California Department of Fish and Wildlife
North Central Region

Lower American River Fall-run Chinook Salmon Escapement Survey October 2020 - January 2021

Presented to the United States
Bureau of Reclamation

by
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INTRODUCTION

The American River is the second-largest tributary to the Sacramento River and flows through a highly developed urban environment (Williams 2001). 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 LAR supports both wild and hatchery fall-run Chinook salmon (FRCS, *Oncorhynchus tshawytscha*) spawning and rearing life stages. Historically, the LAR supported spawning of fall-, spring-, and late fall-runs of Chinook salmon (Yoshiyama et al. 2000); spring-run Chinook was extirpated from the LAR 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). 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 approximately 4 million Chinook salmon annually (CDFW 2021). FRCS mark-recapture escapement surveys are performed to estimate spawner abundance and distribution, and 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). Data collected during escapement surveys are also used to examine life history traits, population age structure, pre-spawn mortality, the ratio of hatchery and natural origin FRCS, and environmental effects on the population. Evaluation of stock-recruitment relationships from escapement survey data is used to aid in establishing harvest limits and fishing seasons. Because of environmental stochasticity and anthropogenic activity, salmon runs in California have exhibited a high degree of variation over time (Satterthwaite and Carlson 2015).

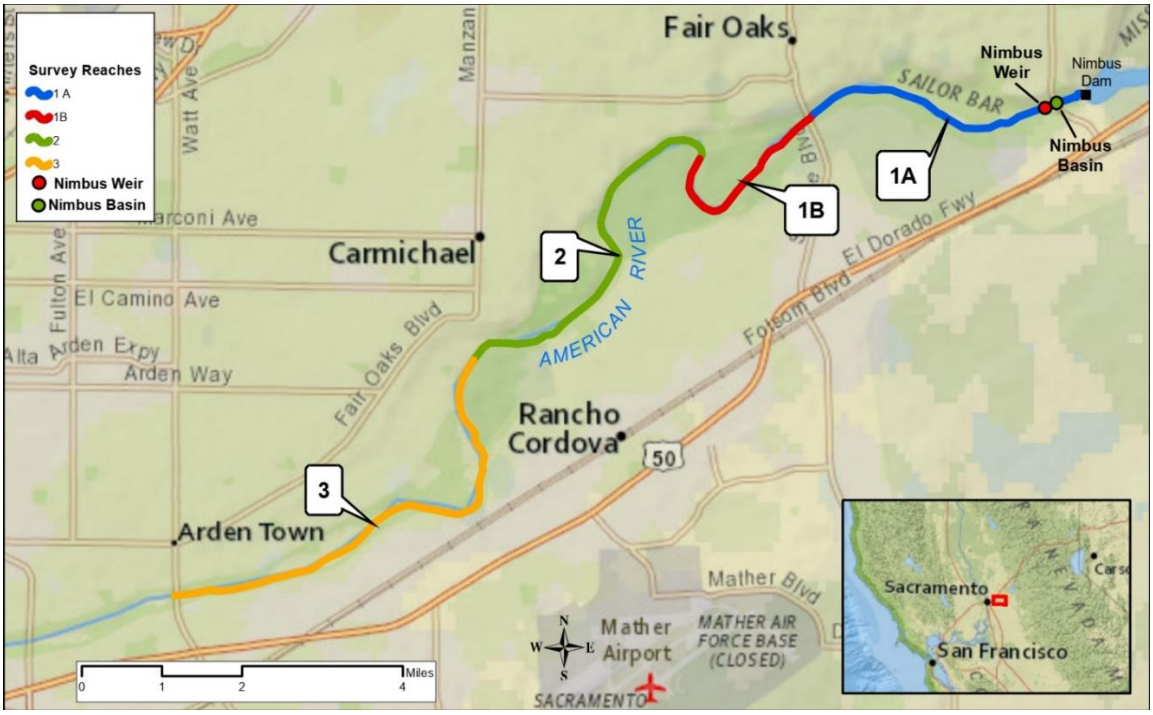
The objectives of the 2020-2021 escapement survey were to: 1) estimate the size of FRCS escapement in the LAR, 2) determine the ratio of adults to grilse, as well as the sex ratios of adults and grilse, 3) determine the degree of female pre-spawn mortality, and 4) collect coded-wire tags (CWT) to investigate the number and origin of hatchery-reared FRCS using spawning habitat in the LAR.

METHODS

A 13.4-mile section of the lower American River, beginning at the Nimbus Dam and ending at the Watt Avenue bridge, was surveyed from October 13, 2020 to January 22, 2021. The survey area was divided into six sections (Figure 1, Table 1), each surveyed once over a 3 to 5-day survey period. The Nimbus 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 Fish Hatchery weir (weir) separates NB from section 1 and is located adjacent to

the Nimbus Fish Hatchery. Section 1 has continuously had the highest number of FRCS spawning activity 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 number 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. 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 a crew consisting of 6-10 members searching for submerged salmon carcasses while walking the riverbanks, riding in a jet boat, or paddling a kayak/canoe. Each river section was surveyed once per survey period, while the 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, 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 of an adipose fin, 3) extent of carcass degradation, and 4) extent of egg retention in females.

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 Fish Hatchery Weir	0.3
W	Nimbus Fish Hatchery Weir	NA
1A	Nimbus Fish Hatchery Weir to Sunrise Blvd River Access	2.6
1B	Sunrise Blvd River Access to El Manto Dr River Access	1.7
2	El Manto Dr River Access to River Bend Park River Access	4.7
3	River Bend Park River Access to Watt Ave River Access	4.1
	Total	13.4

Carcasses were processed in one of three ways: 1) head collection for coded-wire tag (CWT) retrieval, 2) inclusion in the mark-recapture model, or 3) chopped in half and tallied. At the weir, only carcasses missing an adipose fin were processed; carcasses with an intact adipose fin were manually passed through the weir to simulate the natural downstream movement of carcasses. Heads were removed and retained from adipose fin clipped carcasses for CWT removal. 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; any carcasses not meeting these criteria were chopped in half to prevent inclusion in future surveys and tallied. 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 red/pink. Scale samples were also collected from fresh carcasses 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 were chopped and tallied if they were in an advanced state of decomposition (not fresh).

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. The 2020 LAR FRCS escapement estimate was derived using a Cormack-Jolly-Seber (CJS) mark-recapture model for open populations (Cormack 1964 and Bergman et al. 2012) using the escapeMR package (McDonald 2021) in R version 4.0.3 (R Core Team 2020).

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 (FL), 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. 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 season, 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.

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 2021). The Fair Oaks gauge is located at the upper end of section 1 approximately one hundred meters downstream of the weir. Daily average temperature recordings were selected to best measure changes in water temperature through the duration of the study. However, mid-season it was discovered that the flow measurements at the Fair Oaks gauge needed to be recalibrated. Therefore, flow data used in this report were, obtained from the Central Valley Project's Lake Natoma Daily Operations data on the U.S. Bureau of Reclamation's website (USBR 2021). The sum of the average daily water releases for power, spillway, and hatchery were used to obtain an estimate of flow in the LAR.

RESULTS

Survey Periods

The 2020 LAR survey consisted of 15 survey periods from October 13, 2020 to January 22, 2021. All sections were surveyed in each survey period, except for survey period 11, when sections 2 and 3 were not surveyed (Table 2). The weir was last surveyed on December 11, 2020; the weir was later removed that same day. No subsampling was required at any time during the study.

Table 2. Survey dates and sampling regime for the 2020 lower American River Chinook salmon escapement survey.

