California Department of Fish and Wildlife
North Central Region

Lower American River Fall-run Chinook Salmon Escapement Survey, October 2019 - January 2020

Presented to the United States
Bureau of Reclamation

by
Benjamin Kelly
Fisheries Biologist
Pacific States Marine Fisheries Commission
205 SE Spokane Street, Suite 100
Portland, OR 97302

Jeanine Phillips
Environmental Scientist
California Department of Fish and Wildlife
1701 Nimbus Road, Suite A
Rancho Cordova, CA 95670

TABLE OF CONTENTS

List of Figures

List of Tables

INTRODUCTION

The lower American River (LAR) is a 23-mile stretch of the American River starting at the base of Nimbus Dam and extending downstream to the confluence with the Sacramento River at Discovery Park. The American River is the second-largest tributary to the Sacramento River and flows through a highly developed urban environment (Williams 2001). The LAR supports both wild and hatchery fall-run Chinook salmon (FRCS, *Oncorhynchus tshawytscha*) spawning and rearing. Historically, the LAR has supported spawning of fall-, spring-, and perhaps late fall-runs of Chinook salmon (Yoshiyama et al. 2000), although the spring-run was extirpated following the construction of Folsom Dam in 1955. The fall-run represents the largest run of Chinook salmon found in California's Central Valley. Although current FRCS populations are heavily supported by hatchery production (Yoshiyama et al. 2000), the exact percentage of hatchery produced fish in the LAR is unknown but is presumed significant (Williams 2001). Adult FRCS are typically found in the LAR from September to January, and generally begin to spawn in the LAR in early November, or when water temperatures drop below 60°F, with the peak of the run occurring in late November to early December (Williams 2001).

The LAR is heavily influenced by the presence of dams that limit salmon occurrence to the lowest 23 river miles. The Nimbus Fish Hatchery, constructed in 1958 to compensate for the loss of 100 miles of spawning and rearing habitat due to the construction of Nimbus and Folsom Dams, releases roughly 4 million Chinook salmon annually (CDFW 2020). FRCS mark/recapture escapement surveys have been conducted in the LAR since 1976, although escapement estimates of Central Valley salmon have been conducted since the 1940's and 1950's (Bergman et al. 2012). Because of environmental stochasticity and anthropogenic activity, salmon runs in California have exhibited a high degree of variation over time (Satterthwaite and Carlson 2015).

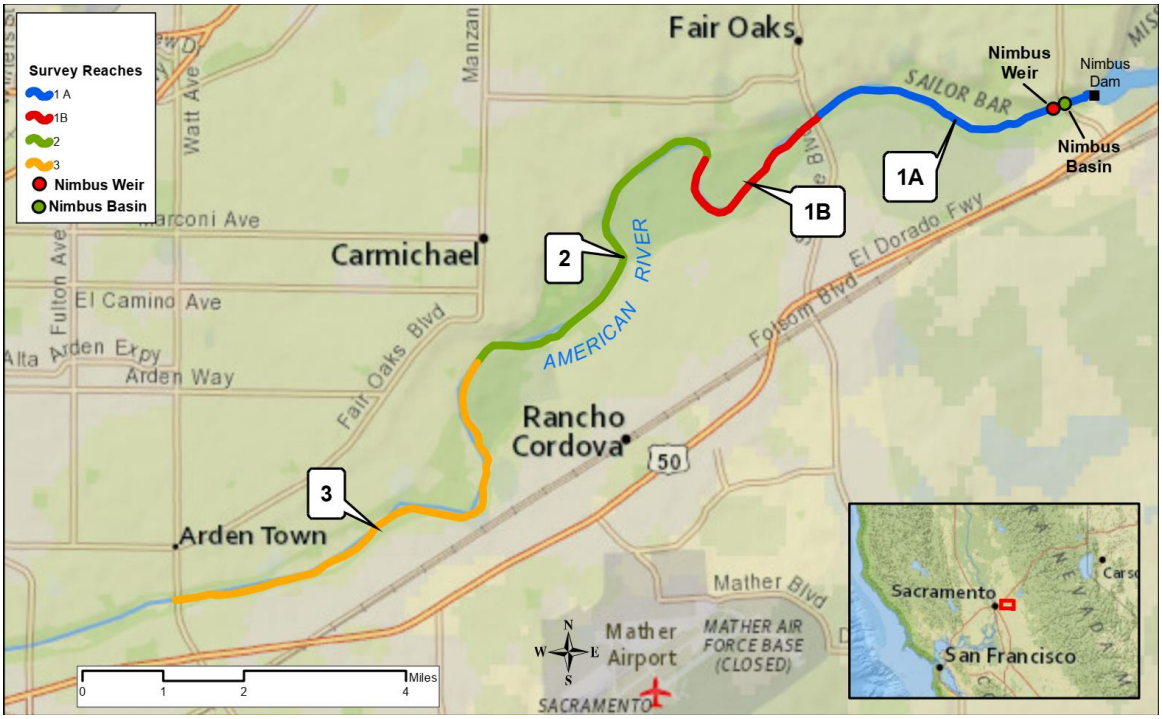
The objectives of the 2019 escapement survey were to: (1) estimate the size of FRCS escapement in the LAR, (2) determine the ratio of adults to grilse, as well as the sex ratios of adults and grilse, (3) determine the degree of female pre-spawn mortality, and (4) collect coded-wire tags (CWT) to investigate the number and origin of hatchery-reared FRCS using spawning habitat in the LAR.

METHODS

During each survey period, the 13.4-mile stretch from the base of Nimbus Dam to Watt Avenue was divided into six sections and surveyed once over a 3 to 5-day period. The Nimbus Dam basin (NB) is composed of a deep pool at the base of the dam, a riffle and run in the main channel, and two side channels composed of riffles, runs and pools. The Nimbus hatchery weir

(weir) separates NB from Section 1 and is located adjacent to the Nimbus Fish Hatchery. Section 1 contains the highest number of FRCS spawning activity (Snider and Reavis 1996) and is composed primarily of riffles, glides and a few deep pools. This section is broken up into sections 1A and 1B for sampling purposes because of the high numbers of carcasses typically encountered. Section 2 contains a few riffles, but is composed primarily of large, deep-water glides. Section 3 consists of riffles, deep glides and several stretches of braided side-channels (Figure 1, Table 1). The LAR downstream of Watt Avenue has little spawning habitat and is primarily a migration corridor and, therefore, it is not included in the escapement survey.

Figure 1. Map of survey sections for the lower American River Chinook salmon escapement survey.



Surveys were conducted by crews consisting of 5-10 members searching for submerged salmon carcasses while walking the riverbank, riding in a jet boat, or paddling a kayak. Each river section was surveyed once per survey period, while the Nimbus Weir was surveyed at least once per week and up to three to five times per week during the height of the spawning season. The NB was surveyed only on foot from the banks, Sections 1 and 2 were surveyed by jet boat or kayak and from the banks, and due to habitat complexity, Section 3 was surveyed by kayaks and walking portions of the banks. Surveys began at the upstream boundary of each river section and progressed downstream, with crew members processing each carcass encountered. Salmon carcasses ≤50% submerged were not included in the escapement survey,

Table 1. Survey section distances and descriptions of the fall-run Chinook salmon escapement survey on the lower American River.

Section	Description	Miles
NB	Nimbus Dam to Nimbus Hatchery Weir	0.3
W	Nimbus Hatchery Weir	n/a
1A	Nimbus Hatchery Weir to Sunrise Blvd boat launch	2.6
1B	Sunrise Blvd boat launch to El Manto Dr access	1.7
2	El Manto Dr access to River Bend Park	4.7
3	River Bend Park to Watt Ave access	4.1
	Total	13.4

as these carcasses do not represent an equal probability of detection, and once dried require a longer time to decompose, which can skew mark-recapture analysis. Each carcass was examined for the following: (1) presence of an external tag, (2) presence or absence of an adipose fin, (3) extent of carcass degradation, and (4) extent of egg retention in females.

