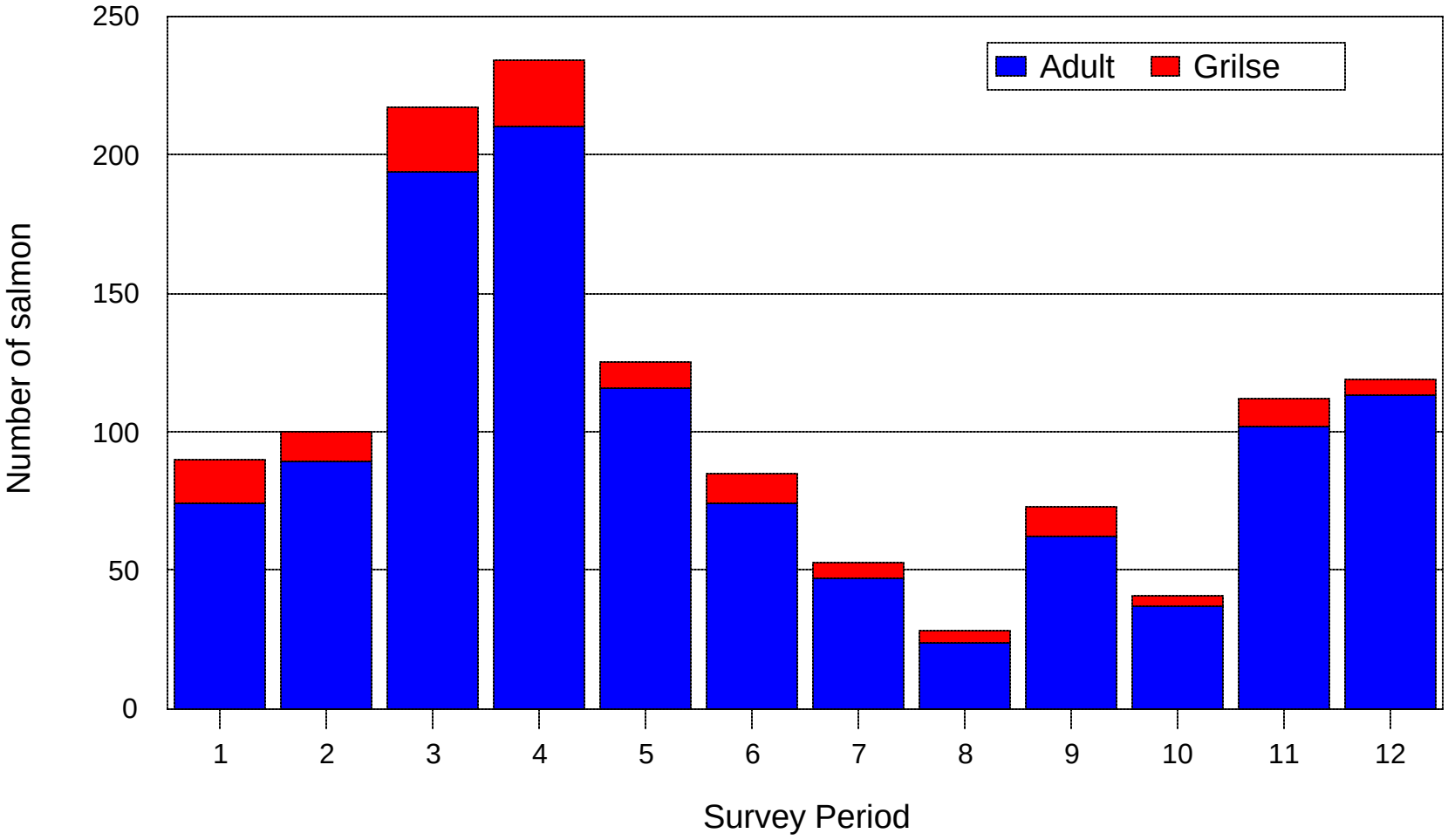

Figure 9. Age composition (adult and grilse) of Chinook salmon measured during the Sacramento River fall-run Chinook salmon spawner escapement survey, October - December 2001.

