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Fall Chinook Salmon Run Characteristics and Escapement for the Mainstem Klamath River, 2016

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Abstract.— Adult fall Chinook Salmon *Oncorhynchus tshawytscha* carcasses were surveyed on the mainstem Klamath River, from Iron Gate Dam to the confluence with the Shasta River, during the 2016 spawning season to estimate annual escapement and characterize the age and sex composition and spawning success of the run. Using postmortem mark–recapture methods and a hierarchical latent variables model, the estimated spawning escapement for this section of the mainstem Klamath River was 746 fish, which was the lowest in the 16 years that this annual survey has been conducted. Based on this estimate and age composition data from scale samples, spawning escapement by year class was 39 (5.2%) jacks (age-2 fish), 236 (31.6%) age-3 spawners, 471 (63.1%) age-4 spawners, and 0 (0.0%) age-5 spawners. An estimated 28.1% of the fish that spawned in the study area were of hatchery origin. The adult female–male ratio was 1.5:1 and pre-spawn mortality rate of females was 4.3%. Estimated egg deposition by adult females in the study area was 1.0 million.

Introduction

Abundant runs of Chinook Salmon *Oncorhynchus tshawytscha* and steelhead *O. mykiss* and smaller runs of Coho Salmon *O. kisutch* were historically supported by the Klamath River Basin (Leidy and Leidy 1984; Figure 1). These species contribute to economically and culturally important subsistence, sport, and commercial fisheries. A drastic decline of anadromous fishes during the past century and a half has occurred in the Klamath River Basin as a result of a variety of flow- and non-flow-related factors (West Coast Chinook Salmon Biological Review Team 1997; Hardy and Addley 2001). These factors include water storage and transfer, environmental phenomena, disease, changed genetic integrity from hatchery-origin fish straying into natural spawning areas, over-harvest, and land-use practices causing habitat loss due to blockages and degradation.

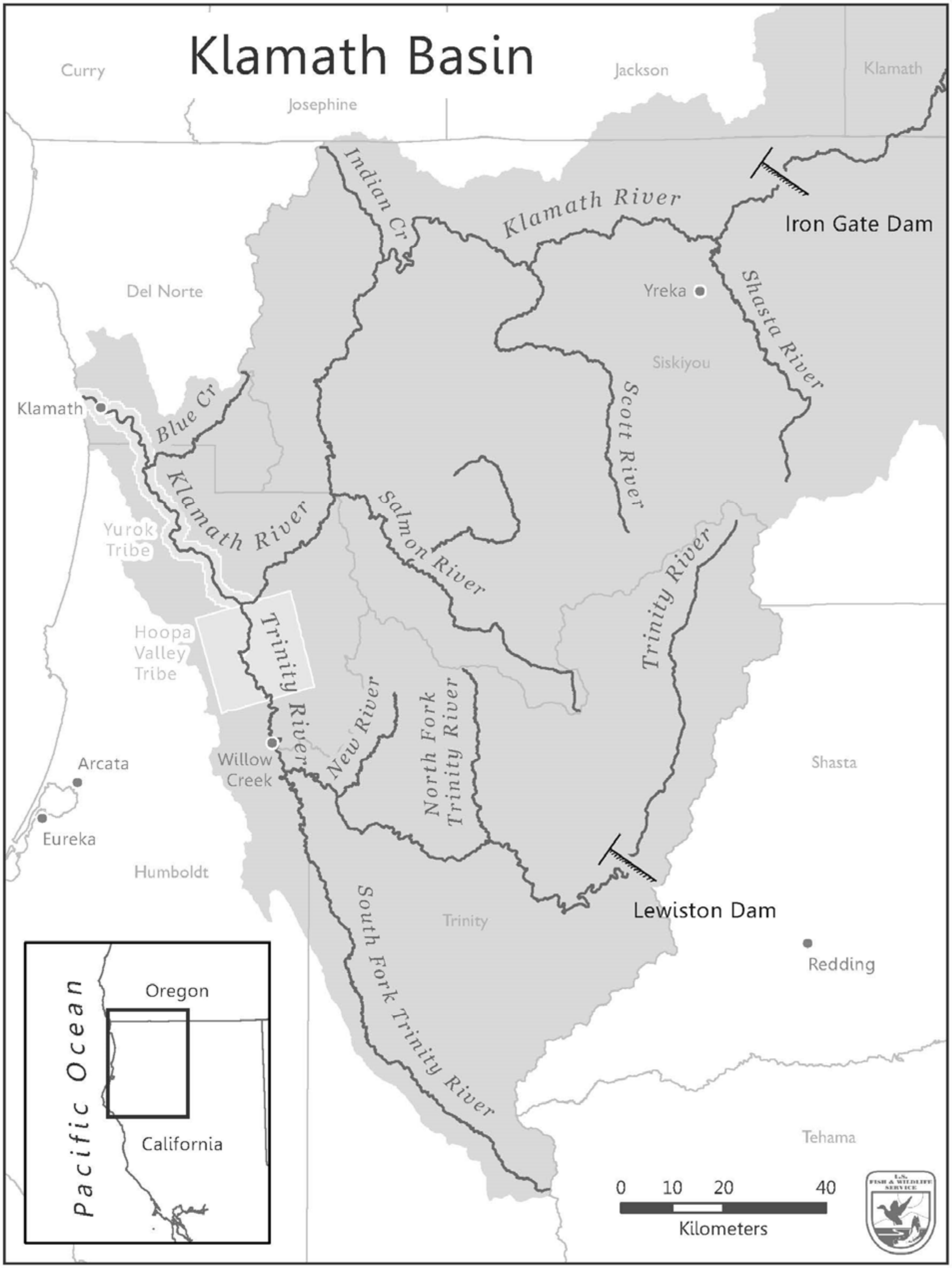

Figure 1. Klamath River Basin, northern California. The mainstem Klamath River carcass survey study area extends from Iron Gate Dam to the Shasta River confluence.

Beginning in 1993, the U.S. Fish and Wildlife Service's Arcata Fish and Wildlife Office (AFWO) initiated the mainstem Klamath River fall Chinook Salmon spawning escapement assessment. In this program, escapement estimates were generated by expanding redd counts under the assumption that each redd represents one adult female and one adult male (e.g., Magneson 2014). This effort was initiated to supplement fall Chinook Salmon spawning escapement and harvest monitoring that had been initiated in the Klamath River Basin in 1978 (CDFW 2016). In 2001, we initiated a carcass tag-recovery (i.e., mark–recapture) methodology with the objective of refining the escapement estimate in the heavily used spawning area between Iron Gate Dam [IGD; river kilometer (rkm) 310.15] and the Shasta River confluence (rkm 288.45). We conducted a postmortem tag-recovery study rather than the more common live tag–postmortem recovery or live mark–live recapture surveys since we had no opportunity to count, mark, or recover live fish (e.g., at a weir; Manly et al. 2005). Petersen tag-recovery-based estimates and redd counts from concurrent surveys from IGD to the confluence of the Shasta River from 2001 to 2004 and 2006 were compared. Estimates of successfully spawned adult females were 3.3–4.8 times higher than redd counts over this stretch of river (Gough and Williamson 2012). We assumed Petersen estimates were the more accurate of the two methods and that redd counts underestimated escapement, presumably due to redd superimposition and difficulty in observing redds due to water clarity. Since 2007, only carcass surveys have been conducted in this section of the river for this reason.

In 2012, a large run of fall Chinook Salmon was predicted to enter the Klamath Basin, the largest since comprehensive monitoring and harvest management activities were initiated in 1978 (O'Farrell 2012; PFMC 2012). The survey effort required to complete the mark–recapture protocol given the projected run size would have been unfeasible due to staffing, equipment, and time constraints. In response, we developed a methodology and protocol for an area-under-the-curve (AUC) escapement estimate (Gough and Som 2015). This new methodology allowed the ability to complete weekly surveys regardless of run size by incorporating weekly systematic sampling rates, when necessary, based on the anticipated number of carcasses. This AUC application was used to estimate escapement from 2012 to 2015.

After four years of AUC implementation, the behavior of the estimates warranted some discussion. Most obvious was the general pattern of very diffuse estimates (i.e., large confidence interval widths). The AUC estimator relied on estimates of carcass survey life, and as a divisor in the AUC's equation, even moderate variance in this estimate propagated to larger variances in the carcass estimates. The variance of the AUC estimates was also influenced by precision in weekly-stratified mark–recapture estimates of carcass capture probabilities. A common phenomenon in these carcass survey data is relatively sparse information for estimating capture probabilities during the first few weeks of the survey season. Accordingly, imprecise estimates of early-season capture probabilities also contributed to the diffuse nature of the carcass estimates. Klamath Basin water managers have recently implemented increased late summer and early fall flow augmentations, and planning is underway for future augmentations (USBOR 2016). By coinciding with the beginning of the carcass survey season, future flow augmentations could exacerbate the sparseness of early season capture probability data. With an aim to provide more precise carcass estimates, we began using a hierarchical latent variables model, which does not rely on estimates of carcass survey life, in 2016 to estimate escapement.

The primary purpose of this project was to provide the Klamath River Technical Team (KRTT) with fall Chinook Salmon spawning escapement estimates for the mainstem Klamath River. KRTT depends on accurate escapement estimates of fall Chinook Salmon throughout the Klamath River Basin to determine the total basin-wide natural escapement and age structure of the run. This information, along with age-structured hatchery escapement and in-river harvest estimates, is then used to project ocean stock abundance and assist in development of harvest management alternatives for the following year (KRTT 2017a). Spawner estimates generated by the carcass survey conducted within the more densely used spawning reaches (i.e., above the Shasta River confluence) are summed with estimates derived from the redd survey below the Shasta River confluence to establish an estimate of escapement for the mainstem Klamath River (KRTT 2017b). Accurately determining the number of spawners within this reach is also needed for an ongoing outmigrant fry study (e.g., David et al. 2016) and for calibrating the Chinook Salmon production model, Stream Salmonid Simulator. Additionally, carcass survey data are used to estimate annual age-class proportions, adult female–male ratios, female spawning success/pre-spawn mortality, fork length distributions, proportions of naturally spawning hatchery-origin fish, and egg deposition.

Study Area

The survey area consists of the 21.2-km section of mainstem Klamath River between IGD (the upper limit of anadromy) and the Shasta River confluence, and is divided into eight reaches (Table 1; Figure 2). Reach delineation is based on previously mapped concentrations of redds with boundaries at distinguishable landmarks.