Survey Period	Dates	Sections Not Surveyed
1	October 13-16	None
2	October 19-22	None
3	October 26-29	None
4	November 2-5	None
5	November 9-13	None
6	November 16-19	None
7	November 23-25	None
8	November 30-December 4	None
9	December 7-11	None
10	December 14-17	None
11	December 21-23	2 and 3
12	December 28-January 2	None
13	January 4-7	None
14	January 11-14	None
15	January 19-22	None

Environmental Conditions

LAR temperatures generally decreased for the duration of the survey season. The maximum mean daily temperature recorded was 67°F on October 15, 2020, and the minimum mean daily temperature was 50°F on January 12, 2021 (Figure 2). Water temperature decreased to a level suitable for spawning on November 25, when mean daily temperature dropped below 56°F. Mean daily water temperatures below 56°F are crucial for egg to fry survival. In order to attain these lower temperatures, a 500 cubic feet per second (cfs) power bypass to access the deepest cold water pool (CWP) at Folsom Dam was initiated by the USBR on October 29, 2020 and ended on November 25, 2020 when resources were depleted.

The maximum mean daily flow recorded was 1,515 cfs on November 23, 2020 and the minimum mean daily flow was 968 cfs on January 21, 2021 (Figure 2). Flows were altered from approximately 1,500 cfs to approximately 1,250 cfs on November 1, 2020 until December 31, 2020. Flows decreased again to approximately 1,200 cfs on January 1, 2021 and then to 968 cfs on January 21, 2021.

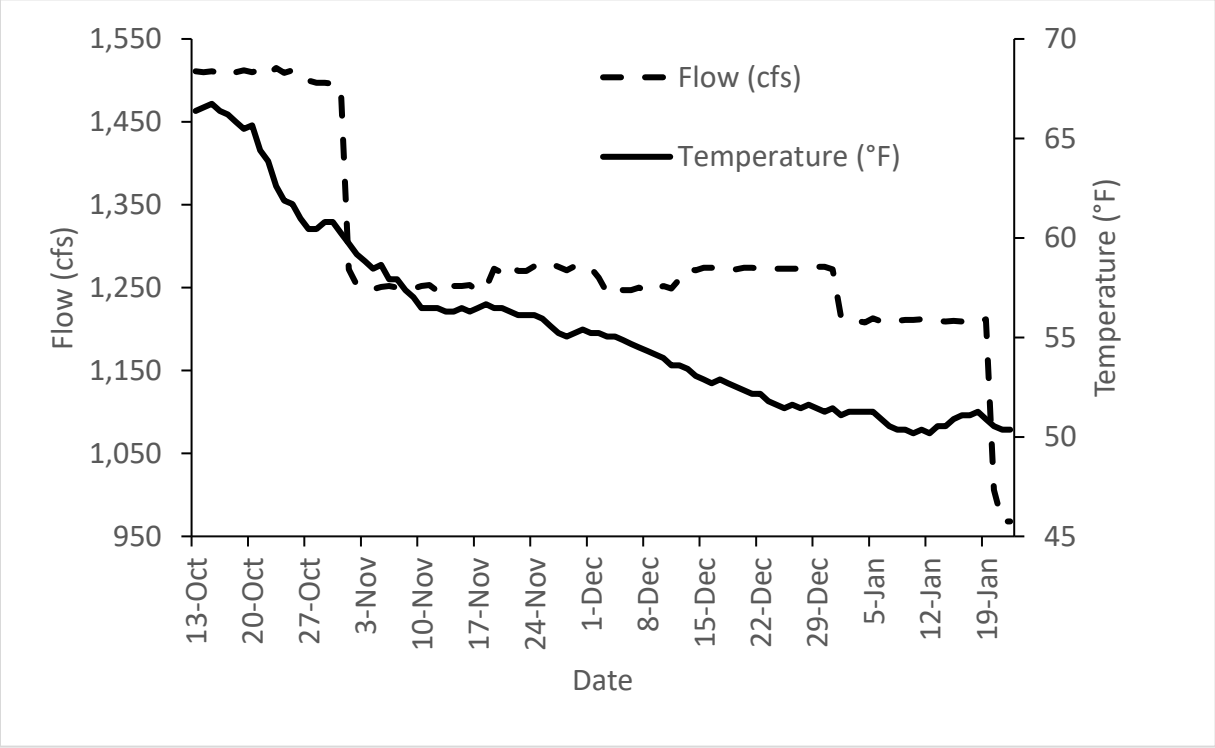


Figure 2. Flow and water temperatures encountered during the 2020 lower American River Chinook salmon escapement survey. Temperature was reported by USGS, American River at Fair Oaks gauge (USGS 2021) and flow was reported by USBR Lake Natoma Daily Operations (USBR 2021).

Final Carcass Count

During the 2020 lower American River escapement survey, 13,032 carcasses were observed and processed (Figure 3). The highest number of carcasses processed in a single survey period (n = 2,528) occurred during survey period 10 (December 14-17). Of the carcasses processed during the season, 1,582 fresh carcasses were encountered (Figure 4). Fresh carcasses were observed during each of the 15 sampling periods, reaching a high of 390 fresh carcasses processed during sampling period 9 (December 7-11).

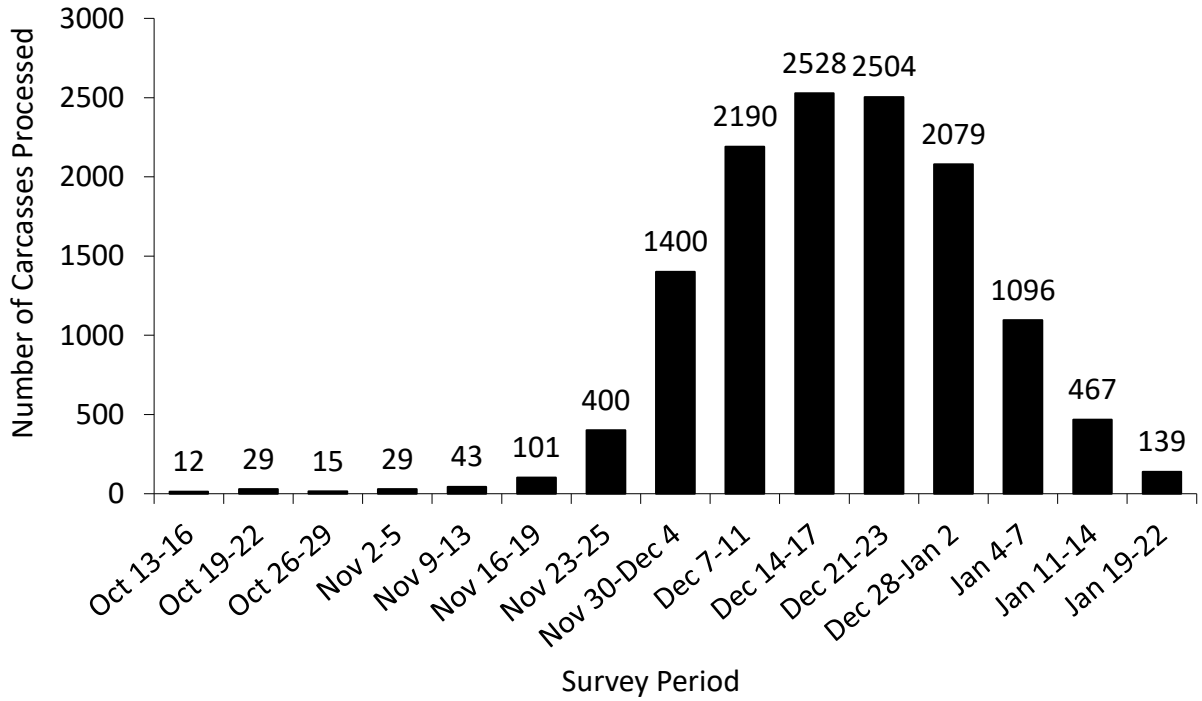


Figure 3. Numbers of carcasses observed and processed during the 2020 lower American River Chinook salmon escapement survey.