Carcasses were processed in one of three ways: (1) inclusion in the mark/recapture model, (2) head collection for coded-wire tag (CWT) retrieval, or (3) chopped and tallied. Carcasses with an intact adipose fin were either included in the mark/recapture model or chopped and tallied. To be included in the mark recapture model, a carcass must be in a fresh enough condition to be detected during subsequent survey periods. The degree of carcass decomposition was determined by the examination of the eyes and gills. Carcasses were considered fresh if at least one eye was clear, or the gills were entirely red. Scale samples were also collected from fresh carcasses. Scales were collected by removing a one-inch square scale sample from the left side of the carcass above the lateral line and posterior to the dorsal fin. Carcasses included in the mark/recapture model were fitted with a hog ring and numbered disk-tag on the left maxilla. Each tag was marked with colored flagging unique to the survey period and the tagged carcasses were deposited in the thalweg adjacent to the tagging location. Heads were removed and retained from adipose fin clipped carcasses for CWT removal. Carcasses were chopped and tallied if they were in an advanced state of decomposition (not fresh).

Covariate data were collected from all carcasses utilized in the mark/recapture model and those destined for CWT retrieval. Covariate data included sex, fork length, level of egg retention in females, and degree of decomposition. Sex was determined through a combination of characteristics including body morphology, presence or absence of a kype, and examination of gametes. Fork length (FL) was measured from the tip of the snout to the fork of the caudal fin and rounded to the nearest centimeter. At the end of the survey, FLs were pooled by sex and plotted in a frequency distribution to classify carcasses as grilse (a two-year-old, sexually

mature fish) or adults. The level of egg retention was determined by examining female carcasses, classifying each female as unspawned if >70% of eggs were present, partially spawned if 30-70% of eggs were retained, or spawned if <30% of eggs were retained.

Carcasses encountered at the weir were processed differently. Carcasses with an adipose fin were manually passed through the weir to simulate the natural downstream movement of carcasses. Carcasses missing an adipose fin were processed for data collection, and heads were removed for CWT retrieval.

The 2019 LAR FRCS in-river escapement estimate was derived using the Cormack-Jolly-Seber (CJS) mark-recapture model for open populations (Cormack 1964 and Bergman et al. 2012) using R statistical software, version 3.3.2 (www.r-project.org).

Flow and water temperature data were obtained for each survey period from the United States Geological Survey gauge for the American River at Fair Oaks (gauge id 11446500) through the USGS website (USGS 2020). The Fair Oaks gauge is located at the upper end of Section 1 approximately one hundred meters downstream of the weir.

RESULTS

Survey Periods

The 2019 LAR carcass survey consisted of 14 survey periods, commencing on October 14, 2019, and ending on January 15, 2020. All sections were surveyed in each survey period, except for survey period 11, when Section 3 was not surveyed due to the Christmas holiday (Table 2). The weir was last surveyed December 13, 2019, before the structure was lifted the following morning.

Environmental Conditions

LAR temperatures generally decreased for the duration of the survey season. The maximum temperature recorded was 61°F on October 26, 2019, and the minimum temperature was 49°F on January 15, 2020 (Figure 2). Water temperatures decreased to a level suitable for spawning on November 5, when mean daily temperature dropped below 58°F.

The maximum mean daily flow recorded was 2,650 cubic feet per second (cfs) on November 27, 2019, and the minimum mean daily flow was 2,110 cfs on January 15, 2020 (USGS 2020).

Table 2. Survey dates and sampling regime for the 2019 lower American River escapement survey.

Survey Period	Dates	Sections Not Surveyed
1	Oct 14-17, 2019	None
2	Oct 21-24, 2019	None
3	Oct 28-31, 2019	None
4	Nov 4-8, 2019	None
5	Nov 11-15, 2019	None
6	Nov 18-22, 2019	None
7	Nov 25-27, 2019	None
8	Dec 2-6, 2019	None
9	Dec 9-13, 2019	None
10	Dec 16-20, 2019	None
11	Dec 26-28, 2019	3
12	Dec 30, 2019-Jan 3, 2020	None
13	Jan 6-9, 2020	None
14	Jan 13-15, 2020	None

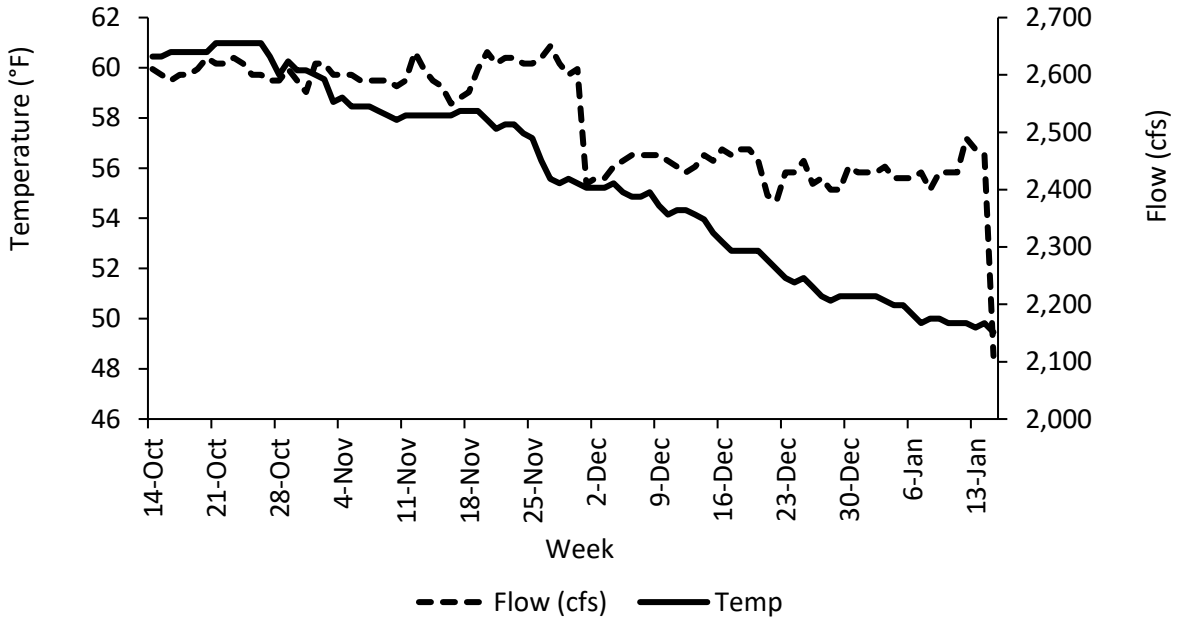


Figure 2. Flow and water temperatures encountered during the 2019 lower American River escapement survey.