Table 1. Reach boundaries and lengths in the Klamath River carcass survey study area. Downstream landmarks were the same as upstream landmarks of the next reach.

	Rkm		Length	
Reach	Upstream	Downstream	(km)	Upstream landmark
1	309.65	309.20	0.45	Boat ramp opposite Iron Gate Hatchery
2	309.20	307.10	2.10	Riffle below USGS Gaging Station
3	307.10	304.30	2.80	Dry Creek confluence
4	304.30	303.15	1.15	First wooden foot bridge
5	303.15	300.70	2.45	KRCE green wooden foot bridge
6	300.70	296.35	4.35	Copco-Ager (Klamathon) Bridge
7	296.35	293.70	2.65	Third (fallen) wooden foot bridge
8	293.70	288.45 [a]	5.25	Carson Creek confluence

[a] Shasta River confluence

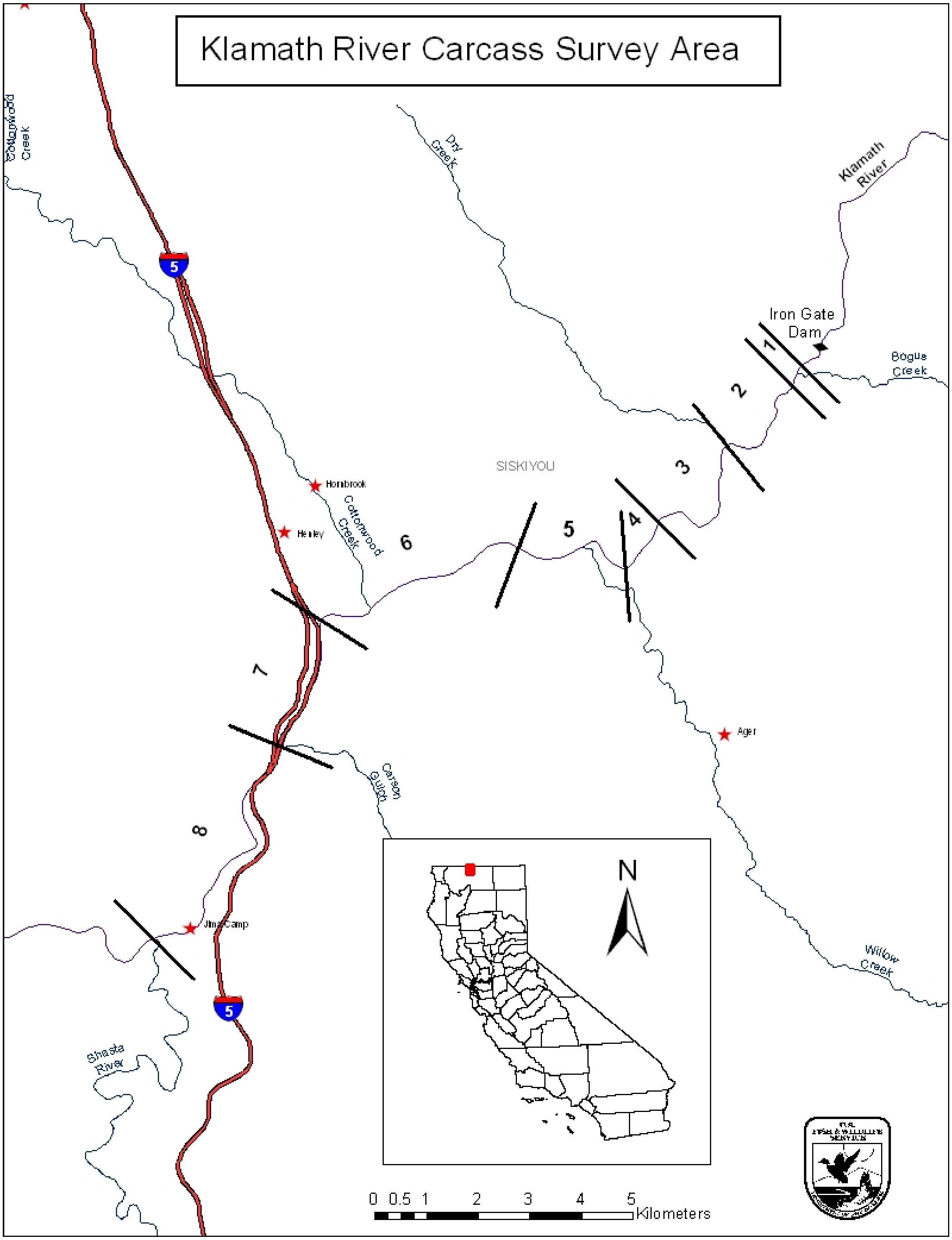

Figure 2. Klamath River carcass survey area from IGD (rkm 310.15) to the Shasta River confluence (rkm 288.45) with reaches delineated. Reach 1 begins at the first river access below IGD (rkm 309.65). Little to no spawning occurs between the dam and the access point.

Methods

Data were collected in a cooperative effort between AFWO and the Yurok Tribal Fisheries Program (YTFP). Weekly surveys were conducted from October 4 to November 30, 2016. Two crews, one AFWO and one YTFP, each comprised of three members, rowed downstream in inflatable catarafts on opposite banks of the river. Each crew, consisting of a rower, a data recorder, and a carcass handler, searched the river for carcasses on their respective bank, from the river's edge to the mid-channel. The crews switched banks every week. Side channels were surveyed for carcasses either by foot or by cataraft. The following information was recorded for each survey: survey week, date, reach(es) surveyed, surveyors' names, predominant weather of the day, daily mean discharge at USGS Gage 11516530 below IGD, and weekly Secchi disk depth. We only recorded Secchi disk depth once per week because only one location in the study area (in Reach 8) was consistently slow and deep enough for this water transparency measurement.

Carcass Data

Each observed carcass not previously tagged (see Escapement Estimate section below) was retrieved and the following data were recorded: reach, location (lateral position in the channel), species, sex, fork length (FL), spawning condition, carcass condition (level of decay), presence or absence of an adipose fin, and scarring.

Lateral position was recorded as left bank (LB), right bank (RB), or mid-channel (MC):

LB = left third of the river channel width;

RB = right third of the river channel width;

MC = middle third of the river channel width.

Location of carcasses found in side channels were recorded as being on their respective bank and a comment was made denoting where in the side channel the carcass was encountered.

Carcass condition was categorized as fresh (F_1), partly decayed (D_2), or one of three stages of rotten (N_3, N_4, or N_5) according to the following indications:

F_1 = firm body, at least one clear eye, or pink or red gills;

D_2 = decayed beyond F_1 but body still has some firmness and little fungus;

N_3 = rotten (decayed beyond D_2; covered with fungus and flesh softening);

N_4 = very rotten (decayed beyond N_3; flesh liquefying);

N_5 = exceedingly rotten (decayed beyond N_4; deteriorated to the point that skin is sloughing off and the carcass is almost skeletal).

F_1-condition carcasses were believed to have expired less than one week prior to capture, D_2-condition carcasses were believed to have expired about one week prior to capture, and N_x-condition carcasses were believed to have expired more than one week prior to capture. Fork lengths from N_x-condition carcasses were not recorded.

Sex was distinguished using morphological differences for F_1- and D_2-condition carcasses only. Adult males are typically larger than adult females of the same age class, develop a more-pronounced kype, and may display reddish coloration along their sides. Spawned females display ventrally eroded anal and caudal fins and an emptied abdomen. Carcasses were also cut open and sex was verified by gonad type or presence of eggs.

Positively identified F_1- and D_2-condition female carcasses were assigned a spawning condition code from 1 to 4:

1 = spawned out or less than one-third of eggs retained;

2 = partially spawned with one- to two-thirds of eggs retained;

3 = unspawned or more than two-thirds of eggs retained;

4 = spawning condition not determined.

Spawning condition data were used to calculate spawning success and, conversely, pre-spawn mortality of female Chinook Salmon. Female carcasses with spawning condition '1' and '2' were considered successful spawners. Carcasses with spawning condition '3' were considered pre-spawn mortalities. F_1- and D_2-condition carcasses with spawning condition '1', '2', and '3' were used to assess the overall spawning success for the entire spawning season. Only F_1-condition carcasses were used to estimate weekly pre-spawn mortality because we assume that only those fish expired the week they were sampled. Measurements of pre-spawn mortality are limited to occurrence within the space and time of the surveys. Pre-spawn mortality occurring in the lower Klamath River or prior to these surveys are not reflected in our data and analyses.

Throughout this report the term 'jack' refers to age-2 (precocious) spawners, including males (true jacks) and females (jills). The size cut-off between adults and jacks was decided after the sampling season based on scale-age data and length-frequency distributions compiled and analyzed by the KRTT (2017b). The KRTT reviews data from throughout the basin provided by various collaborators and jointly decides which method best represents the jack–adult proportions for each monitoring area that should be used in the stock projection estimate.

Scale samples were collected to aid in calculating the age-structured estimates developed each year by the KRTT. Scales were collected from all sampled F_1- and D_2-condition carcasses. A minimum of five scales were collected from the preferred area of the fish, described by DeVries and Frie (1996) as the area laterally between the dorsal and anal fins above the lateral line. Scale samples were placed in individual envelopes and provided to YTFP, who coordinate the Klamath River portion of the KRTT (2017b) age composition analysis.

Escapement Estimate

Counts of carcasses were conducted weekly over the entire study area throughout the active spawning period. Systematic sampling was not necessary in 2016 and every visible carcass was counted and every F_1- and D_2-condition carcass was measured each survey week. All sampled F_1- and D_2-condition carcasses were marked with uniquely numbered aluminum tags attached to a hog ring clamped around the upper jaw, allowing the fate of individual carcasses to be tracked over time and space. Tags were not applied to adipose fin-clipped ('ad-clipped') carcasses since their snouts were removed (see Hatchery Contribution section below). Tagged carcasses were replaced near the location and depth where they were found.

N_x-condition carcasses were sampled, tallied, and replaced. Recaptured (previously tagged) carcasses were examined and the following data were recorded: reach, tag number, and condition. Recaptured carcasses were replaced to allow the possibility of multiple recaptures.

Carcass abundance estimates of Chinook Salmon in the mainstem Klamath River between Iron Gate Dam and the Shasta River confluence were generated via a hierarchical latent variables model in 2016. This model assumes a latent (unobservable) ecological process interacts with a detection process to produce the observed counts of carcasses (Kery and Schaub 2012). For this survey, the latent process is the true abundance of carcasses. As not all carcasses are observed (imperfect detection), a separate observation process links the unobserved latent process to the observed data.