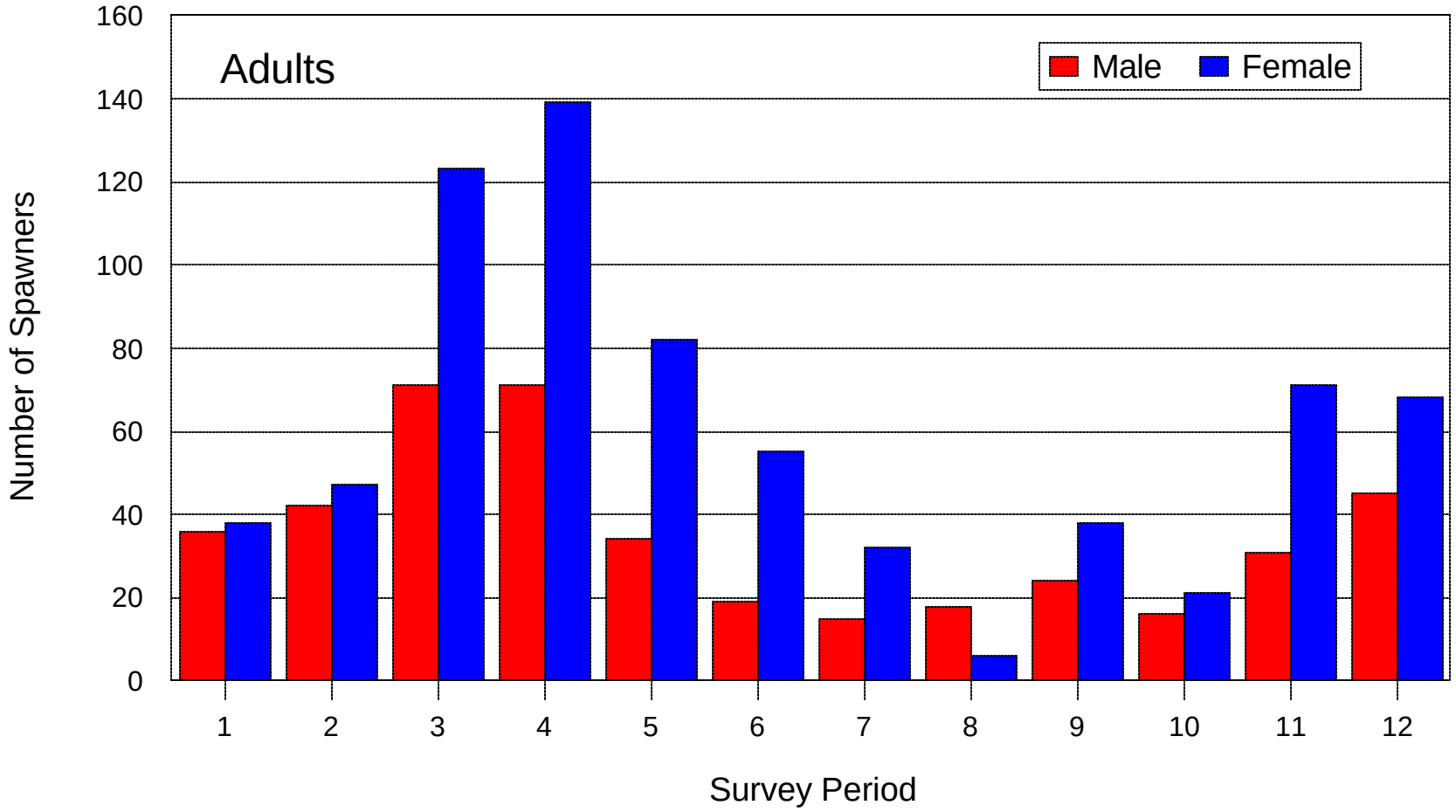

Figure 10. Weekly gender (sex) distribution of adult-sized Chinook salmon measured during the upper Sacramento River fall-run chinook salmon spawner escapement survey, October - December 2001.