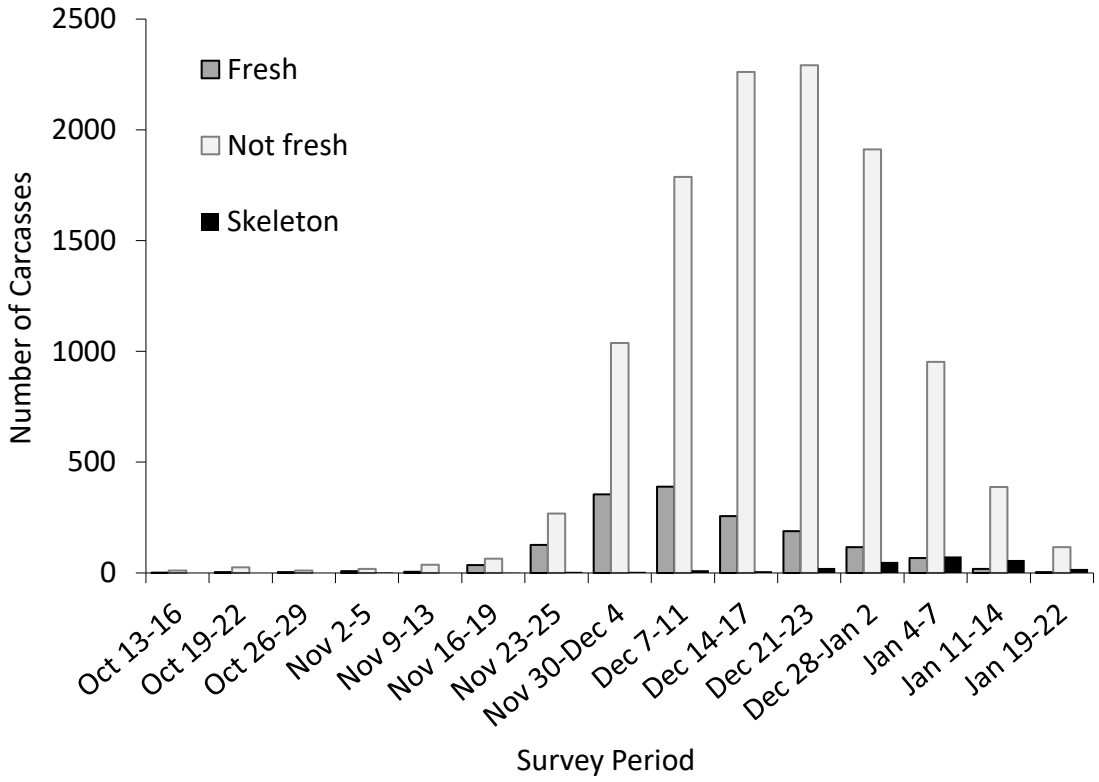


Figure 4. Number of fresh, not fresh, and skeleton carcasses processed in each survey period for the 2020 lower American River Chinook salmon escapement survey.

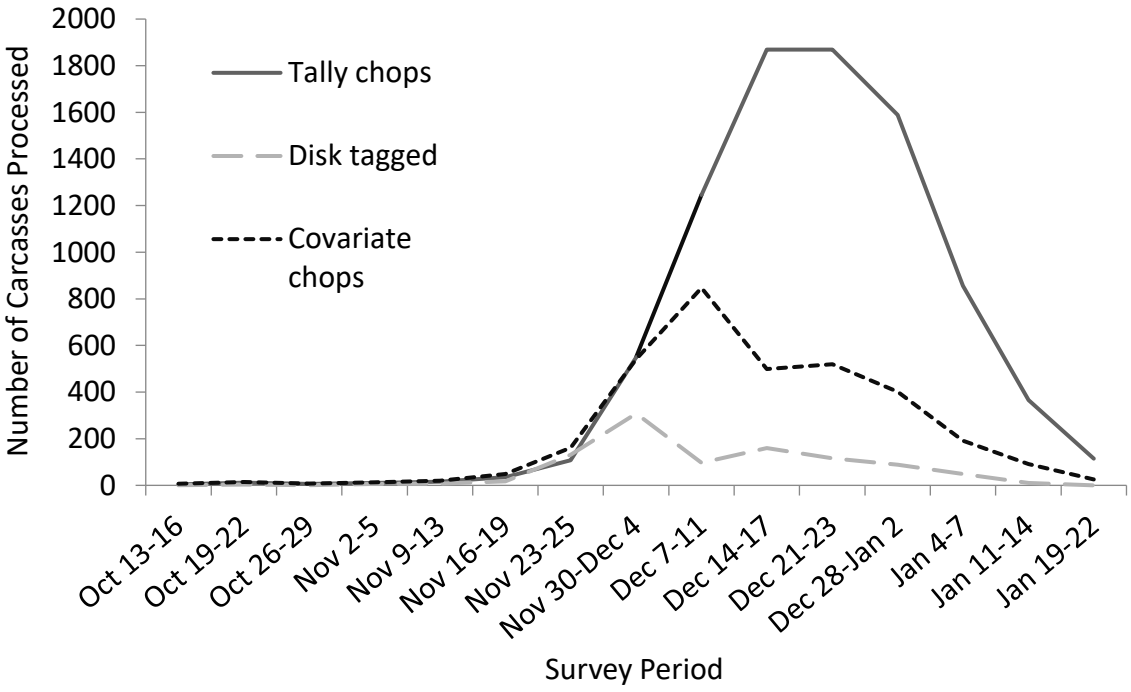


Figure 5. Frequency of processing method for carcasses collected during the 2020 lower American River Chinook salmon escapement survey.

Carcass Processing

Of the 13,032 carcasses processed, 8,649 (66%) were in an advanced stage of decomposition and were chopped and tallied. Of the remaining carcasses, 3,388 (26%) were processed for covariate data collection and chopped, including 3,322 heads retained for CWT extraction, while 995 (8%) were disk-tagged and included in the mark-recapture study (Figure 5).

Spatial Distribution

Of the total number of carcasses processed during the survey, 35% were detected in NB (n = 4,532), 8% on the weir (n = 986), 53% in section 1 (n = 6,927), 4% in section 2 (n = 535), and less than 1% in section 3 (n = 52) (Figure 6, Table 3). After the weir was removed on December 11, 2020, there was an increase in carcass detection in section 1.