Final Carcass Count

A total of 15,350 individual carcasses was observed and processed during the survey (Figure 3). The maximum number of carcasses was processed during sampling period 10 (December 16-20). A total of 2,823 fresh carcasses was observed during the season (Figure 4). Fresh carcasses were observed during each of the 14 sampling periods, reaching a high of 660 fresh carcasses processed during sampling period 9 (December 9-13)

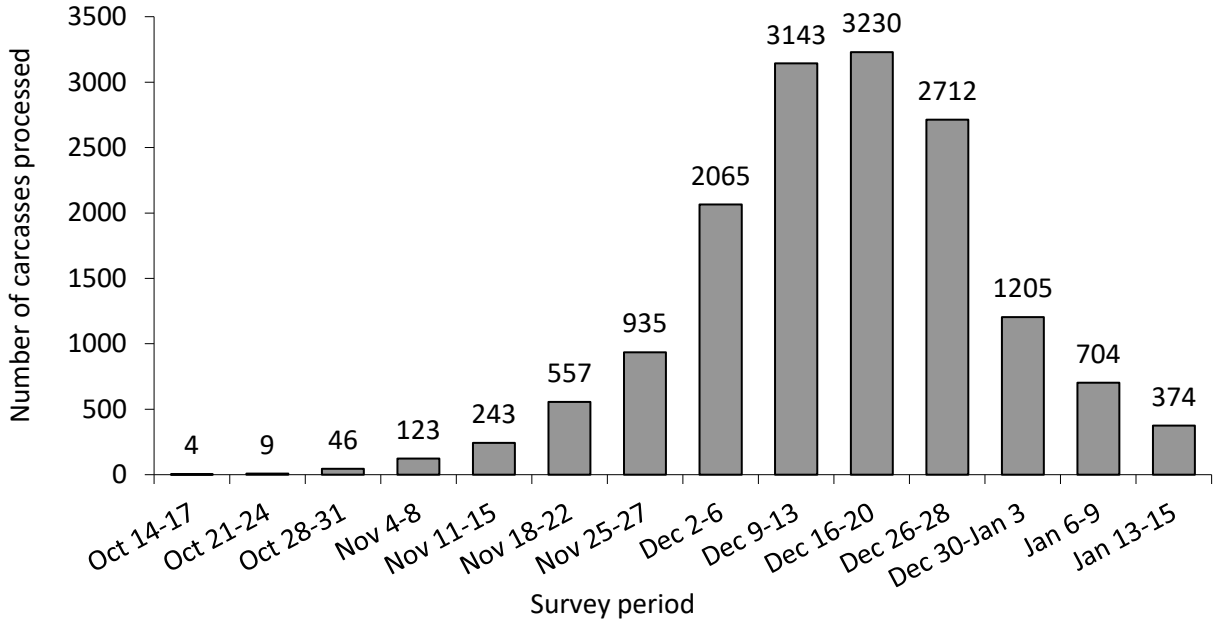


Figure 3. Numbers of carcasses observed and processed during the 2019 lower American River escapement survey.

Processing Methods and Counts

Of the 15,350 carcasses processed, 9,087 (59%) were too decomposed to collect covariate data from and were, therefore, chopped and tallied. Of the remaining carcasses, 4,216 (27%) were processed for covariate data including 4,185 heads retained for CWT extraction, while 2,047 (13%) were disk-tagged and included in the mark-recapture study. (Figure 5).

Spatial Distribution

Of the total number of carcasses processed during the survey, 20% were found in the NB, 10% were from the weir, 58% were found in section 1 (A+B), 10% were found in section 2, and 3% were found in section 3 (the extra 1% is due to rounding) (Table 3).

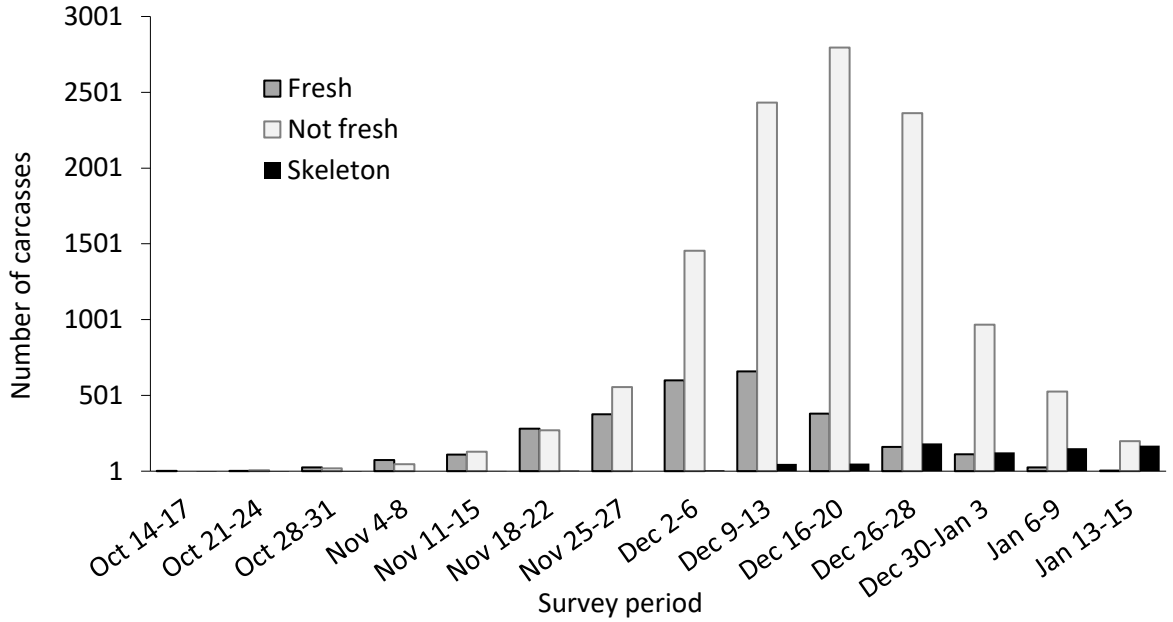


Figure 4. Number of fresh, not fresh and skeleton carcasses processed in each survey period for the 2019 lower American River escapement survey.

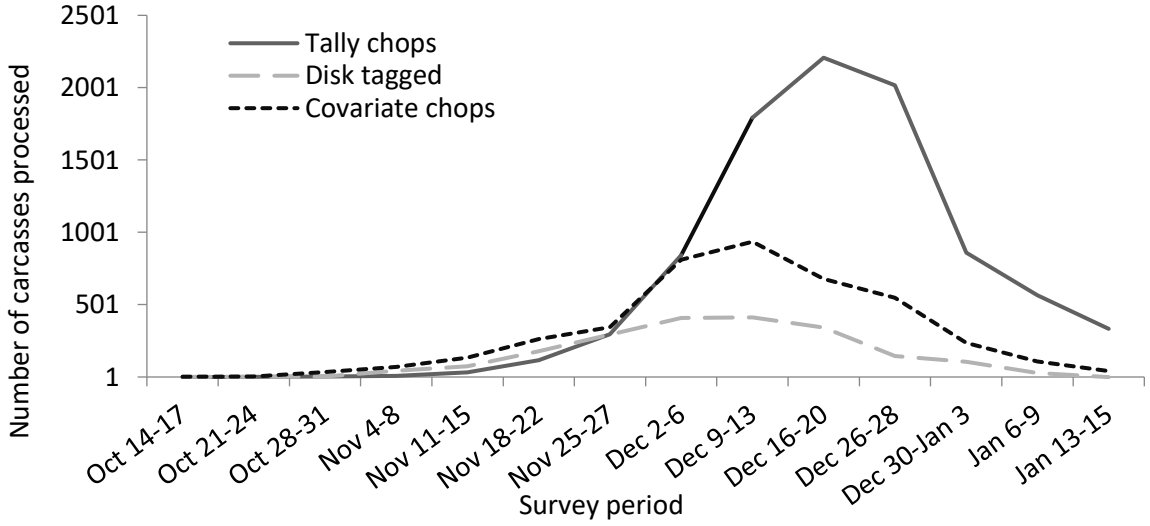


Figure 5. Frequency of processing method for carcasses collected during the 2019 lower American River escapement survey.

Table 3. Spatial distribution and totals of carcasses processed by survey period during the 2019 lower American River salmon escapement survey.