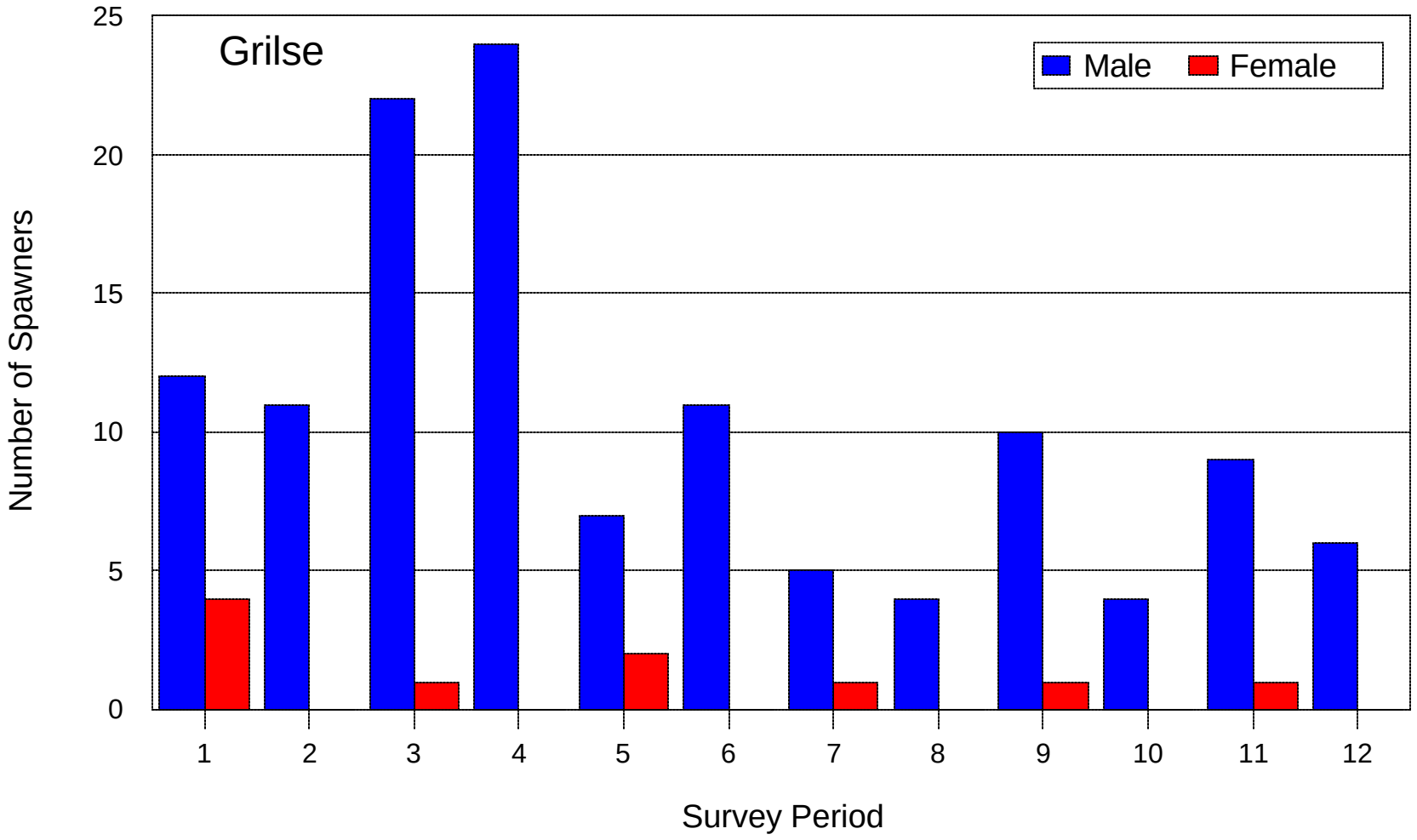

Figure 11. Weekly gender (sex) distribution of grilse-sized Chinook salmon measured during the Sacramento River fall-run Chinook salmon spawner escapement survey, October - December 2001.