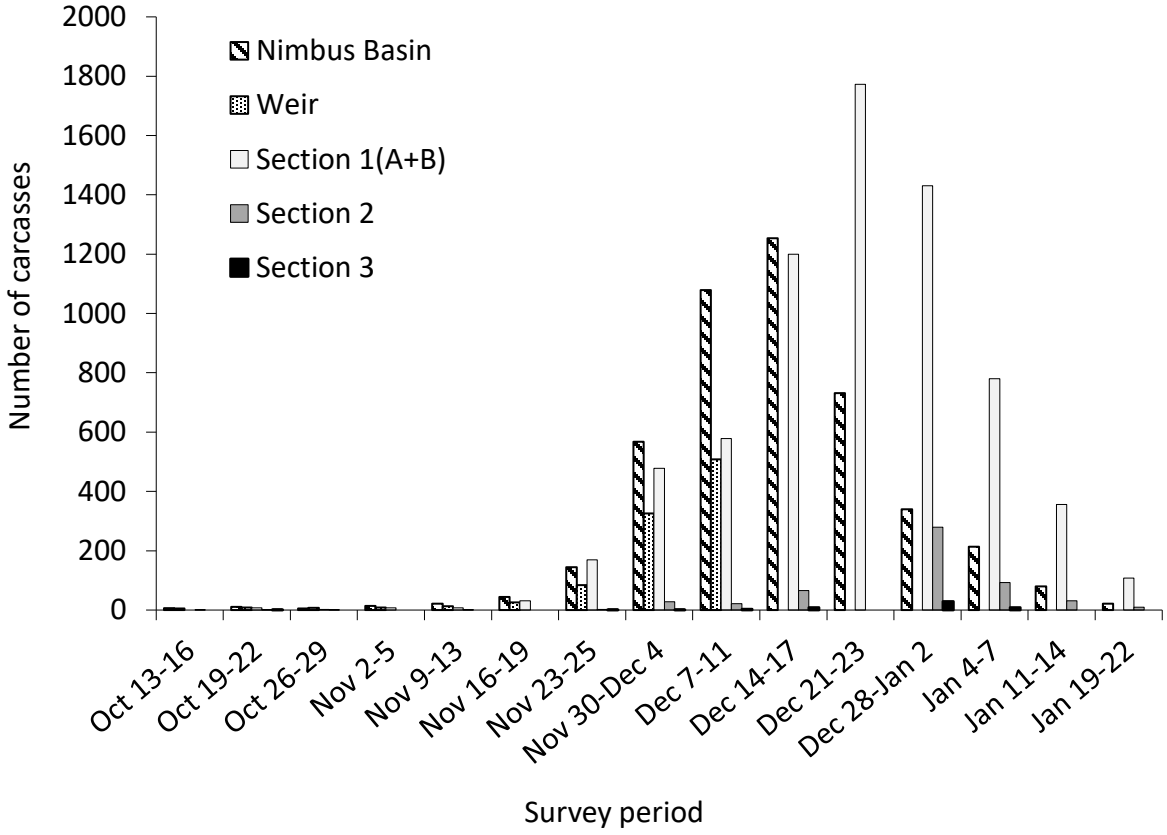


Figure 6. Spatial distribution of carcasses by survey period for the 2020 lower American River Chinook salmon escapement survey.

Table 3. Spatial distribution of carcasses processed by survey period during the 2020 lower American River Chinook salmon escapement survey.

Survey Period	Date	Nimbus Basin	Weir	Section 1 (A+B)	Section 2	Section 3	Total
1	Oct 13-16	6	5	0	1	0	12
2	Oct 19-22	11	9	7	1	1	29
3	Oct 26-29	5	7	2	1	0	15
4	Nov 2-5	14	8	7	0	0	29
5	Nov 9-13	22	13	7	1	0	43
6	Nov 16-19	44	26	31	0	0	101
7	Nov 23-25	144	84	169	2	1	400
8	Nov 30-Dec 4	567	326	478	28	1	1400
9	Dec 7-11	1079	508	578	22	3	2190
10	Dec 14-17	1254	NA	1200	66	8	2528
11	Dec 21-23	731	NA	1773	NA	NA	2504
12	Dec 28-Jan 2	340	NA	1431	279	29	2079
13	Jan 4-7	214	NA	780	93	9	1096
14	Jan 11-14	80	NA	356	31	0	467
15	Jan 19-22	21	NA	108	10	0	139
Total		4532	986	6927	535	52	13032
% of total		35	8	53	4	<1	

Sex Ratios

Sex data were recorded for 4,370 carcasses. Females represented 51% (n = 2,230) of the carcasses and males represented 49% (n = 2,140). Sex could not be determined for the remaining 8,662 carcasses because gonads were too deteriorated. The sex ratio was approximately equal throughout the 15 survey periods, with the only exception occurring during survey period 8, where 487 females were recorded compared to 371 males (Figure 7).

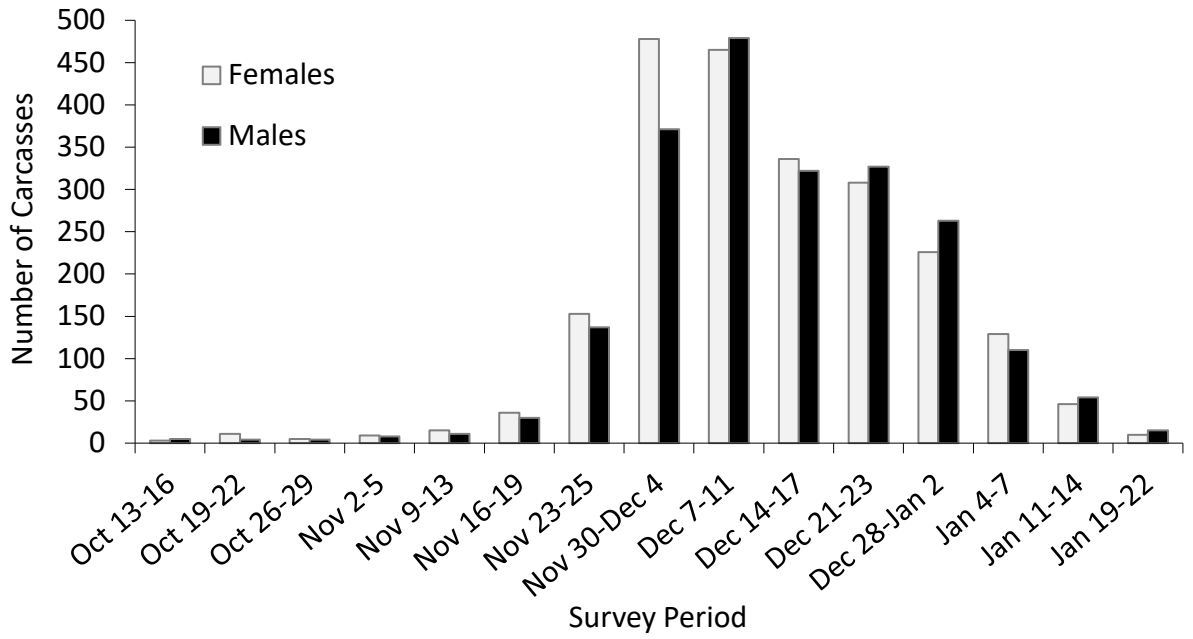


Figure 7. Distribution of male and female carcasses by survey period processed during the 2020 lower American River Chinook salmon escapement survey.

Figure 8. Fork length frequency distribution by sex for carcasses processed during the 2020 lower American River Chinook salmon escapement survey.

Length Distributions

Fork length was recorded for 4,369 carcasses of known sex (Figure 8). The average length for females (n = 2,229) was 78 cm with a range of 45 cm to 104 cm. The average length for males (n = 2,140) was 81 cm with a range of 46 cm to 110 cm. The average length for carcasses of unknown sex (n = 13) was 77 cm with a range of 59 cm to 97 cm.

Age Classification

Length-frequency distributions of known-age CWT carcasses were used to determine the size boundaries for adult and grilse carcasses (Figure 9, Figure 10). Fish were classified as adults (≥3 years-old) if females had a FL ≥65 cm and males had a FL ≥71 cm. Fish were classified as grilse (≤2 years-old) if females had a FL of ≤64 cm and males had a FL of ≤ 70 cm.