Survey Periods	Nimbus Basin	Weir	Section 1(A+B)	Section 2	Section 3
Oct 14-17	0	2	2	0	0
Oct 21-24	2	2	3	2	0
Oct 28-31	8	29	8	1	0
Nov 4-8	45	54	22	2	0
Nov 11-15	82	96	59	5	1
Nov 18-22	113	203	221	17	3
Nov 25-27	321	208	376	26	4
Dec 2-6	480	503	916	134	32
Dec 9-13	636	392	1703	282	130
Dec 16-20	498	n/a	2178	410	144
Dec 26-28	572	n/a	1844	296	n/a
Dec 30-Jan 3	196	n/a	730	174	105
Jan 6-9	87	n/a	475	111	31
Jan 13-15	28	n/a	314	17	15
Total	3068	1489	8851	1477	465
% of total	20	10	58	10	3

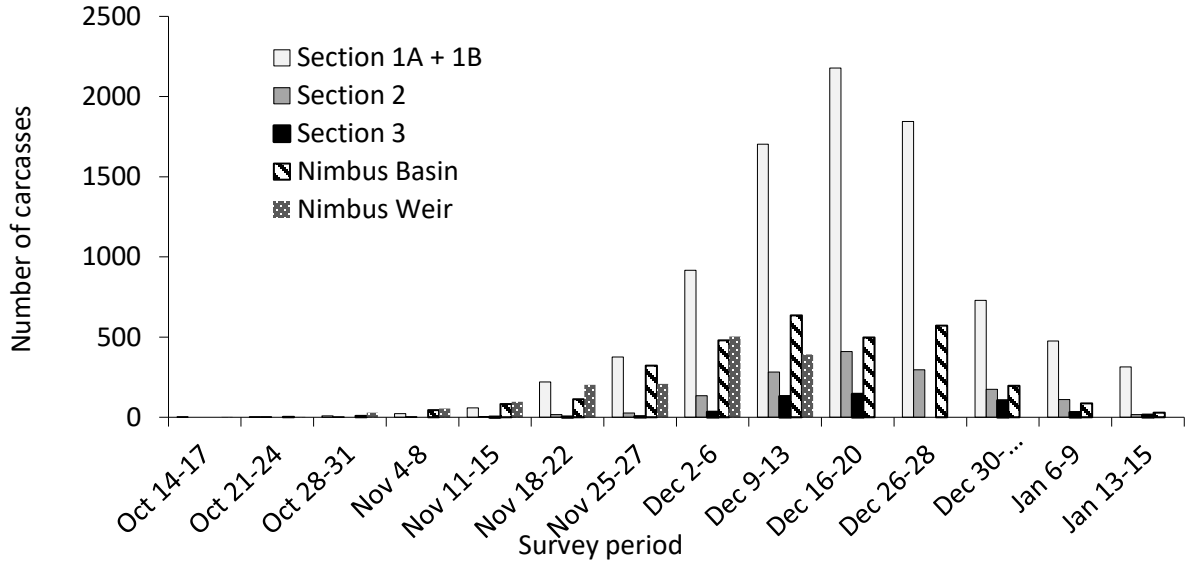


Figure 6. Spatial distribution of carcasses by survey period for the 2019 lower American River escapement survey.

Sex Ratios

Sex was assigned for 6,200 carcasses. Females accounted for 3,185 (51%) of the carcasses, and males accounted for the remaining 3,015 (49%) (Table 4).

Table 4. Numbers of male and female carcasses observed by survey period during the 2019 lower American River escapement survey.

Survey Period	Females	Males
Oct 14-17	1	3
Oct 21-24	3	4
Oct 28-31	23	18
Nov 4-8	63	48
Nov 11-15	97	102
Nov 18-22	206	228
Nov 25-27	335	294
Dec 2-6	588	627
Dec 9-13	710	627
Dec 16-20	550	468
Dec 26-28	341	345
Dec 30-Jan 3	175	168
Jan 6-9	69	68
Jan 13-15	24	15
Total	3185	3015
% of total	51	49

Length Distributions

FLs were recorded for 6,197 carcasses of known sex (Figure 7). The minimum length for female carcasses (*n*= 3,183) was 48 cm, and the maximum 100 cm, with a mean length of 75 cm and a mode of 77 cm. The minimum length for male carcasses (*n*= 3,014) was 40 cm, and the maximum 108 cm, with a mean length of 74 cm and a mode of 87 cm. FLs were recorded for 60 carcasses in which sex could not be determined.

Age Classification

A total of 6,242 carcasses was assigned to one of two age classes for the 2019 LAR carcass survey based upon length-frequency histograms of known-age CWT fish. Fish were determined to be adult (≥3 years-old) if females had a FL ≥60 cm and males had a FL ≥68 cm. Fish were

classified as grilse (≤2 years-old) if females had a FL of ≤59 cm and males had a FL of ≤ 67 cm. (Figure 8, Figure 9)

A total of 5,026 (81%) carcasses was classified as adults and 1,216 (19%) carcasses were classified as grilse. The adult age class consisted of 3,068 (61%) females, 1,922 (38%) males and 36 adults of unknown sex (1%). The grilse age class consisted of 1,092 (90%) males, 115 (9%) females, and 9 grilse of unknown sex (1%) (Figure 10). Both age classes were observed in all survey periods, with grilse numbers peaking in survey period 8 (December 2-6).

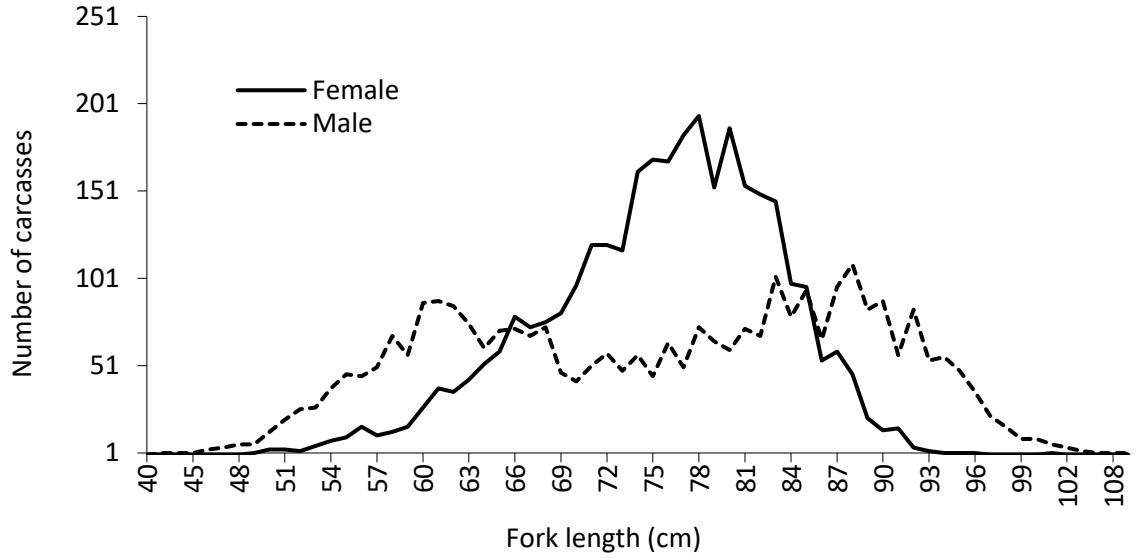


Figure 7. Fork length frequency histogram for male and female Chinook carcasses observed during the 2019 lower American River escapement survey.

Pre-spawn Mortality

A total of 3,042 female carcasses was assessed for spawn status (Table 5, Figure 11). Spawned females accounted for 2,135 (70%) carcasses, partially spawned females accounted for 228 (7%) carcasses, and unspawned females accounted for 679 (22%) carcasses.