The general model described above was executed with counts of fresh Chinook Salmon carcasses (C_i, and here after i indexes week; i.e., those arriving since the prior survey) and weekly detection probabilities (p_i) estimated from mark–recapture data. Detection probability (p_i) is estimated via the count of recovered carcasses (R_i) that had been marked the previous week (M_{i-1}). Weekly abundances (N_i) are estimated by assuming that the weekly counts of fresh Chinook Salmon carcasses (C_i) arise from a binomial distribution (index parameter = N_i, probability of detection = p_i; Kery and Schaub 2012). Finally, weekly estimates were summed to create an annual abundance estimate of carcasses (N) as a derived parameter (Kery and Schaub 2012). The assumptions of this modeling framework include: 1) crews correctly identify fresh Chinook Salmon carcasses among all other carcasses (e.g., decaying carcasses or carcasses of other species), 2) marked carcasses remain in the study area for at least one week, and 3) the detection probability of all carcasses is equal within a given week.

$$R_i \sim binomial(M_{i-1}, p_i), C_i \sim binomial(N_i, p_i);$$

$$N = \sum_i N_i.$$

Implementing our abundance model in a Bayesian framework and estimating parameters via Markov Chain Monte-Carlo (MCMC) methods allowed us to propagate all sources of estimation uncertainty (over all detection probabilities and weeks) and generate confidence intervals for each annual abundance estimate (Kery and Schaub 2012). A requirement of Bayesian implementation is specifying prior distributions for all estimated parameters. In all cases, we implemented non-informative priors, and commenced with MCMC sampling via JAGS software (Plummer 2014) implemented with R statistical software (R Core Team 2016).

Age-Class Estimates

Adult estimates were obtained by multiplying the total carcass estimate by the percentage of adult (ages 3 and up) spawners (P_{adult}) determined by the scale readings:

$$\hat{N}_{adult} = \hat{N} * P_{adult} .$$

Individual age class estimates were calculated likewise:

$$\hat{N}_x = \hat{N} * P_x ,$$

where x is age class 2, 3, 4, or 5.

Hatchery Contribution

Iron Gate Hatchery (IGH), located just below IGD and operated by the California Department of Fish and Wildlife (CDFW), produces fall Chinook Salmon and Coho Salmon. A proportion, varying with release group, of the juvenile Chinook Salmon produced at the hatchery are injected with a coded-wire tag (CWT) and ad-clipped. CWT codes are linked to the hatchery of origin, race, release type, and brood year of the individual fish. All F_1- and D_2-condition carcasses captured were examined for ad-clips. Only F_1- and D_2-condition carcasses were included in this analysis to avoid the misidentification of ad-clips in non-fresh carcasses (Mohr and Satterthwaite 2013). The snouts of ad-clipped carcasses were removed and frozen in individual bags. CWTs were later removed from recovered snouts and read by AFWO and CDFW personnel.

An estimate of hatchery-origin Chinook Salmon that spawned in the study area was calculated using the same methodology described in Harris et al. (2012). The number of CWT fish for each code was estimated by multiplying the number of CWTs recovered by a sample expansion factor (ϵ) for the season which accounts for CWTs that were lost during dissection, unreadable tags, and missing snout samples (i.e., not collected from ad-clipped carcasses or lost prior to processing):

$$\epsilon = \left(\frac{AD_{obs}}{AD_{sample}}\right)\left(\frac{AD_{cwt}}{AD_{code}}\right),$$

where AD_{obs} = the number of ad-clipped Chinook Salmon carcasses observed, AD_{sample} = the number of snout samples collected from ad-clipped carcasses, AD_{cwt} = the number of samples with a CWT, and AD_{code} = total number of CWTs recovered and decoded after processing samples. Those carcasses observed when systematic sampling was implemented were expanded by the sampling rate [e.g., under a 1:3 systematic sampling rate each sampled carcass represents three carcasses with its attributes (i.e., ad-clip, CWT number, etc.)].

To account for unmarked hatchery fish, the expanded estimates for each CWT code, *i*, were multiplied by a production multiplier ($PM_{code(i)}$) specific to each CWT code. Each $PM_{code(i)}$ was calculated from hatchery release data (PSMFC 2017):

$$PM_{code(i)} = \frac{AD_{tag} + AD_{no-tag} + U}{AD_{tag}},$$

where AD_{tag} = the number of ad-clipped Chinook Salmon released with a CWT, $AD_{no\text{-}tag}$ = the number of ad-clipped Chinook Salmon without a tag, presumably because the tag had been shed, and U = the number of unmarked Chinook Salmon in a release group.

The total contribution of hatchery Chinook Salmon (N_H) was estimated by summing estimated contributions attributable to a specific CWT code ($H_{code(i)}$):

$$\widehat{N}_H = \sum \widehat{H}_{code(i)} = \sum \left(AD_{code(i)} * \epsilon * PM_{code(i)}\right),$$

where $AD_{code(i)}$ = the number of CWTs recovered with code *i*.

Egg Deposition

Total egg deposition (N_e) in the study area was estimated by multiplying predicted egg production (n_e) by the estimate of adult females ($\widehat{N}_{adult}$). Chinook Salmon females deposit multiple pockets of eggs in a single redd (Healey 1991). Successful deposition of eggs by partially spawned females was assumed to average half that of a fully spawned female. We used the 2016 mean egg production per female at IGH (n_e = 2,590) as a surrogate for mainstem spawning female Chinook Salmon (Pomeroy 2017). Escapement estimates of fully spawned females (F_{fs}) multiplied by n_e were added to escapement estimates of partially spawned females (F_{ps}) multiplied by one-half of n_e to yield total egg deposition in the study area:

$$\widehat{N}_e = \left(n_e * \hat{F}_{fs}\right) + \left(\frac{1}{2} * n_e * \hat{F}_{ps}\right).$$

Results and Discussion

Temporal and Spatial Distribution of Carcasses

A total of 257 F_1- and D_2-condition carcasses were counted during the 2016 surveys, of which 233 were marked with uniquely numbered jaw tags (Table 2). The peak of new carcass observations, which typically occurs in calendar weeks 44–46, occurred in calendar weeks 44 and 45. Like previous years, carcass density was higher in the upper reaches of the survey but was still low compared to previous years in all reaches (Figure 3).

Table 2. Number of F_1- and D_2-condition fall Chinook Salmon carcasses captured by calendar week, Klamath River surveys, 2001–2016. Annual peak counts are in bold font. Dashes (-) indicate no survey conducted.

	Calendar week										
Year	41	42	43	44	45	46	47	48	49	50	Total
2001	-	50	165	310	**336**	251	-	16	-	-	1,128
2002	-	39	251	**1,032**	655	348	40	2	-	-	2,367
2003	-	23	91	583	**740**	181	49	4	-	-	1,671
2004	-	-	237	**292**	260	93	20	2	-	-	904
2005	3	30	87	**182**	70	10	1	-	-	-	383
2006	14	36	169	**203**	94	34	1	-	-	-	551
2007	7	27	41	145	241	**385**	216	142	26	9	1,239
2008	-	40	103	335	**345**	173	35	7	-	-	1,038
2009	-	14	64	267	**386**	280	89	45	2	-	1,147
2010	-	8	15	50	149	**156**	69	14	1	-	462
2011	-	17	45	107	200	**262**	111	18	1	-	761
2012	31	49	159	418	**526**	238	63	7	-	-	1,491
2013	8	8	149	**514**	283	154	50	19	3	-	1,188
2014	5	24	175	712	**894**	562	120	50	3	-	2,545
2015	5	16	70	**203**	133	99	39	14	1	-	580
2016	1	7	45	**84**	**84**	14	9	10	3	-	257

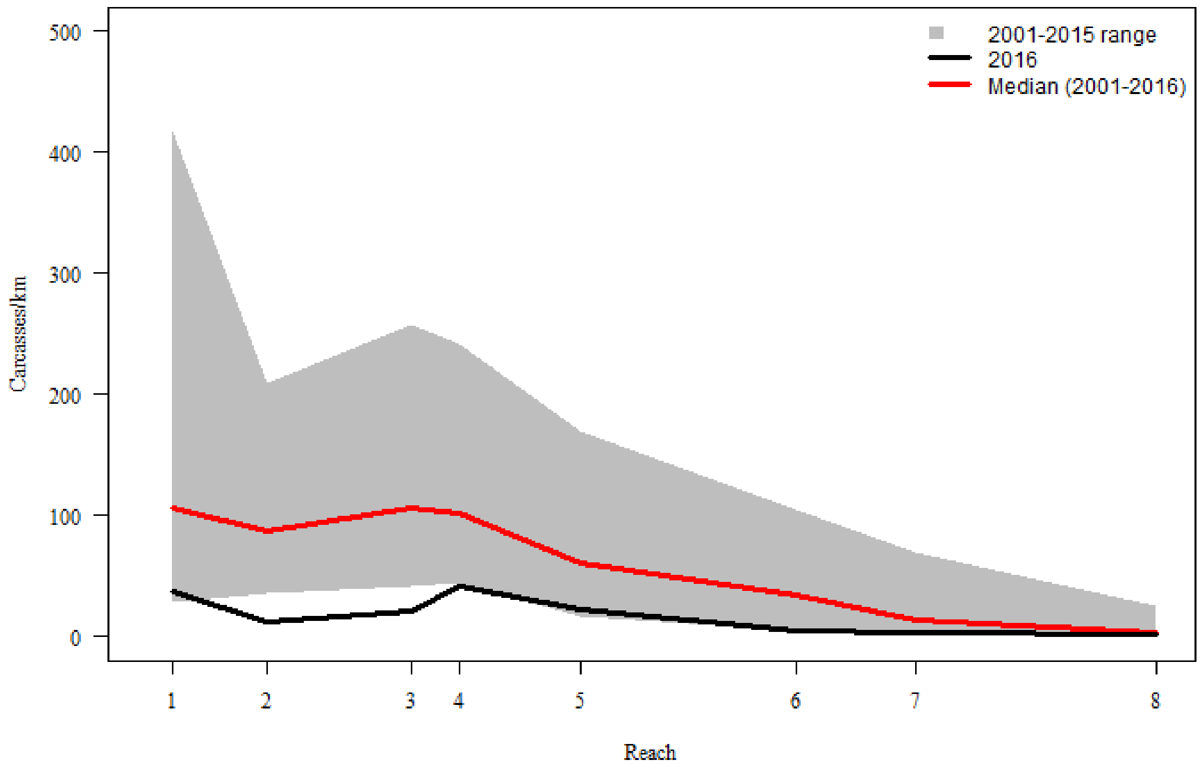

Figure 3. Fall Chinook Salmon carcass density (from *counts* of F_1- and D_2-condition carcasses only) by reach, Klamath River surveys, 2001–2016. Reach 1 was not surveyed from 2002 to 2005.