A total of 3,789 (86%) carcasses were classified as adult and 592 (14%) carcasses were classified as grilse. The adult age class consisted of 2,116 (56%) females, 1,664 (44%) males, and 9 adults of unknown sex (<1%). The grilse age class consisted of 476 (80%) males, 113 (19%) females, and 3 grilse of unknown sex (1%) (Figure 11). Adults were observed during every survey period, while grilse were not observed in survey periods 2 and 3. Grilse and adult numbers both peaked during survey period 9 (Table 4).

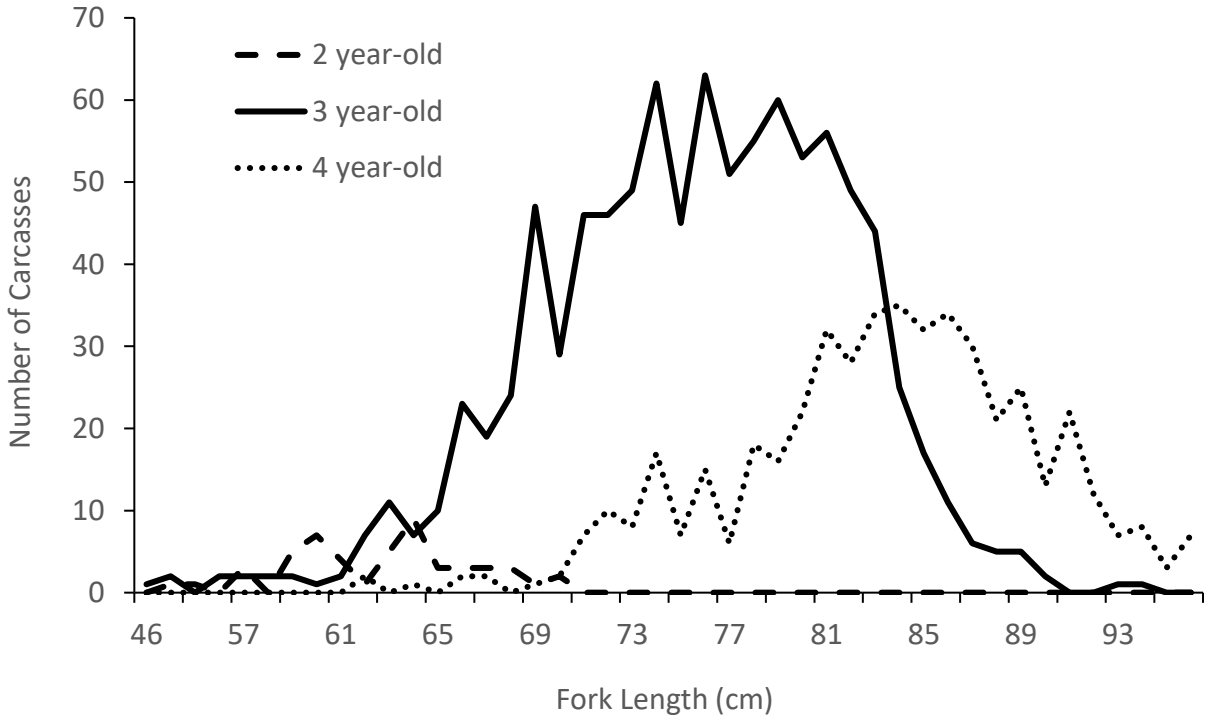


Figure 9. Fork length-frequency distribution of known-age coded wire tagged female carcasses processed during the 2020 lower American River Chinook salmon escapement survey.

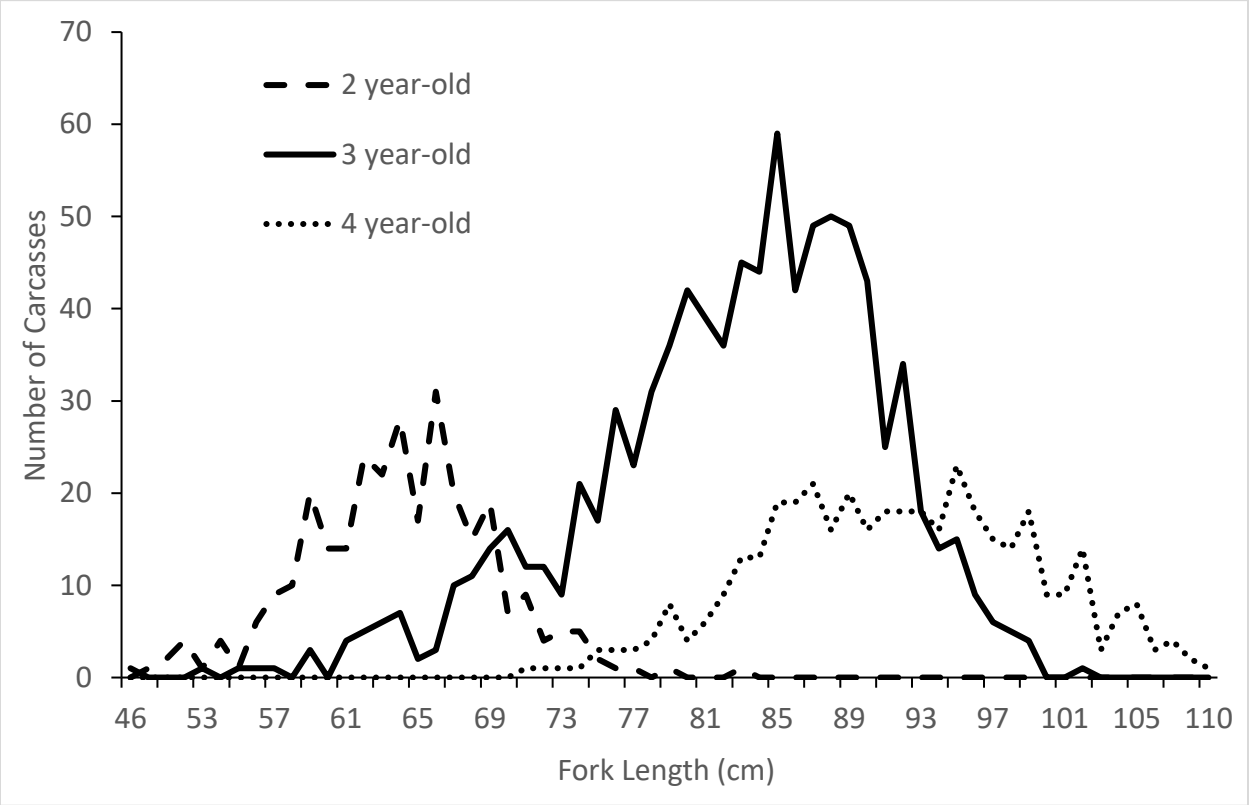


Figure 10. Fork length-frequency distribution of known-age coded wire tagged male carcasses processed during the 2020 lower American River Chinook salmon escapement survey.