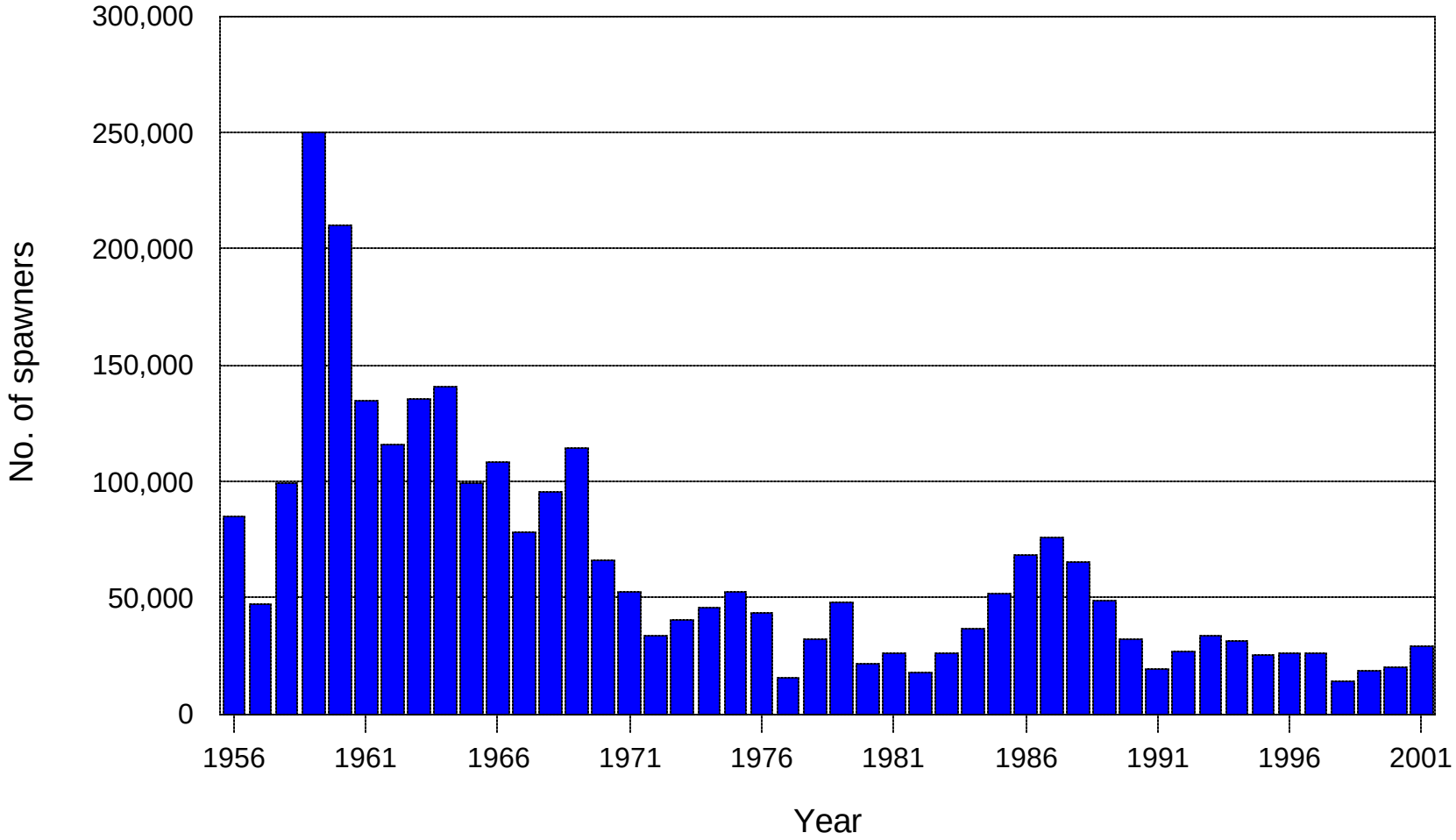

Figure 12. Summary of fall-run Chinook salmon escapement estimates (adults and grilse) made on the mainstem Sacramento River from Keswick Dam downstream to Red Bluff Diversion Dam excluding tributaries (1956 - 2001).