Length Distribution

The 2016 jack–adult size cut-off (55 cm FL) was determined after the sampling season by the KRTT (2017b; Table 3; Appendix A). Of the 10 fish that measured less than or equal to 55 cm FL, only one was female. Mean fork lengths of adult females, adult males, and jacks were 73.0, 79.4, and 49.4 cm, respectively.

Adult Female–Male Ratio

The percentage of females among handled adult carcasses was 60.2% (adult female–male ratio = 1.5:1) in 2016 (Figure 4). Historically, the percentage of females ranged from 51.8% (adult female–male ratio = 1.1:1) to 72.9% (2.7:1) from 2001 to 2015. This ratio likely underestimates the proportion of males that spawned in the survey area. Female salmon tend to reside on their redds longer than males (Neilson and Geen 1981). Therefore, males were more likely to mobilize and leave the survey area after spawning. Though we were unable to measure how many males may have left the study area before dying, the removal of males is supported by our observed decrease in the female–male ratio moving downstream within the study area (Appendix B). Adult females were more abundant than males in Reaches 1–5, while males were more abundant in Reach 6. Reaches 7 and 8 did not have large enough sample sizes (n = 9 and 12, respectively) to include in this inference. Compared to adult Chinook Salmon that returned to IGH, the percentage of returning adults that were female was 9.4% higher in the mainstem in 2016 (Appendix C).

Table 3. Mean fork lengths by year of fall Chinook Salmon carcasses, Klamath River surveys, 2001–2016.

Year	Jack–adult FL (cm) cut-off (jacks ≤)	Adult females n	Adult females FL (cm) mean	Adult females FL (cm) s.d.	Adult males n	Adult males FL (cm) mean	Adult males FL (cm) s.d.	Jacks n	Jacks FL (cm) mean	Jacks FL (cm) s.d.
2001	63	571	76.3	6.3	486	85.4	9.6	75	53.8	6.3
2002	63	1,133	75.8	6.9	1,063	82.7	9.2	166	56.0	6.6
2003	55	985	76.9	7.8	667	87.0	10.2	24	48.0	5.4
2004	57	446	78.9	7.3	400	87.3	9.7	52	50.7	5.4
2005	52	247	73.7	7.6	219	83.3	9.7	5	47.0	4.3
2006	60	438	74.5	6.9	432	84.0	9.8	242	52.6	5.7
2007	51	918	66.6	5.3	402	77.2	10.0	26	46.5	3.5
2008	59	595	76.8	6.4	433	84.0	12.0	272	53.4	4.9
2009	58	729	73.2	5.7	381	83.0	8.4	74	51.6	4.1
2010	61	255	78.9	6.3	186	85.4	9.2	61	55.8	4.5
2011	63	235	76.6	7.2	178	84.2	9.9	319	56.6	4.4
2012	58	737	71.0	4.9	459	78.0	8.0	119	51.7	4.4
2013	57	725	75.1	6.7	387	81.4	9.9	69	51.4	4.3
2014	60	1,187	75.8	6.3	812	83.1	9.9	162	54.1	4.7
2015	54	352	71.3	6.0	207	80.6	9.2	15	49.8	3.7
2016	55	141	73.0	6.3	93	79.4	10.4	10	49.5	5.1

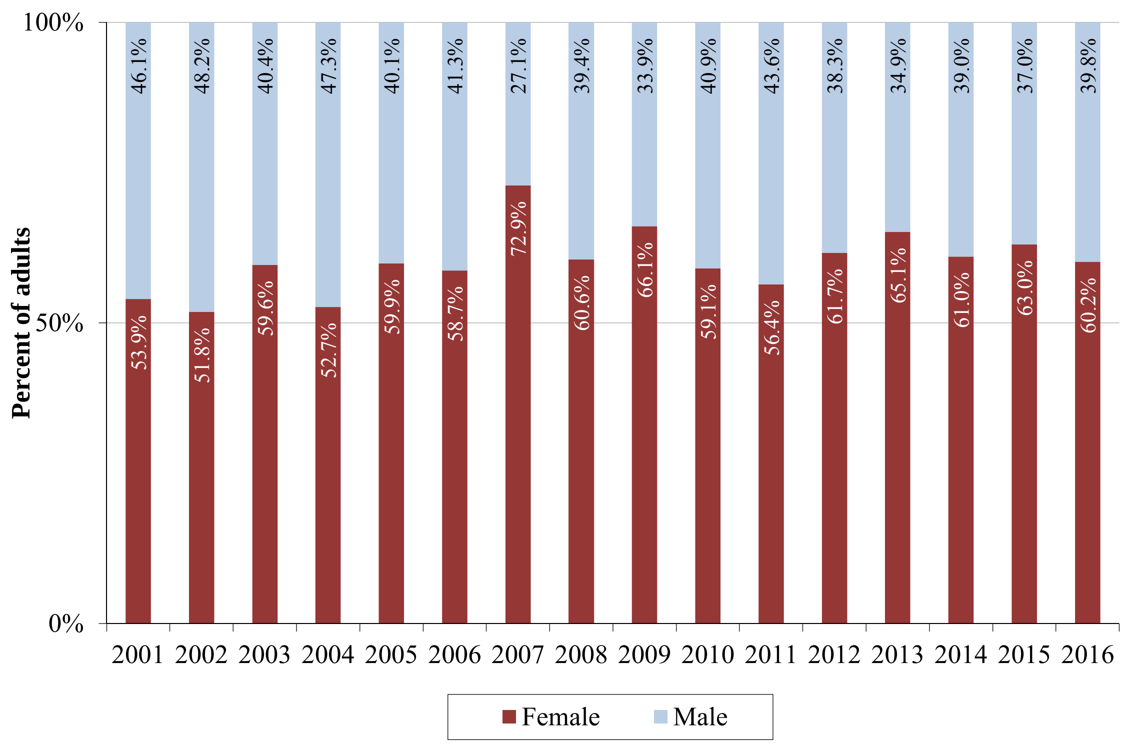

Figure 4. Female and male proportions of adult fall Chinook Salmon carcasses, Klamath River surveys, 2001–2016.

Pre-spawn Mortality

Pre-spawn mortality was 4.3% in 2016 (Figure 5). Fully spawned individuals made up 89.3% of F_1- and D_2-condition female adult carcasses. Pre-spawn mortality in previous years ranged from 1.0% (in 2009) to 22.1% (in 2005) with a mean of 8.6%. Pre-spawn mortality observed in previous years was generally highest at the beginning of the surveys and decreased as the season progressed. Similarly, pre-spawn mortality in 2016 was only observed during the first three survey weeks (Figure 6; Appendix D).

Escapement Estimates and Age Composition

The mainstem spawning escapement estimate in this study area for 2016 was 746 Chinook Salmon (95% CI: 590–962), which was the lowest estimate over the 16-year history of this survey (Table 4). The estimated weekly recapture rates for carcasses captured one week after tagging ranged from 0.23 to 0.39. The first four survey weeks of mark–recapture data were combined, as were the last three weeks, in order to achieve adequate sample sizes. The consequence of grouping consecutive weeks of mark–recapture data is an assumption of constant detection probability within each grouped time block.

We assumed that males leaving the survey area after spawning (see Adult Female–Male Ratio section) did not significantly bias the escapement estimates. A large majority (82.8%) of carcasses in 2016 were found in the first five survey reaches, indicating that most spawning activity occurred in the upper 9.0 km of the 21.2-km study area. Few, if any, of

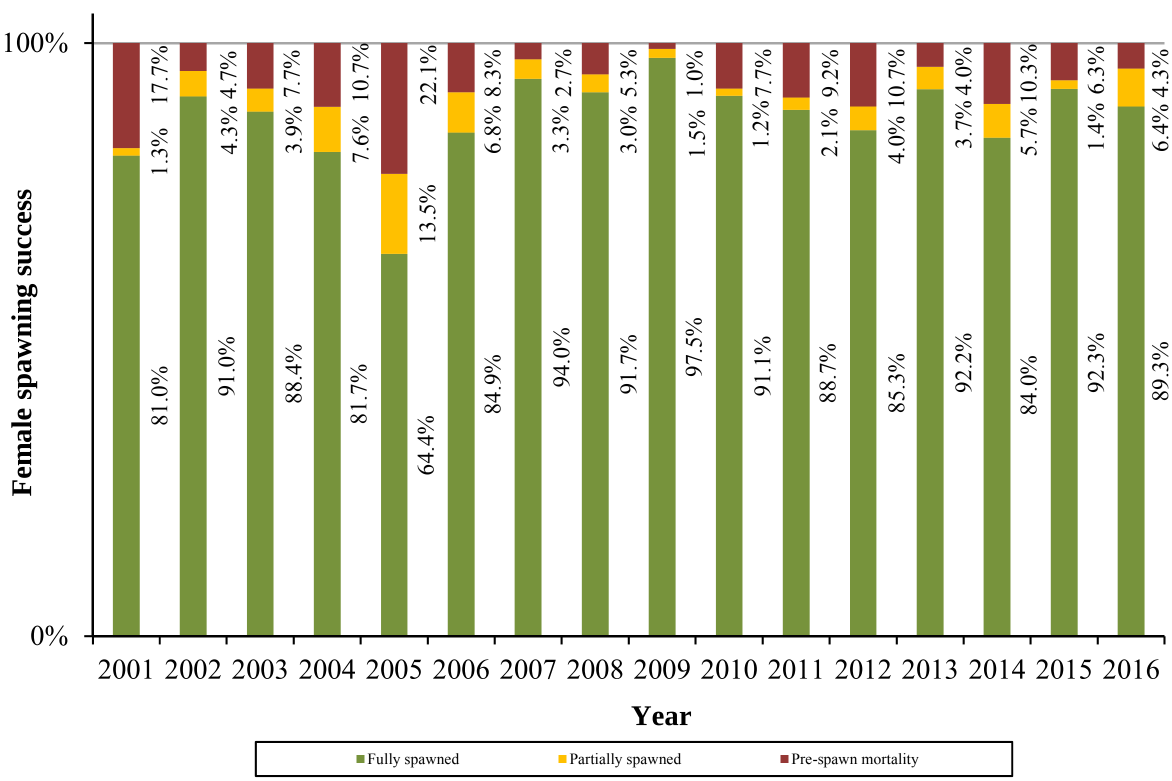

Figure 5. Spawning success of female fall Chinook Salmon based on F_1- and D_2-condition carcasses, Klamath River surveys, 2001–2016.