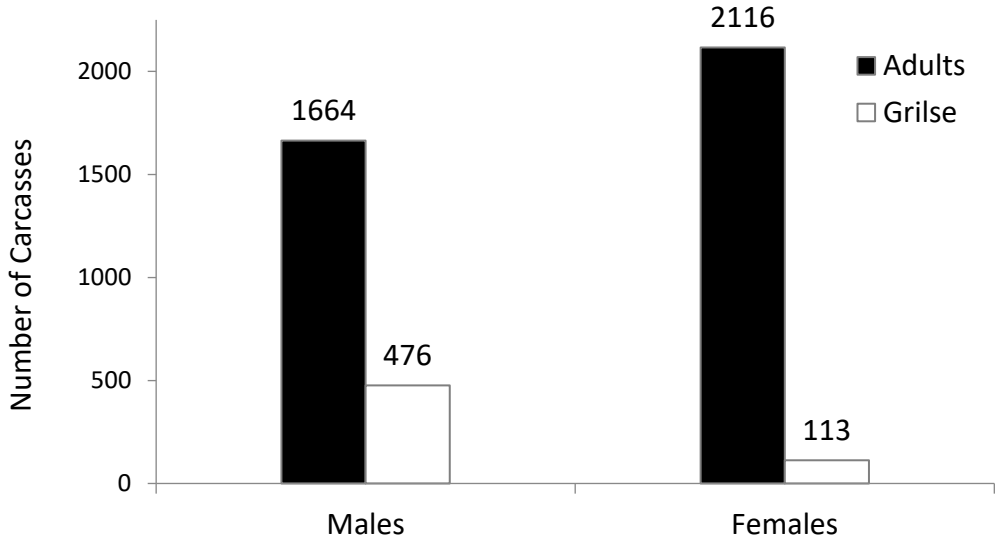


Figure 11. Number of male and female carcasses assigned to adult or grilse age classes during the 2020 lower American River Chinook salmon escapement survey.

Table 4. Summary of processed salmon carcasses by age class during the 2020 lower American River Chinook salmon escapement survey.

		Grilse		Adult	
Survey Period	Date	n	%	n	%
1	Oct 13-16	3	38	5	63
2	Oct 19-22	0	0	18	100
3	Oct 26-29	0	0	9	100
4	Nov 2-5	1	5	18	95
5	Nov 9-13	4	15	23	85
6	Nov 16-19	9	14	57	86
7	Nov 23-25	51	17	241	83
8	Nov 30-Dec 4	113	13	736	87
9	Dec 7-11	142	15	802	85
10	Dec 14-17	71	11	588	89
11	Dec 21-23	93	15	542	85
12	Dec 28-Jan 2	71	14	419	86
13	Jan 4-7	19	8	220	92
14	Jan 11-14	14	14	87	86
15	Jan 19-22	1	4	24	96
	Total	592		3789	
	% of total	14		86	

Pre-spawn Mortality

Degree of egg retention was determined for 1,978 female carcasses (Table 5). Spawned females accounted for 60% (n = 1,195), partially spawned accounted for 13% (n = 264), and unspawned accounted for 26% (n = 519) of examined female carcasses. The proportion of spawned females generally increased throughout the survey, aside from a decrease during survey periods 9 and 10 (Dec. 7-17, Figure 12).

Table 5. Egg retention status of female carcasses by survey period during the 2020 lower American River Chinook salmon 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	Date	Unspawned	Partial	Spawned	Total
1	Oct 13-16	3	0	0	3
2	Oct 19-22	7	0	0	7
3	Oct 26-29	5	0	0	5
4	Nov 2-5	6	2	1	9
5	Nov 9-13	6	2	3	11
6	Nov 16-19	6	9	14	29
7	Nov 23-25	23	35	82	140
8	Nov 30-Dec 4	103	71	269	443
9	Dec 7-11	157	67	188	412
10	Dec 14-17	99	35	167	301
11	Dec 21-23	73	20	183	276
12	Dec 28-Jan 2	23	14	153	190
13	Jan 4-7	6	6	98	110
14	Jan 11-14	2	3	32	37
15	Jan 19-22	0	0	5	5
	Total	519	264	1195	1978
	% of total	26	13	60	

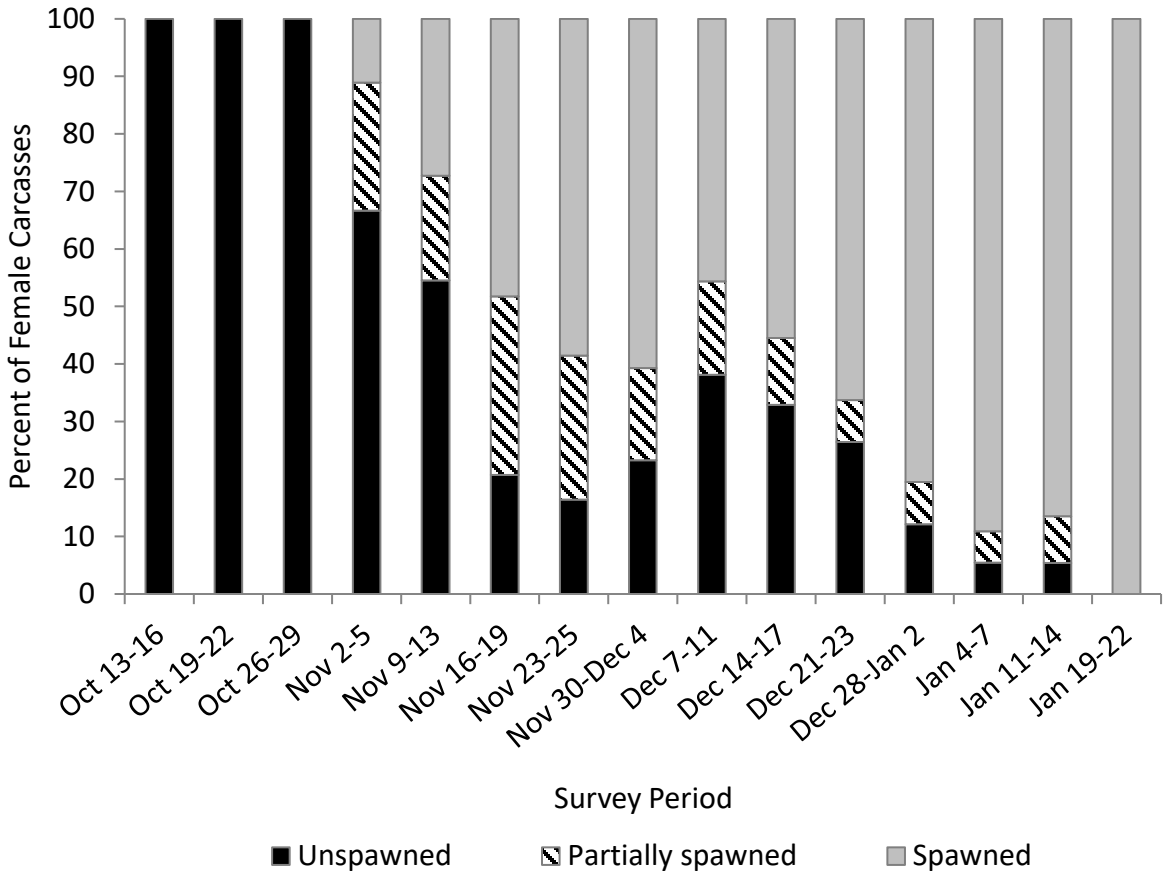


Figure 12. Egg retention status by percent of female carcasses per survey period for the 2020 lower American River Chinook salmon escapement survey.

CWT Carcasses

All Chinook salmon carcasses were inspected for the presence or absence of an adipose fin. Adipose fin clipped carcasses were recovered during all weeks of the survey (Table 6, Figure 13). A total of 3,325 (25.5 %) carcasses had an adipose fin clip, of those, heads were collected from 3,322 for CWT recovery. After the weir was removed (Dec. 11), there was an increase in the proportion of carcasses processed with an intact adipose fin. Excluding the carcasses encountered on the weir (n = 986), the proportion of carcasses that had adipose fin clip was 19% (n = 2,339). Adipose fin presence or absence could not be determined for 258 (2%) of carcasses.

Table 6. Adipose condition of carcasses by survey period for the 2020 lower American River escapement survey.