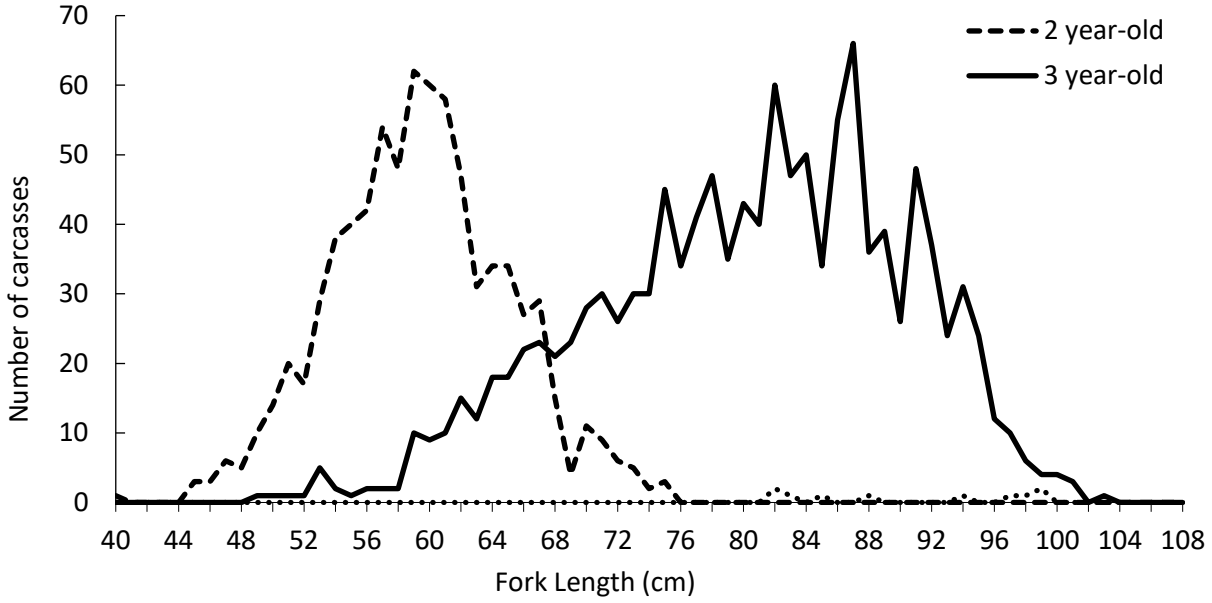


Figure 8. Fork length-frequency histogram of known-age coded-wire tagged male Chinook salmon from the 2019 lower American River escapement survey.

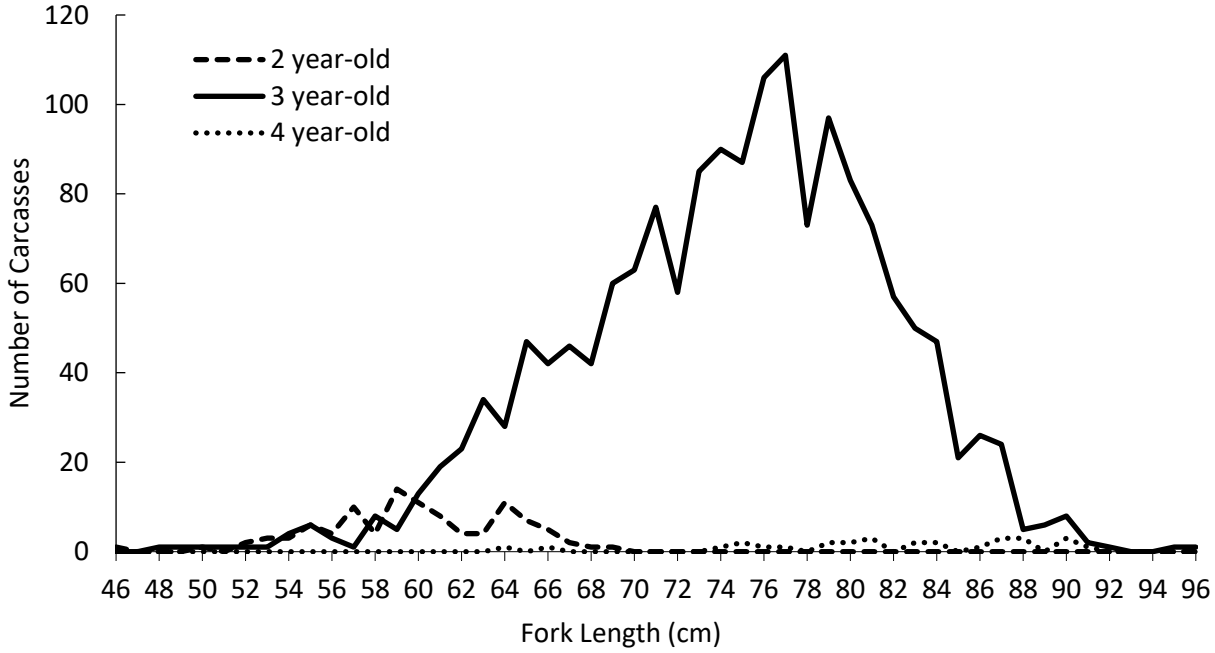


Figure 9. Fork length-frequency histogram of known-age coded-wire tagged female Chinook salmon from the 2019 lower American River escapement survey.

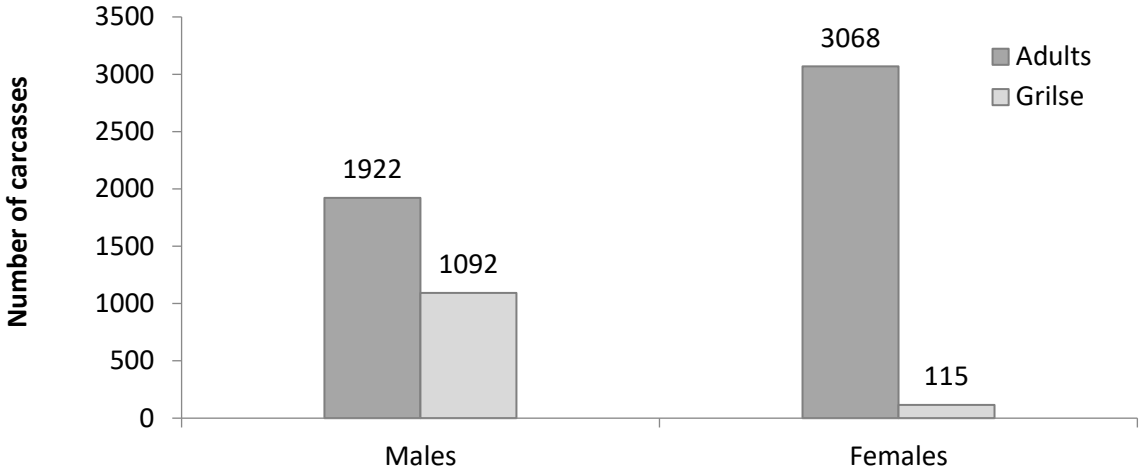


Figure 10. Number of carcasses assigned to adult or grilse age classes by sex during the 2019 lower American River escapement survey.

Table 5. Egg retention status of female carcasses by survey period for the 2019 lower American River escapement survey. Unspawned females retained >70% of eggs, partially spawned females retained 30-70% of eggs and spawned females retained <30% of eggs.