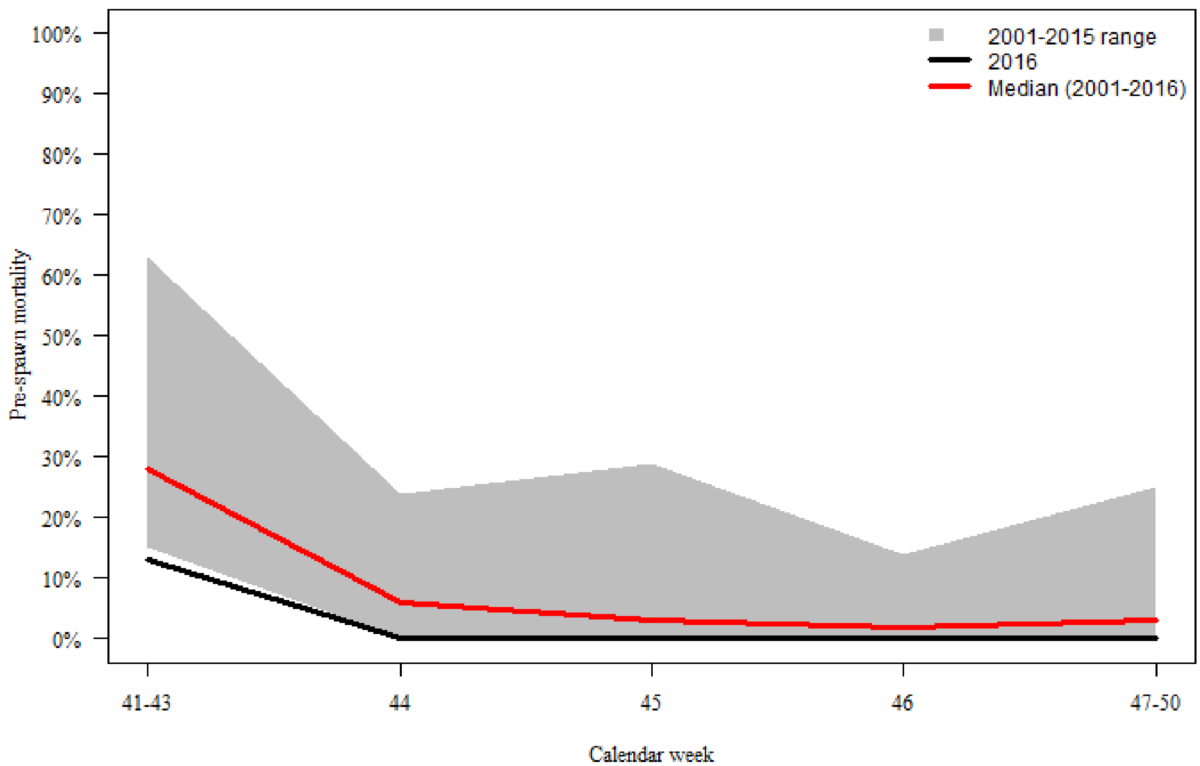

Figure 6. Weekly pre-spawn mortality from F_1-condition female fall Chinook Salmon carcasses, Klamath River surveys, 2001–2016. Calendar weeks 41–43 and 47–50 were combined since sample sizes were typically low in calendar weeks 41, 42, 48, 49, and 50, if surveyed.

those male fish likely migrated or drifted downstream more than 12.2 km after spawning and left the study area. Of the few males that spawned in the three downstream-most reaches, any that left the study area after spawning should have only minimally affected the escapement estimate.

Secchi disk depths ranged from 7.5 to 12.0 ft in 2016. Visibility measurements were between 8.0 and 10.0 ft in seven of the nine survey weeks. We believe this range in visibility only minimally influenced observation efficiency. With the exception of a mid-November pulse flow event, steady flows contributed to consistent observation efficiency throughout most of the season (Figure 7). The pulse flow event was implemented to mobilize and strand spawned salmon carcasses to decrease *Ceratonova shasta* spore input into the river where mainstem natural spawning is most concentrated (Appendix E). Flows out of Iron Gate Dam increased on November 9 from about 1,000 cfs to a peak of around 3,200 cfs on November 10. Flows remained around 3,200 cfs for about 3 hours before decreasing back down to 1,000 cfs. We believe that this pulse flow event did not move carcasses out of the survey area and therefore did not reduce the escapement estimate.

Two hundred forty-four scale samples were collected from carcasses and analyzed in 2016 to estimate the age composition of the mainstem spawning escapement. Based on age-composition estimates (KRTT 2017b) and the total escapement estimate, jacks (age-2 fish) represented 5.2% ($\hat{N}_{jacks}$ = 39) of the total escapement (Table 5). The proportion of fish

Table 4. Fall Chinook Salmon escapement estimates, Klamath River surveys, 2001 to 2016. HLVM = hierarchical latent variables model.

Year	Escapement estimate	95% confidence limits Lower	Upper	Estimator
2001	7,828	7,253	8,403	Petersen
2002	14,394	13,934	14,855	Petersen
2003	12,958	12,274	13,642	Petersen
2004	4,715	4,469	4,960	Petersen
2005	4,585	3,860	5,309	Petersen
2006	3,587	3,296	3,879	Petersen
2007	5,523	5,273	5,774	Petersen
2008	4,894	4,649	5,140	Petersen
2009	4,427	4,238	4,615	Petersen
2010	2,572	2,362	2,782	Petersen
2011	4,880	4,551	5,209	Petersen
2012	12,626	9,592	16,721	AUC
2013	7,358	5,902	21,161	AUC
2014	16,720	13,676	23,021	AUC
2015	2,507	1,883	3,305	AUC
2016	746	590	962	HLVM

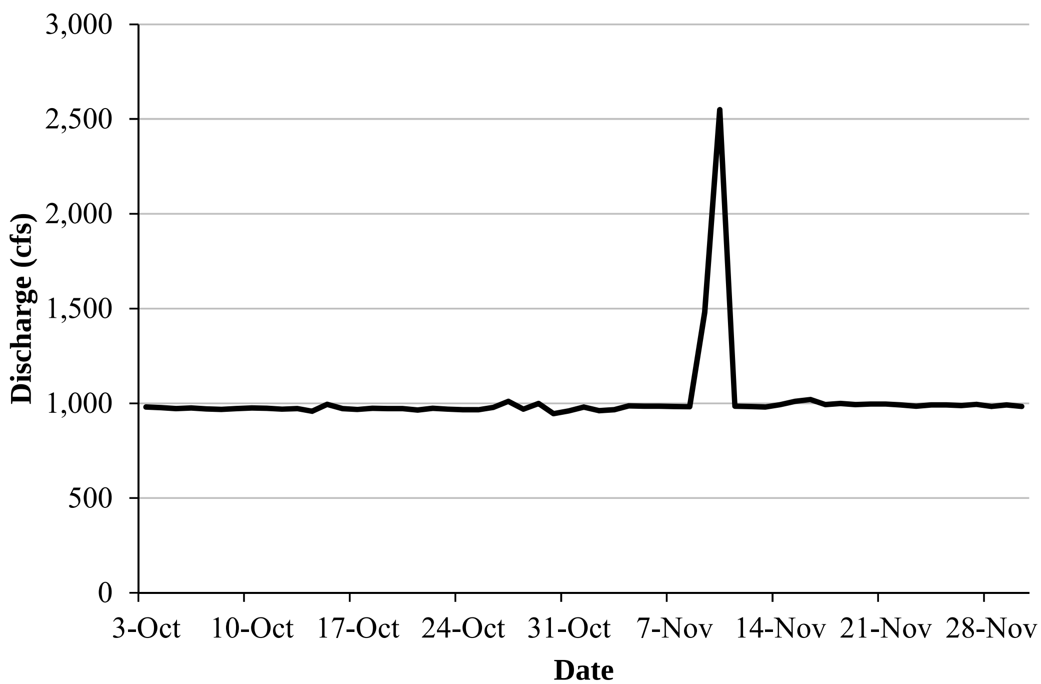

Figure 7. Mean daily discharge below Iron Gate Dam (USGS Gage 11516530) on the mainstem Klamath River during the 2016 Chinook Salmon carcass surveys.Note: Actual flows peaked around 3,200 cfs on November 9 but this figure only presents *mean daily* discharge.

Table 5. Fall Chinook Salmon spawning escapement estimates (and percent of total run) for each age class, Klamath River surveys, 2001–2016. Note: Adults are ages 3–5.

	Age				
Year	2 [a]	3	4	5	Adults [b]
2001	734 (9.4%)	3,479 (44.4%)	3,616 (46.2%)	0 (0.0%)	7,095
2002	424 (2.9%)	7,189 (49.9%)	6,743 (46.8%)	37 (0.3%)	13,970
2003	215 (1.7%)	5,957 (46.0%)	6,706 (51.8%)	80 (0.6%)	12,743
2004	184 (3.9%)	1,107 (23.5%)	3,349 (71.0%)	75 (1.6%)	4,531
2005	4 (0.1%)	2,092 (45.6%)	1,673 (36.5%)	816 (17.8%)	4,581
2006	567 (15.8%)	1,030 (28.7%)	1,873 (52.2%)	118 (3.3%)	3,021
2007	73 (1.3%)	5,032 (91.1%)	397 (7.2%)	21 (0.4%)	5,450
2008	836 (17.1%)	950 (19.4%)	3,075 (62.8%)	33 (0.7%)	4,058
2009	157 (3.6%)	3,162 (71.4%)	1,001 (22.6%)	107 (2.4%)	4,270
2010	176 (6.8%)	1,091 (42.4%)	1,294 (50.3%)	12 (0.5%)	2,398
2011	2,229 (45.7%)	1,133 (23.2%)	1,511 (31.0%)	6 (0.1%)	2,651
2012	1,186 (9.4%)	10,382 (82.2%)	1,058 (8.4%)	0 (0.0%)	11,440
2013	393 (5.3%)	2,951 (40.1%)	4,015 (54.6%)	0 (0.0%)	6,965
2014	1,271 (7.6%)	6,477 (38.7%)	8,862 (53.0%)	110 (0.7%)	15,449
2015	85 (3.4%)	1,036 (41.3%)	1,264 (50.4%)	122 (4.9%)	2,422
2016	39 (5.2%)	236 (31.6%)	471 (63.1%)	0 (0.0%)	707

[a] age 2 same as jacks

[b] sum of ages 3 to 5 may be one less than the adult total due to rounding to whole numbers

designated as jacks by the fork length cut-off was 1.1% lower than that determined to be 2-year olds by scale aging. The majority (63.1%) of the 2016 run returning to the study area were age-4 fish ($\widehat{N}_{age4}$ = 471).