Survey Period	Date	Adipose Intact	Adipose Clipped	Skeleton/Unknown	Total
1	Oct 13-16	5	7	0	12
2	Oct 19-22	14	15	0	29
3	Oct 26-29	8	7	0	15
4	Nov 2-5	16	13	0	29
5	Nov 9-13	25	18	0	43
6	Nov 16-19	56	44	1	101
7	Nov 23-25	241	153	6	400
8	Nov 30-Dec 4	856	539	5	1400
9	Dec 7-11	1330	846	14	2190
10	Dec 14-17	2061	459	8	2528
11	Dec 21-23	1962	520	22	2504
12	Dec 28-Jan 2	1630	400	49	2079
13	Jan 4-7	831	190	75	1096
14	Jan 11-14	317	91	59	467
15	Jan 19-22	97	23	19	139
	Total	9449	3325	258	13032
	% of total	72.5	25.5	2	

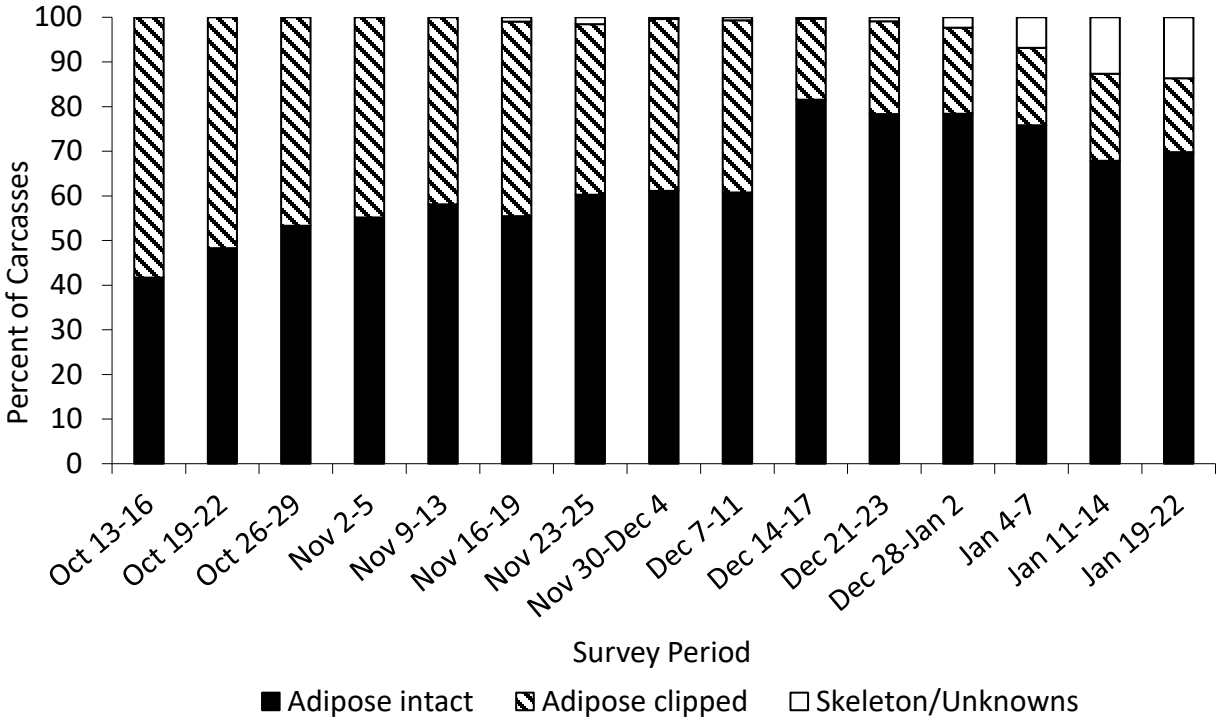


Figure 13. Temporal distribution of adipose fin condition for carcasses processed during the 2020 lower American River escapement survey.

Escapement Estimate

In order to calculate an escapement estimate, 995 fresh carcasses were marked with uniquely numbered disk tags for inclusion in the CJS population model. Of the tagged carcasses, 444 carcasses (45%) were recaptured at least once, with 644 recapture events in total. The LAR FRCS escapement estimate for 2020 was 22,456 (90% CI = 21,464 to 23,254). The bootstrap (n = 1,000) estimate of standard error was 541 FRCS. The total escapement estimate was multiplied by the fraction of adults and grilse (approximately 86% and 14%, respectively) to obtain an escapement estimate of 19,422 and 3,034 for adults and grilse, respectively. In addition to the in-river escapement, 6,264 Chinook (5,104 adult and 1,160 grilse) entered Nimbus Fish Hatchery via a fish ladder. The hatchery uses a length boundary of 68 cm to assign an age class for both sexes.

DISCUSSION

The Central Valley Project Improvement Act (CVPIA) established the goal to double the number of naturally spawning anadromous fish in the Central Valley based on a baseline period of 1967-1991. Mark-recapture efforts during the 2020 lower American River escapement survey produced an escapement estimate of 22,456 fall-run Chinook salmon, which is similar to 2019 (27,030) and 2018 (21,092) escapement estimates (Figure 14) yet is still far below the doubling

goal of 160,000 fall-run Chinook salmon on the American River (U.S. Fish and Wildlife Service 2015). Peak carcass recovery occurred the third week of December (survey period 10), which is 2-3 weeks later than the historical average for LAR FRCS. Sections 2 and 3 were not surveyed during the fourth week of December (survey period 11) but it is likely, if they were, it would have resulted in the latest recorded peak for carcass recovery on the LAR. Survey period 11 resulted in only 24 fewer carcasses than the preceding survey period; based on the number of carcass recoveries in sections 2 and 3 the preceding and following survey periods, more than 24 carcasses would likely have been recovered during this survey period (Table 3).

The majority of FRCS carcasses were encountered in section 1 (53%), which is consistent with previous surveys (Kelly and Phillips 2020; Snider and Reavis 1996). However, early season trends revealed a higher proportion of carcasses in the NB. After the weir was removed (Dec. 11), there was a substantial increase in carcass detection in section 1 and a decrease in NB. The purpose of the weir is to direct salmon to the Nimbus Fish Hatchery fish ladder and to prevent migration past the ladder into the NB, but the deterioration of the weir over several decades and damage from high flows no longer prevents salmon from entering the NB. While the weir is in place, it prevents carcasses within the NB from drifting downstream of the weir. On the weir, all adipose clipped carcasses were processed for head collection and CWT retrieval. All adipose intact carcasses were released downstream to mimic natural downstream movement. The gaffing technique used to retrieve carcasses from the weir creates additional punctures in the body cavity, which may have contributed to a reduced buoyancy and lower probability of detection in the deep waters downstream of the weir. Additionally, while thousands of salmon were trapped above the weir and contributed to the in-river escapement estimate, it is unlikely there will be a significant contribution to juvenile production in 2021 because spawning habitat in the NB is limited.