Survey period	Unspawned	Partial	Spawned	Total
Oct 14-17	1	0	0	1
Oct 21-24	2	0	1	3
Oct 28-31	9	2	12	23
Nov 4-8	38	9	16	63
Nov 11-15	36	20	38	94
Nov 18-22	65	25	113	203
Nov 25-27	91	36	201	328
Dec 2-6	151	31	392	574
Dec 9-13	177	43	462	682
Dec 16-20	58	44	416	518
Dec 26-28	31	8	278	317
Dec 30-Jan 3	19	6	129	154
Jan 6-9	1	2	62	65
Jan 13-15	0	2	15	17
Total	679	228	2135	3042
% of total	2	7	70	

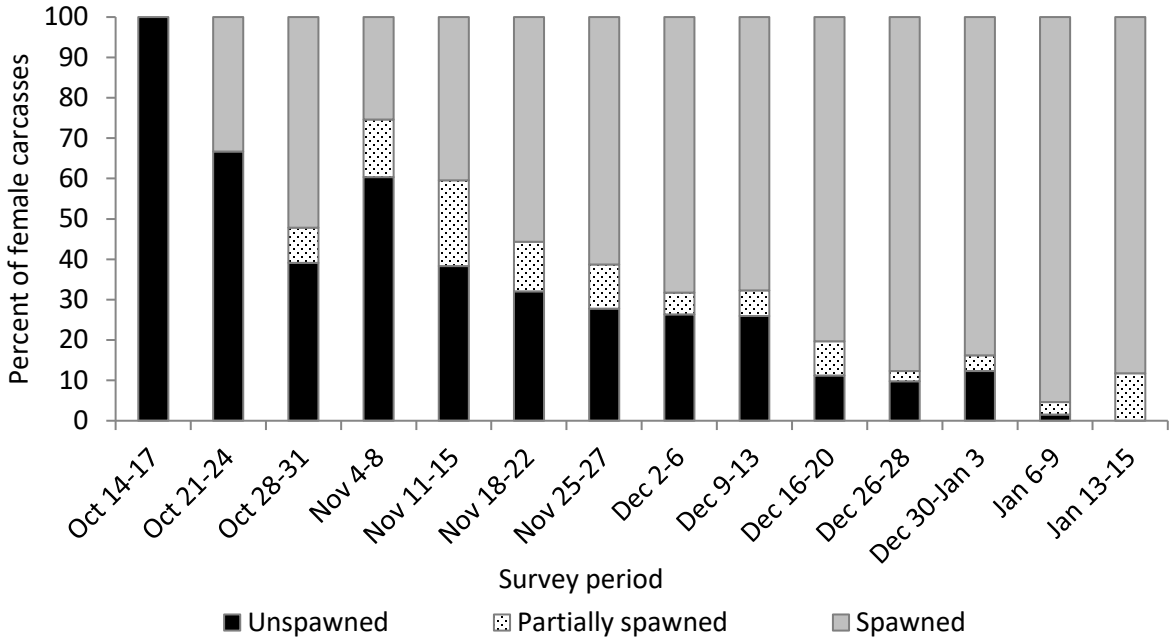


Figure 11. Egg retention status by percent of female carcasses per survey period for the 2019 lower American River escapement survey.

CWT Carcasses

All carcasses were inspected for an adipose fin clip. A total of 4,208 (27%) carcasses had an adipose fin clip, of those, heads were collected from 4,185 for CWT recovery. Adipose fin clipped carcasses were recovered during all weeks of the survey (Table 6, Figure 12). Adipose fin presence or absence could not be determined for 798 (5%) of carcasses.

Escapement Estimate

A total of 2,047 carcasses was disk-tagged and used for the mark-recapture model. Of the tagged carcasses, 889 carcasses were recaptured. The LAR FRCS escapement estimate was 27,030 (90% CI: 25,675 – 27,090). The bootstrap (*n*=1,000) estimate of standard error was 454 FRCS.

Table 6. Adipose condition of carcasses by survey period for the 2019 lower American River escapement survey.

Survey Period	Adipose Intact	Adipose Clipped	Unknown/ Skeleton
Oct 14-17	2	2	0
Oct 21-24	6	2	1
Oct 28-31	9	35	2
Nov 4-8	51	69	3
Nov 11-15	122	118	3
Nov 18-22	291	262	5
Nov 25-27	589	345	1
Dec 2-6	1245	813	7
Dec 9-13	2152	940	51
Dec 16-20	2496	681	54
Dec 26-28	1954	553	205
Dec 30-Jan 3	830	241	134
Jan 6-9	434	110	160
Jan 13-15	165	37	172
Total	10344	4208	798
% of total	67	27	5

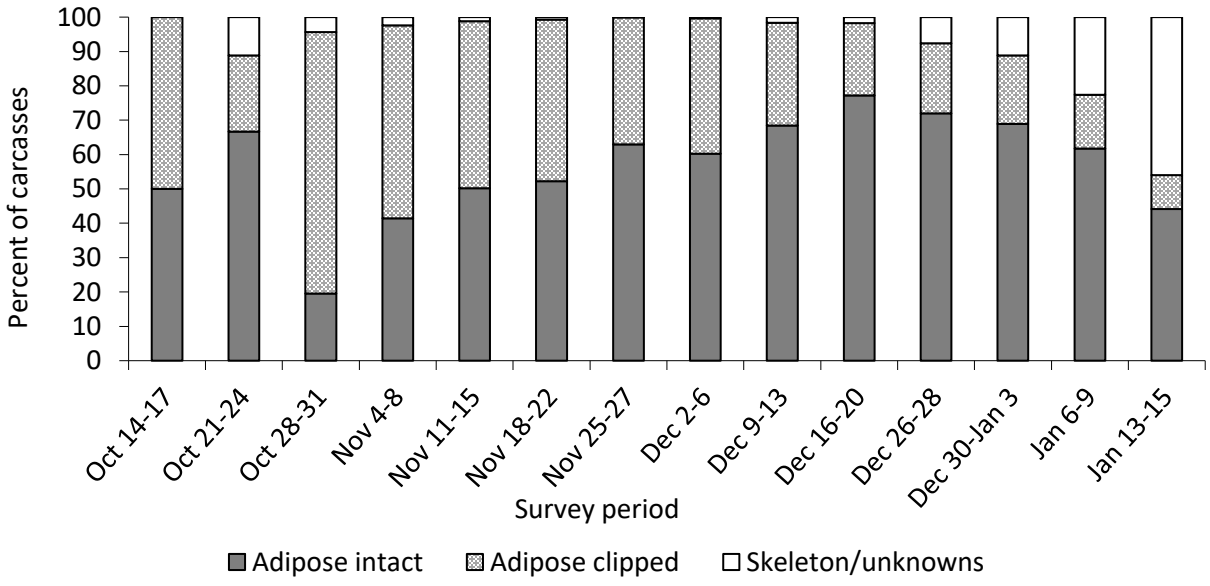


Figure 12. Temporal distribution of adipose fin condition for carcasses processed during the 2019 lower American River escapement survey.

DISCUSSION

The 2019 LAR FRCS escapement estimate of 27,030 is the largest estimate since 2013 (Figure 13). Peak carcass recovery occurred the third week of December, 2-3 weeks later than the historical average for LAR FRCS.

Spawn timing of Chinook salmon is associated with environmental conditions, and higher water temperatures are correlated with later spawning (Quinn et al. 2002; Carter 2005; Goniea et al. 2006) and higher pre-spawn mortality (Carter 2005). Climate driven variations in temperature are of increasing relevance for the Central Valley population of FRCS, which spawn at the southern extent of the species' range, therefore making it more susceptible to climate change (Williams 2006). Maintenance of the cold-water pool (CWP) behind Folsom Dam and cold-water releases have become increasingly relevant for survival of LAR FRCS stocks (Yates et al. 2008). In the water year 2019, a CWP was available to offset the warmer temperatures observed in October, but was not used.