Adult Chinook Salmon spawners in the mainstem Klamath River between IGD and the Shasta River confluence accounted for 24.4% of natural-area adult spawners in the mainstem Klamath River above Indian Creek, 6.8% in the Klamath River Basin above the Trinity River, and 5.1% in the entire Klamath River Basin in 2016 (Table 6). The proportion of adult spawners in the IGD–Shasta survey area relative to natural-area spawners above Indian Creek, above the Trinity River, and within the Klamath River Basin were the lowest in the 16-year history of these surveys. In the entire Klamath River Basin, fall Chinook Salmon adult spawners in the mainstem Klamath River between IGD and the Shasta River accounted for 4.0% of total adult escapement (hatchery and natural spawners) and 2.9% of the total adult in-river run (hatchery and natural spawners plus in-river harvest). The proportion of natural spawners in the IGD–Shasta study area has trended downward over the 16-year history of these surveys at all these scales, but only significantly above Indian Creek ($p < 0.001$), above the Trinity River ($p < 0.01$), and among Klamath River Basin natural spawners ($p = 0.04$; Appendix F). We hypothesize that this downward trend may be due to decreased survival in Chinook Salmon as juveniles since the survey area is a short distance upstream of a *C. shasta* infectious zone [River Mile 177–144 (rkm 285.5–232.3);

Table 6. Proportions of fall Chinook Salmon adult spawners in the mainstem Klamath River from IGD to the Shasta River confluence within different scales of the Klamath River Basin, 2001–2016. Data compiled from KRTAT (2003a, 2003b, 2004), KRTAT (2005–2009), and KRTT (2010–2016, 2017b).

Year	Mainstem Klamath R. natural spawners IGD to Indian Cr.	Klamath Basin natural spawners above Trinity R.	Klamath Basin natural spawners (includes Trinity Basin)	Klamath Basin escapement (hatchery + natural)	Klamath Basin in-river run [a] TOTAL
2001	72.6%	17.4%	9.1%	5.3%	3.8%
2002	73.3%	27.2%	22.2%	15.5%	8.9%
2003	77.7%	23.7%	14.8%	8.6%	6.7%
2004	84.9%	40.2%	18.5%	9.5%	5.7%
2005	89.5%	32.6%	16.5%	8.3%	7.0%
2006	67.3%	21.2%	10.0%	6.1%	4.9%
2007	79.3%	25.6%	9.0%	5.7%	4.1%
2008	69.3%	21.3%	13.1%	9.1%	5.7%
2009	53.7%	15.4%	9.6%	6.7%	4.2%
2010	65.0%	15.8%	6.4%	4.3%	2.6%
2011	67.7%	15.6%	5.8%	3.9%	2.6%
2012	62.8%	15.7%	9.4%	6.4%	3.9%
2013	57.2%	22.0%	11.8%	9.1%	4.2%
2014	69.1%	21.8%	16.2%	12.2%	9.6%
2015	32.7%	10.4%	8.6%	6.2%	3.1%
2016	24.4%	6.8%	5.1%	4.0%	2.9%

[a] includes natural spawners, hatchery spawners, and in-river harvest

Hallet and Bartholomew 2006; Fujiwara et al. 2011; True et al. 2016]. The spring release of juvenile Chinook Salmon from IGH typically occurs after most naturally produced fish have already migrated downstream and when infections can be most prominent. Therefore, if this hypothesis is true, we would expect to see a similar pattern for hatchery fish. Though not very strong, evidence supporting this hypothesis include 1) a downward trend in the number of hatchery-origin Chinook Salmon that returned to IGH from 2001 to 2016 and 2) a downward trend in the proportion of Chinook Salmon that were estimated to be of hatchery origin that returned to both IGH and the IGD–Shasta River study area from 2007 to 2016 (Appendix G). A number of larger-scale environmental factors may have also affected the population dynamic and determining the cause will require further investigations.

Hatchery Fish Contribution

From the 18 F_1- and D_2-condition ad-clipped carcasses encountered in 2016, 16 snout samples were collected and their CWTs were recovered and decoded (Appendix H). Production multipliers from recovered CWTs ranged from 4.00 (25.0% tag rate; codes 060422 from Brood Year 2011 and 068796 and 068797 from Brood Year 2012) to 4.05 (24.7% tag rate; code 060597 from Brood Year 2013). The estimated proportion of hatchery-origin spawners in the study area was 28.1% (n = 210; Table 7). The estimated proportions of hatchery-origin spawners ranged from 1.2% to 14.2% between 2001 and 2004 and from 22.7% to 48.1% between 2005 and 2015.

Table 7. Hatchery composition of fall Chinook Salmon spawning escapement in the mainstem Klamath River from IGD to the Shasta River confluence, based on carcass surveys, 2001–2016. See Appendix H for an explanation of the different methods used in estimating annual hatchery composition.

Year	Estimated hatchery-origin proportion	Escapement estimate	
		Total	Hatchery-origin
2001	11.8%	7,828	925
2002	14.2%	14,394	2,043
2003	3.8%	12,958	489
2004	1.2%	4,715	58
2005	26.6%	4,585	1,222
2006	22.7%	3,587	815
2007	39.8%	5,523	2,201
2008	37.0%	4,894	1,810
2009	25.1%	4,427	1,112
2010	48.1%	2,572	1,238
2011	40.9%	4,880	1,995
2012	45.3%	12,626	5,726
2013	31.7%	7,358	2,329
2014	24.5%	16,720	4,096
2015	26.2%	2,507	657
2016	28.1%	746	210

Consistent with previous years, the proportion of hatchery-origin Chinook Salmon in 2016 was highest in Reach 1 (23.7%), with the exception of Reach 7 (29.8%), which was based on a small sample size of nine fresh carcasses (Figure 8). We expect annual in-river spawning by hatchery-origin fish to be concentrated in the uppermost reach due to its immediate proximity to IGH. As also exhibited in previous years, the proportion of hatchery-origin spawners gradually trended downward, again with exception for Reach 7, from Reach 2 to Reach 8, ranging between 0.0% and 14.9%.

Egg Deposition

Egg deposition in the study area was estimated to be 1.0 million from 407 female Chinook Salmon in 2016 (Table 8). Egg deposition in 2016 was the lowest in the 16-year history of these surveys. Annual survival of these eggs during incubation depends on a variety of factors, including redd superimposition, temperature, dissolved oxygen, predation by invertebrates, fine sediment infiltration into the redd, periphyton biomass, and flow (McNeil 1964; Nelson et al. 2012).

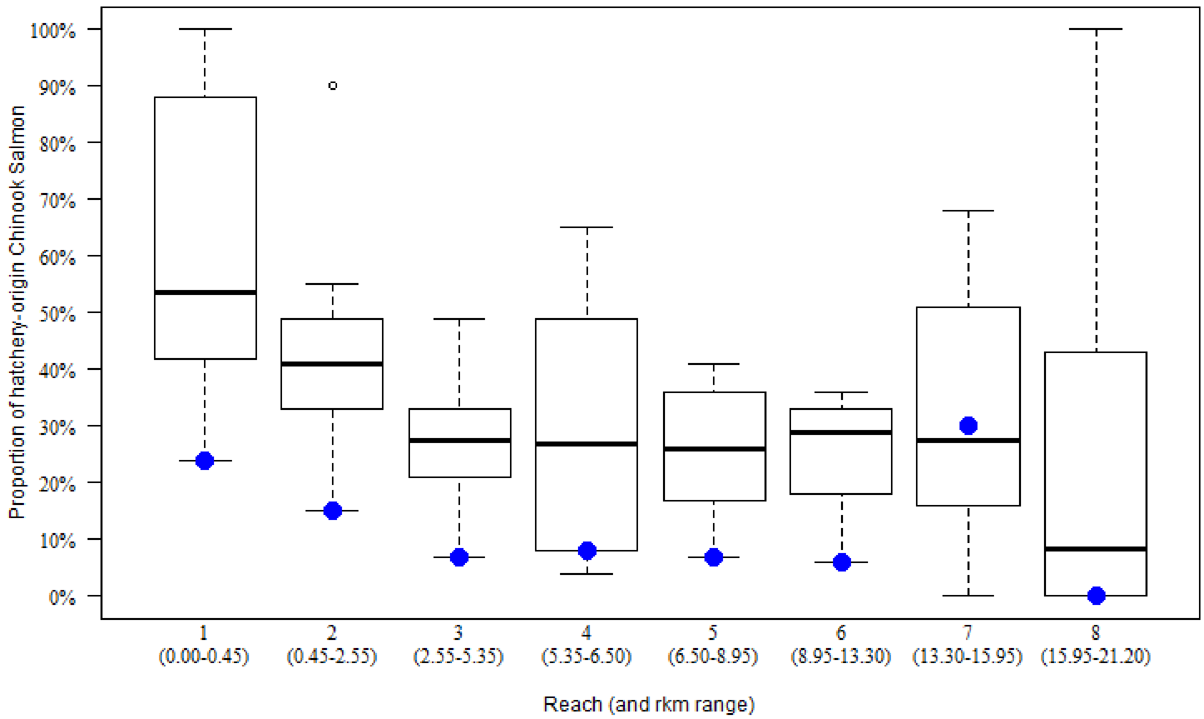

Figure 8. Box plot of proportions of hatchery-origin Chinook Salmon carcasses by reach, Klamath River surveys, 2007–2016. Data from 2016 are represented with blue circles.

Table 8. Egg deposition (N_e) by fall Chinook Salmon in the Klamath River from IGD to the Shasta River confluence, 2001–2016. F_{fs} and F_{ps} are escapement of fully and partially spawned females and n_e is the mean number of eggs produced per female at IGH.