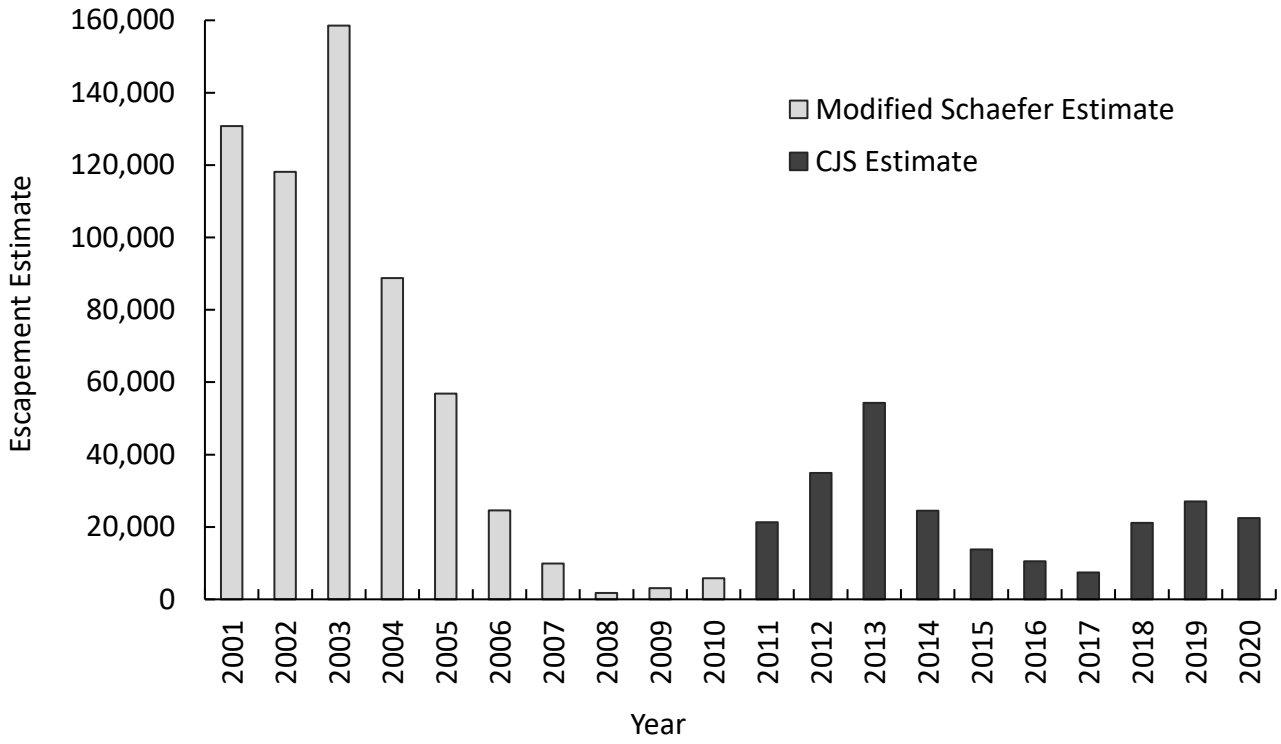


Figure 14. Historical in-river escapement estimates for the lower American River escapement survey from 2001-2020.

Preliminary data from CWTs recovered 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 strayed into the LAR. Hatcheries in the Central Valley generally mark and tag approximately 25% of hatchery-reared FRCS with CWTs. Of the 3,322 carcass heads collected for CWT extraction, 52.1% (1,731) originated from Nimbus Fish Hatchery, 30.9% (1,025) from Mokelumne River Hatchery, 6% (199) from Feather River Hatchery, 3.8% (126) from Merced River Fish Facility, and <0.1% (2) were spring-run Chinook salmon. The remaining 7.2% (239) Chinook salmon heads collected either had no CWT or the CWT was lost during extraction. Of the CWT returns for FRCS, approximately 44% (1,350 of 3,081) originated from hatcheries outside of the American River watershed. While 33.3% (1,025 of 3,081) of CWT recoveries were from the Mokelumne River Hatchery, it is important to note that 45% of the CWTs originating from Mokelumne River Hatchery were tagged at a rate of 100% as opposed to 25% at other hatcheries, partially accounting for the higher rate of return. Juvenile release location has a strong association with return and stray rates and can dramatically influence salmon survival rates (Palmer-Zwahlen et al. 2019, Sturrock et al. 2019).

The cutoff length separating adult from grilse age classes for both males (71 cm) and females (65 cm) was greater this survey year than observed during the 2019 LAR FRCS escapement

survey. The 2020 cutoff lengths were similar to the lengths for both sexes over the past 10 years (Figure 15). However, the proportion of grilse (14%) was the lowest it has been since 2014 when it was 9%.

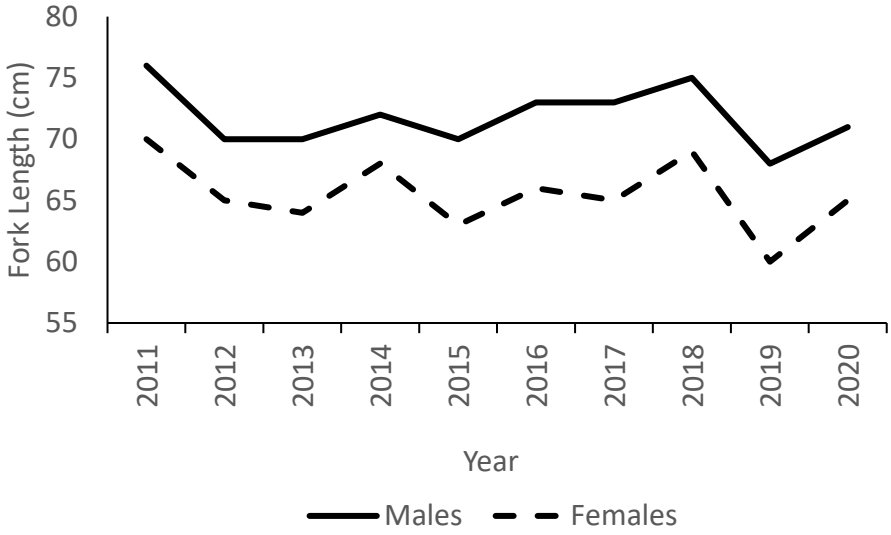


Figure 15. Minimum fork lengths for male and female adult Chinook salmon observed from 2011-2020 lower American River escapement surveys.

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). The 2020 LAR FRCS spawning season began slowly with only 629 carcasses processed over the first 7 survey periods, followed by a rapid increase to 1,400 carcasses during survey period 8. Water conditions reached a maximum suitable spawning temperature of 56°F at the end of the survey period 7, when the power bypass ended at Folsom Dam. There was also a notable decrease in pre-spawn mortality in female carcasses examined after this water management action. Pre-spawn mortality of females (26%) was the highest rate since 2012 (29%). The average pre-spawn mortality rate from 2000-2020 is 21%. Relatedly, this annual survey produced the lowest rate of spawned females (60%) since 2012 (50%), with a 20-year average rate of 66%. Releases of cool water from reservoirs has been identified as an important management practice for providing suitable spawning and rearing habitat for Chinook salmon in the Sacramento basin (Yates et al. 2008). The maintenance of the CWP behind Folsom Dam and cold-water releases continues to be increasingly relevant for survival of LAR FRCS stocks in the LAR.

Discharge from Nimbus Dam began at approximately 1,500 cfs on October 13 and decreased throughout the survey, ending at approximately 1,000 cfs on January 22. Although river connectivity issues were not observed to be associated with the 500 cfs decrease in discharge,

dry riverbed side channels were observed at the start of the survey season that would have been inundated at higher discharge levels. Essentially, the low flows in the river limited the available spawning habitat which likely limited successful spawning activity. In addition to potentially compromising river connectivity, the low overall discharge levels may have threatened the successful incubation of redds. Low levels of intra-gravel dissolved oxygen can have lethal and sublethal effects on salmon embryos, including changes to the time to hatching and size of emerging fry (Bjornn and Reiser 1991, Carter 2005, Geist et al. 2006). Additionally, higher temperatures increase oxygen demand, exacerbating the challenge of egg survival in a highly altered system undergoing climate change (Martin et al. 2020).

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