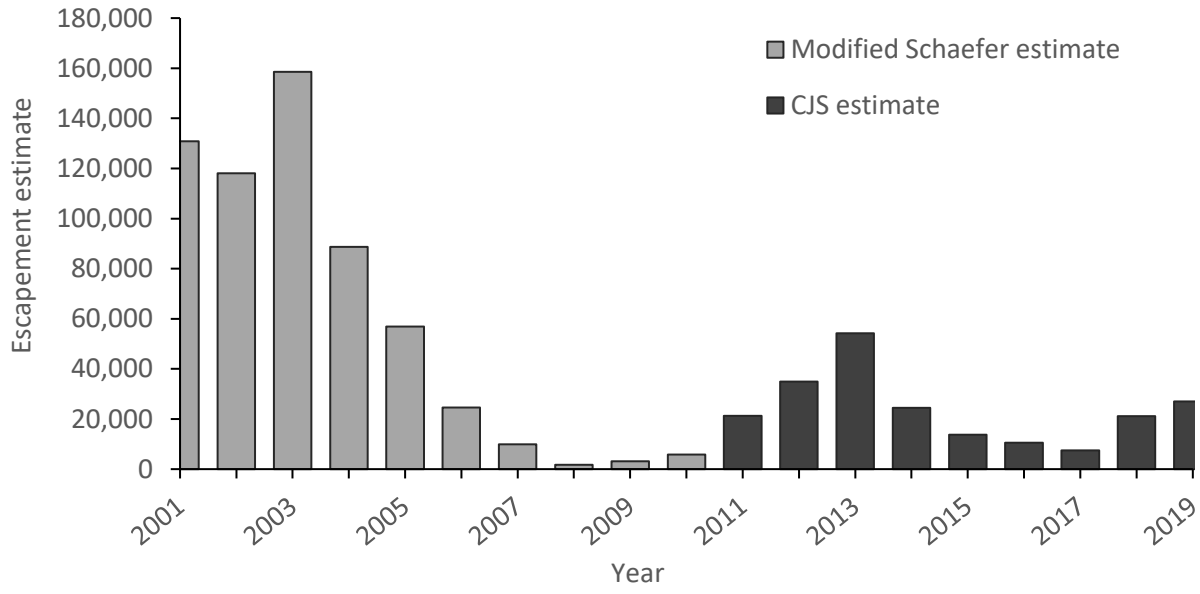


Figure 13. Historical in-river escapement estimates for the lower American River escapement survey.

The NB and weir were added to the survey during the 2018 escapement survey. Prior to the 2018 season, angler surveys were used to estimate the number of salmon harvested by anglers above the weir, but these numbers were not included in the in-river escapement estimate.

Since 2018, anglers are no longer allowed to fish in the NB, so the alternative sampling method was established.

The weir no longer represents a complete barrier to fish passage into the NB due to deterioration of the weir and supporting structure over several decades. Time and staff resource limitations allowed for only adipose-clipped carcasses to be recovered and processed from the weir to retrieve CWTs, thus the proportion of adipose-clipped carcasses reported is higher than would be if all carcasses recovered from the weir were processed. All other carcasses found on the weir were released intact downstream into section 1A to mimic the natural downstream drift of carcasses thereby avoiding any mark-recapture bias.

Preliminary data recovered from CWTs by the CDFW Central Valley Salmonid Archive staff from heads collected during the survey indicates a high proportion of FRCS produced at hatcheries other than Nimbus Fish Hatchery (NFH) straying into the LAR. Hatcheries implant 25 percent of FRCS with CWTs. Of the carcasses containing CWTs, 53% (*n*=2,106) originated at the NFH, which was the highest percentage of returning NFH-produced FRCS since 2015 (62%). Hatchery produced strays consisted of 44.8% of CWT recoveries including 35.2% (*n*=1,472) from the Mokelumne River Fish Hatchery, 7.2% *(n*=301) from the Feather River Hatchery, 2.4% (*n*=101) from the Merced River Fish Facility, and <1% (*n*=2) from the Coleman National Fish Hatchery. Adipose-clipped carcasses in which a CWT could not be retrieved equaled 4.9%. The proportion of strays into the LAR is within the range of straying rates from previous years.

FRCS in the Sacramento River basin have reported stray rates ranging from 8-86%, with a speculative estimate of up to 32% for NFH FRCS (CDFG and NMFS 2001). Juvenile release location has a strong correlation with return and stray rates and can dramatically influence salmon survival rates (Palmer-Zwahlen and Kormos 2012). Additionally, historical practices of transferring eggs between hatcheries in conjunction with high stray rates has resulted in a relatively low level of genetic differentiation in FRCS stocks of the Central Valley (Bartley and Gall 1990).

Water temperatures above 61.7°F increase mortality of Chinook salmon eggs (Geist et al. 2006), with highest egg survival occurring below 58°F (Williams 2001). Pre-spawn mortality of female FRCS was 22%, matching the previous year's rate. FRCS eyed-egg survival at NFH was lower than average in 2019, likely due to adults holding in water temperatures above 58°F past November 1 (P. Hoover, pers. comm. 2019). Mean pre-spawn mortality from years 2000 to 2019 is 19%. Spawned females this season was 70%, whereas the mean spawn rate from the past 20 years is 66%.

FRCS escapement consisted of 81% adults and 19% grilse, within the range exhibited in prior surveys (Figure 14). Since 2007, the adult class has accounted for 57-99% of total carcasses. In addition, male and female grilse proportions continue to follow a trend wherein male grilse proportions are much higher than females, 91% versus 9%, respectively.

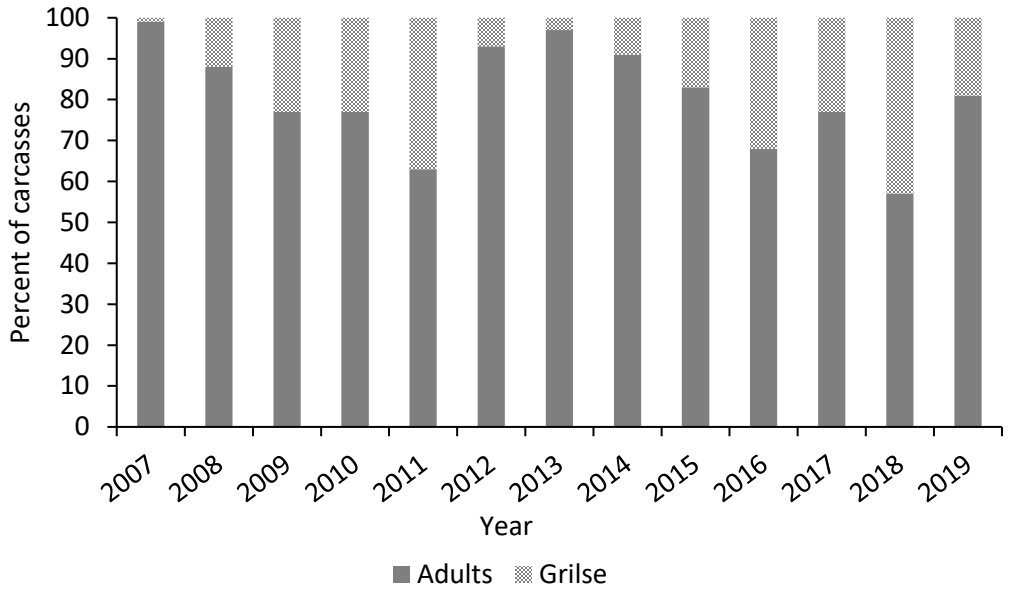


Figure 14. Proportion of adult and grilse carcasses observed each year from 2007 to 2019 during the lower American River escapement survey.

The cutoff length between grilse and adult age classes for both sexes occurred at a much shorter FL than in recent years, reflecting smaller sizes across both age classes (Figure 15). The cutoff FL for male adults was 68 cm, 7 cm shorter than the previous season. The cutoff for female adults was 60 cm, 9 cm shorter than the previous season. Chinook returns and size at return has shown to be correlated with ocean conditions (Wells et al. 2006, Peterson et al. 2006 and Wells et al. 2007). Chinook salmon have been known to exhibit density dependent reproductive success, with larger fish often being most successful resulting in population level size selection (Roni and Quinn 1995). Recent variations in ocean conditions, combined with warmer temperatures, may play a role in the exhibited salmon sizes during the 2019 season.