Year	$\hat{F}_{fs}$	$\hat{F}_{ps}$	n_e	$\hat{N}_e$
2001	3,100	49	3,776	11,800,000
2002	6,589	310	3,656	24,700,000
2003	6,718	296	3,333	23,000,000
2004	1,948	181	3,572	7,300,000
2005	1,767	371	2,890	5,600,000
2006	1,506	120	3,080	4,800,000
2007	3,732	131	2,834	10,800,000
2008	2,255	74	3,513	8,100,000
2009	2,743	42	3,030	8,400,000
2010	1,291	17	3,024	3,900,000
2011	1,326	31	3,550	4,800,000
2012	6,206	291	3,402	21,600,000
2013	4,181	168	3,401	14,500,000
2014	7,935	528	3,349	27,500,000
2015	1,408	21	2,749	3,900,000
2016	380	27	2,590	1,000,000

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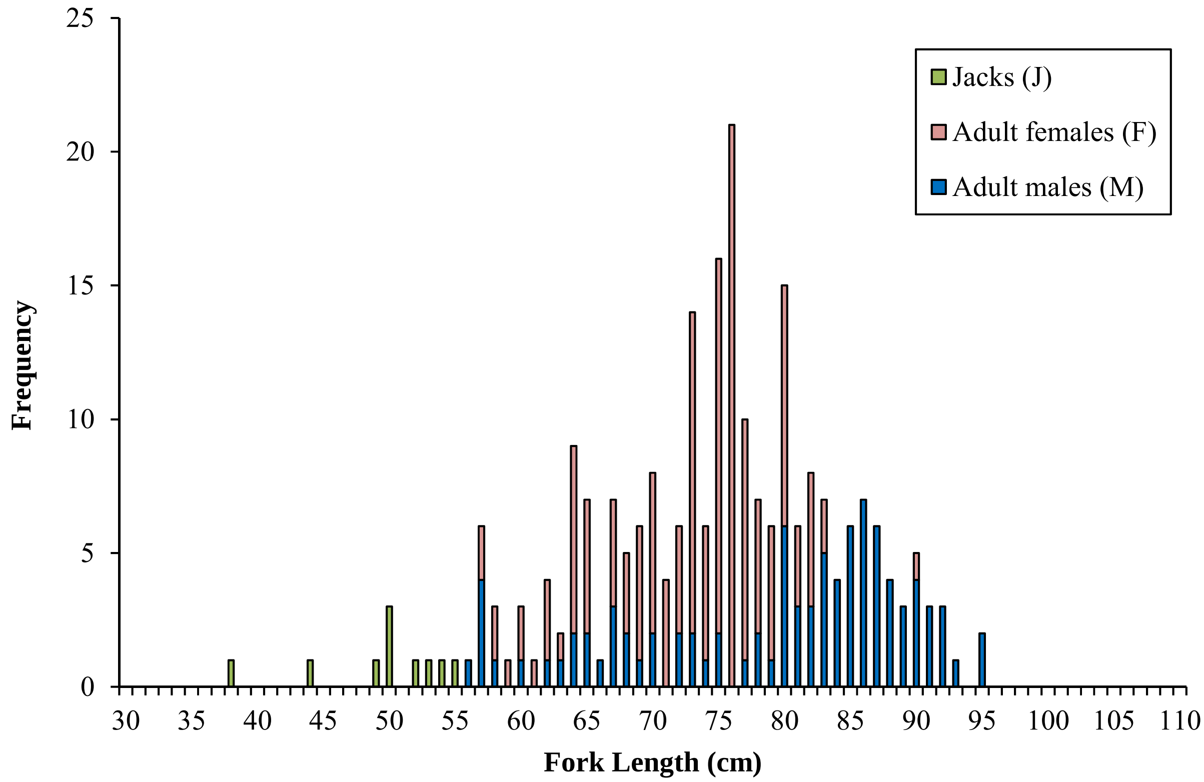
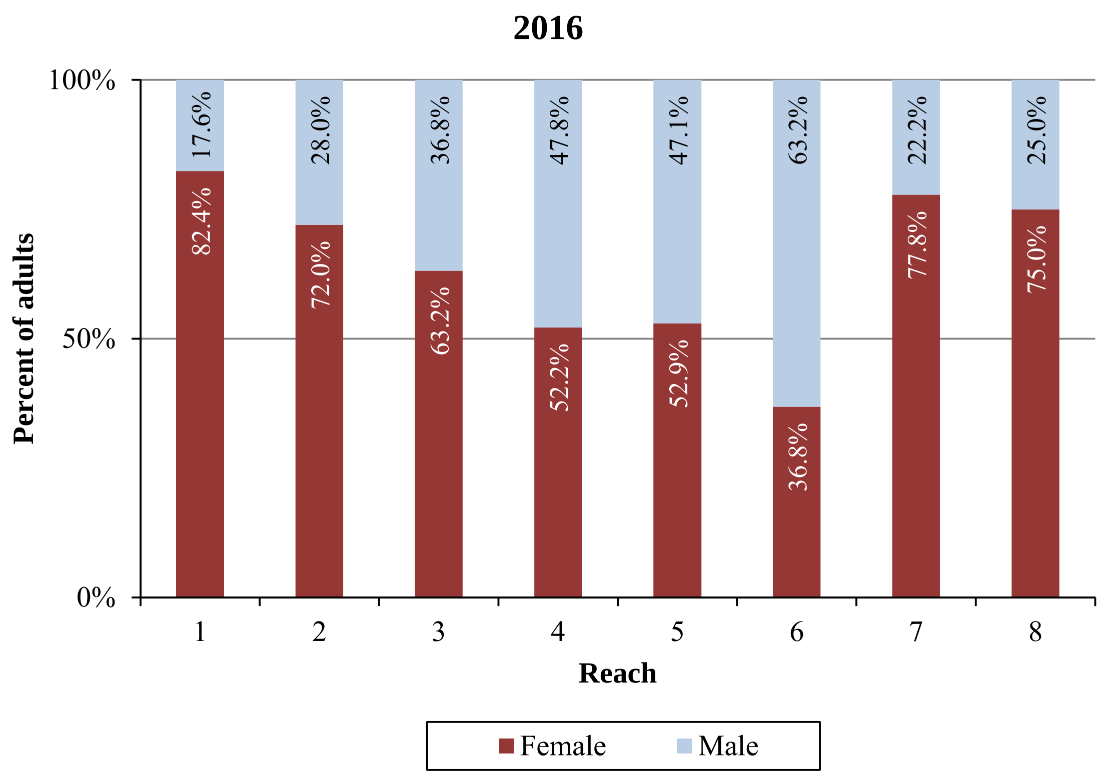
Appendices

Appendix A. Length-frequency of F_1- and D_2-condition fall Chinook Salmon carcasses, Klamath River surveys, 2016. n = 244 (n_F = 141; n_M = 93; n_J = 10).



Appendix B. Proportions of adult female and male Chinook Salmon carcasses by reach, Klamath River surveys, 2016.

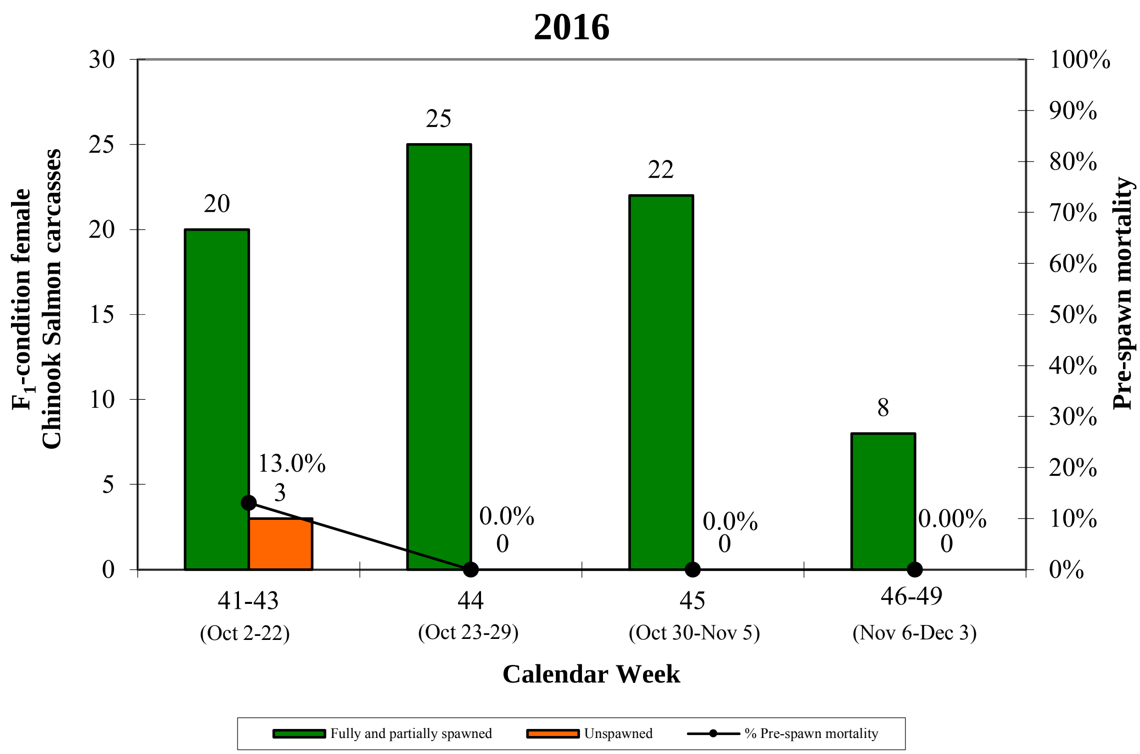


Appendix C. Proportions of female and male Chinook Salmon returning to IGH and the mainstem Klamath River, 2001–2016. IGH adult proportions were determined by first subtracting the jack percentage from the male percentage. Proportions of adult females and males were then recalculated from the remaining adult numbers. IGH data compiled from CDFG (2003), Hampton (2005), Richey (2006, 2007), Chesney (2007–2009), Chesney and Knechtle (2010–2017), and Pomeroy (2017).