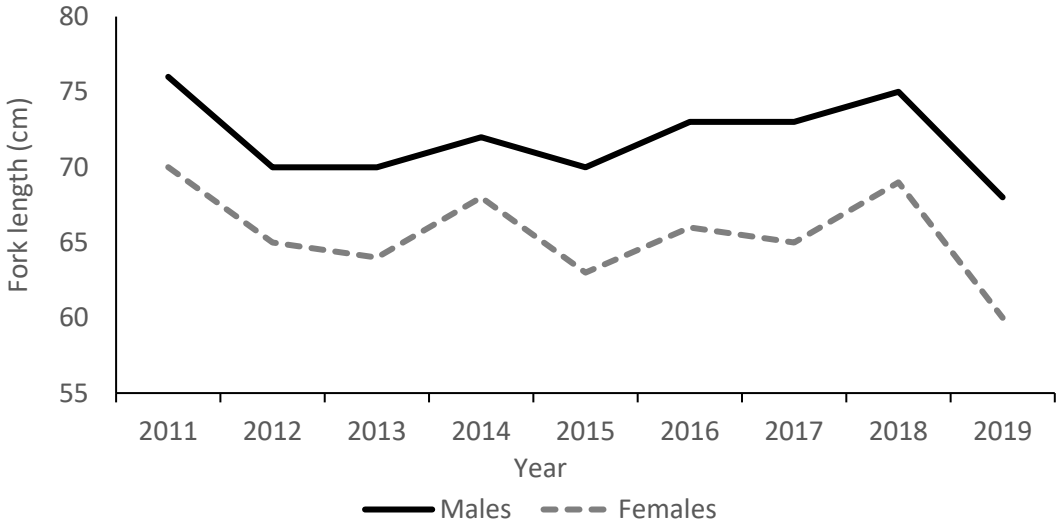


Figure 15, Minimum fork lengths for adult Chinook salmon of both sexes observed from 2011-2019 during the lower American River escapement survey.

ACKNOWLEDGMENTS

The successful completion of the LAR escapement survey is a direct result of the dedication of the 2019 survey crew: Jeffrey Vang, Nicholas Potter, Hannah Holmquist, Daniel Knox, Michaela Grubb, Alex Studd-Sojka, Benjamin Kelly, Jeanine Phillips and volunteers: Crystal Rigby, Eric Bradbury, Cory Starr, Skyler Burson, and Chase Macherzak**.** We extend our appreciation to the United States Bureau of Reclamation for funding the survey. The voluntary assistance of the Cramer Fish Sciences staff proved valuable in daily on-water data collection. Stan Allen and Amy Roberts with the Pacific States Marine Fisheries Commission were instrumental in the completion of supervisory and administrative duties.

LITERATURE CITED

Bartley, D.M. and Gall, G.A.E. 1990. Genetic Structure and Gene Flow in Chinook Salmon Populations of California. Transactions of the American Fisheries Society, 119: 55-71.

Bergman, J. M., R. M. Nielson, and A. Low. 2012. Central Valley in-river salmon escapement monitoring plan. Fisheries Branch Administrative Report Number: 2012-1. California Department of Fish and Game. Sacramento, California.

[CDFG and NMFS] California Department of Fish and Game, National Marine Fisheries Service Southwest Region Joint Hatchery Review Committee. 2001. Final Report on Anadromous Salmonid Fish Hatcheries in California.

[CDFW] California Department of Fish and Wildlife. Nimbus Fish Hatchery. https://wildlife.ca.gov/Fishing/Hatcheries/Nimbus Accessed January 2020.

Carter, K. 2005. The effects of temperature on steelhead trout, coho salmon, and Chinook salmon biology and function by life stage: Implications for Klamath Basin TMDLs. California Regional Water Quality Control Board, North Coast Region. August 2005. https://www.waterboards.ca.gov/northcoast/water_issues/programs/tmdls/shasta_river/060707/28appendixaetheeffectsoftemperatureonsteelheadtroutcohosalmonandchinooksalmonbiologyandfunction.pdf Accessed March 2020.

Cormack, R. M. 1964. Estimates of survival from the sightings of marked animals. Biometrika (51)429 – 438.

Geist, D. R., C. S. Abernethy, K. D. Hand, V. I. Cullinan, J. A. Chandler, and P. A. Groves. 2006. Survival, development, and growth of fall Chinook salmon embryos, alevins, and fry exposed to variable thermal and dissolved oxygen regimes. Transactions of the American Fisheries Society 135(6).

Goniea, T.M., Keefer, M.L., Bjornn, T.C., Peery, C.A., Bennett, D.H. and Stuehrenberg, L.C. 2006. Behavioral Thermoregulation and Slowed Migration by Adult Fall Chinook Salmon in Response to High Columbia River Water Temperatures. Transactions of the American Fisheries Society, 135: 408-419.

Quinn, T.P., Peterson, J.A., Gallucci, V.F., Hershberger, W.K. and Brannon, E.L. 2002. Artificial Selection and Environmental Change: Countervailing Factors Affecting the Timing of

Spawning by Coho and Chinook Salmon. Transactions of the American Fisheries Society, 131: 591-598.

Palmer-Zwahlen, M., and Kormos, B. 2015. Recovery of Coded-Wire Tags from Chinook Salmon in California's Central Valley Escapement, Inland Harvest, and Ocean Harvest in 2012. California Department of Fish and Game. Fisheries Administrative Report 2015-4.

Peterson, W.T., Hooff, R.C., Morgan, C.A., Hunter, K.L., Casillas, E. and Ferguson, J.W. 2006. Ocean Conditions and Salmon Survival in the Northern California Current.

Roni, P. and Quinn, T.P. 1995. Geographic Variation in Size and Age of North American Chinook Salmon. North American Journal of Fisheries Management, 15: 325-345.

Satterthwaite, W.H., and Carlson, S.M. 2015. Weakening portfolio effect strength in a hatchery-supplemented Chinook salmon population complex. Canadian Journal of Fisheries and Aquatic Sciences, 72:1860-1875.

Snider, B. and Reavis, B. 1996. Lower American River Chinook Salmon Escapement Survey October 1995-January 1996. California Department of Fish and Game Environmental Services Division Stream Evaluation Program.

[USGS] United States Geological Survey. 2020. USGS 11446500 AMERICAN R A FAIR OAKS California. Retrieved from: http://waterdata.usgs.gov/ca/nwis/uv/?site_no=11446500&PARAmeter_cd=00065,00060

Wells, B.K., Grimes, C.B., Field, J.C. and Reiss, C.S. 2006. Covariation between the average lengths of mature coho (*Oncorhynchus kisutch*) and Chinook salmon (*O. tshawytscha*) and the ocean environment. Fisheries Oceanography, 15: 67-79.

Wells, B.K., Grimes, C.B. and Waldvogel, L, J.B. 2007. Quantifying the effects of wind, upwelling, curl, sea surface temperature and sea level height on growth and maturation of a California Chinook salmon (*Oncorhynchus tshawytscha*) population. Fisheries Oceanography, 16: 363-382.

Williams, J. G. 2001. Chinook salmon in the Lower American River, California's largest urban stream. Contributions to the Biology of Central Valley Salmonids. State of California, The Resources Agency, Department of Fish and Game. Fish Bulletin 179(2)1-38.

Williams, J. G. 2006. Central Valley Salmon: A Perspective on Chinook and Steelhead in the Central Valley of California. *San Francisco Estuary and Watershed Science*, 4(3).

Yates, D., Galbraith, H., Purkey, D., Huber-Lee, A., Sieber, J., West, J., Herrod-Julius, S. and Joyce, B. 2008. Climate warming, water storage, and Chinook salmon in California's Sacramento Valley. Climatic Change. 91: 335.

Yoshiyama, R. M., E. R. Gerstung, F. W. Fisher, and P. B. Moyle. 2000. Chinook salmon in the California Central Valley: an assessment. Fisheries 25(2)6-20.