	IGH returns					Mainstem carcasses	
	Overall [a]			Adults		Adults	
Year	Female	Male	Jacks	Female	Male	Female	Male
2001	49.1%	50.9%	2.1%	50.1%	49.9%	53.9%	46.1%
2002	48.9%	51.1%	5.2%	51.6%	48.4%	51.8%	48.2%
2003	51.3%	48.7%	0.9%	51.8%	48.2%	59.6%	40.4%
2004	46.0%	54.0%	8.8%	50.4%	49.6%	52.7%	47.3%
2005	50.4%	49.6%	0.3%	50.6%	49.4%	59.9%	40.1%
2006	44.0%	56.0%	16.8%	52.9%	47.1%	58.7%	41.3%
2007	60.9%	39.1%	0.9%	61.5%	38.5%	72.9%	27.1%
2008	42.3%	57.7%	21.5%	53.9%	46.1%	60.6%	39.4%
2009	53.9%	46.1%	8.4%	58.8%	41.2%	66.1%	33.9%
2010	50.2%	49.8%	9.4%	55.4%	44.6%	59.1%	40.9%
2011	26.5%	73.5%	52.9%	56.3%	43.7%	56.4%	43.6%
2012	52.5%	47.5%	3.8%	54.6%	45.4%	61.7%	38.3%
2013	48.5%	51.5%	8.9%	53.2%	46.8%	65.1%	34.9%
2014	49.0%	51.0%	4.1%	51.1%	48.9%	61.0%	39.0%
2015	57.0%	43.0%	2.7%	58.6%	41.4%	63.0%	37.0%
2016	47.9%	52.1%	5.8%	50.8%	49.2%	60.2%	39.8%

[a] Female and male proportions were calculated prior to distinguishing jacks and therefore total 100%

Appendix D. Weekly pre-spawn mortality from F_1-condition female fall Chinook Salmon carcasses, Klamath River surveys, 2016. Only F_1-condition carcasses were included since we can assume only those fish expired the week they were found. Calendar weeks 41–43 and 46–49 were combined since sample sizes were low.



Appendix E. Chinook Salmon Carcass Movement During the November 9–10, 2016, Pulse Flow Event at Iron Gate Dam

Introduction

A pulse flow event was implemented to strand spawned salmon carcasses on the river banks and to mobilize carcasses further downstream to decrease *Ceratonova shasta* spore input into the river below Iron Gate Dam where mainstem natural spawning is most concentrated. Flows out of Iron Gate Dam increased at approximately 15:00 on November 9, 2016, from about 1,000 cfs to a peak of around 3,200 cfs at approximately 04:00 on November 10 (Figure E1). Flows remained around 3,200 cfs for about 3 hours before decreasing back down to 1,000 cfs by about 22:00 on November 10.

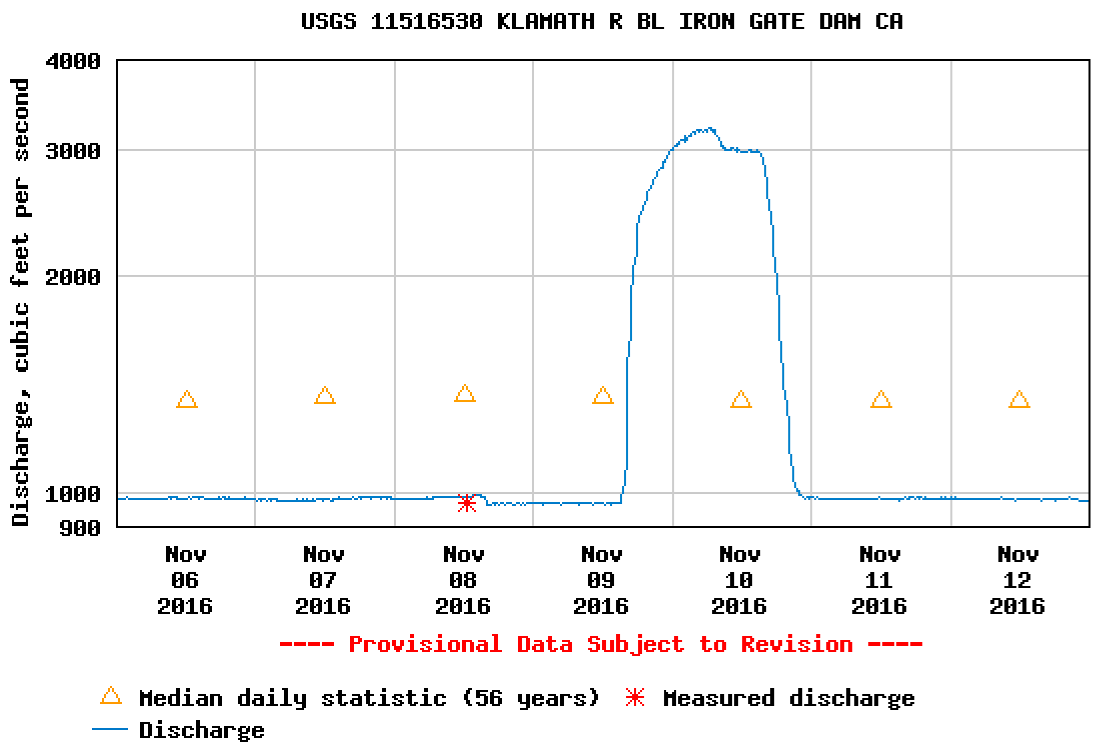


Figure E1. Klamath River discharge below Iron Gate Dam (USGS Gage 11516530) from November 6 to 12, 2016, the week of the pulse flow event.

Methods

Just prior to the pulse event, on November 8 and 9, carcass survey crews from the U.S. Fish and Wildlife Service and Yurok Tribal Fisheries Program collected GPS waypoints of uniquely marked Chinook Salmon carcasses in the 21.2-km section of the mainstem Klamath River between Iron Gate Dam and the Shasta River confluence. The crews also noted any carcasses observed already on the river banks and out of the water.

During the survey the week following the pulse flow event, on November 16 and 17, the crews again collected waypoints of marked carcasses in the same section of the river. The crews noted any carcasses observed on the river banks and out of the water. Crews that surveyed salmon redds below the Shasta River confluence also looked for marked carcasses.

Results

The locations of 75 carcasses were collected prior to the pulse flow event. Of these 75 carcasses, 17 (22.7%) were recaptured the following week. Of the 17 recaptured carcasses, 8 (47.1%) did not move or moved less than 0.1 km downstream, 3 (17.6%) moved between 0.1 and 0.5 km downstream, 3 (17.6%) moved between 1.0 and 2.0 km downstream, and 3 (17.6%) moved between 3.0 and 4.0 km downstream (Table E1).

The week prior to the pulse flow event, 3 carcasses were observed out of the water and on the bank. The week following the event, 2 carcasses were observed on the bank.

Table E1. Numbers and proportions of recaptured marked Chinook Salmon carcasses by the distances that they moved downstream following the November 9–10, 2016, pulse flow event on the Klamath River below Iron Gate Dam.

Distance moved (km)	Number	Proportion
<0.1	8	47.1%
0.1-0.5	3	17.6%
0.5-1.0	0	0.0%
1.0-2.0	3	17.6%
2.0-3.0	0	0.0%
3.0-4.0	3	17.6%
>4.0	0	0.0%

Discussion

Although the sample size of Chinook Salmon carcasses used for this analysis was sufficient (n = 75), a larger sample size from a larger run may have provided greater detail on the resulting redistribution of carcasses following a pulse flow event. The 2016 escapement estimate based on carcass counts and mark-recapture methodologies in this section of the river was the lowest in the 17-year history of these surveys. We also did not track carcass movement between weeks when flows remained stable. Therefore we are unable to assess the movement of carcasses caused directly by the event.

We believe carcasses did not move downstream and out of the carcass survey area based on the following:

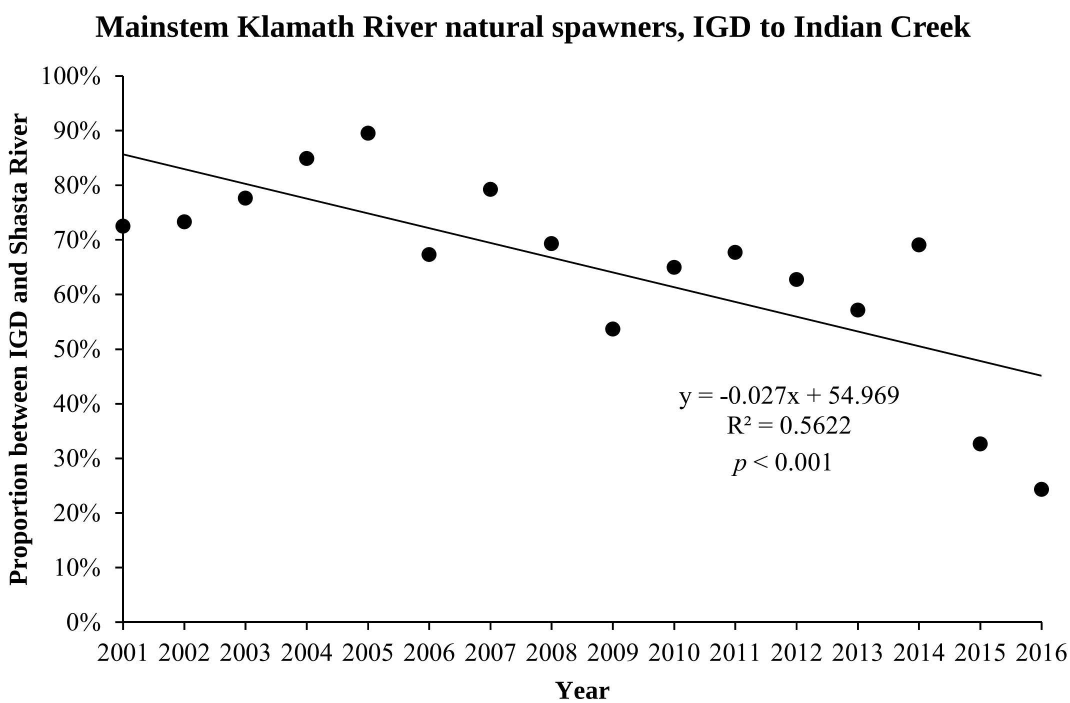
1. Salmon redds in the mainstem Klamath River are surveyed by the U.S. Fish and Wildlife Service and Karuk Tribe from Ash Creek (3.0 km downstream of the Shasta River confluence and 1.7 km downstream of the river access point used by the carcass crews) to Indian Creek in Happy Camp, California. The redd survey crews did not observe any of the marked carcasses following the pulse flow event.
2. If carcasses did not move out of the survey area, we would still expect to see small drop in carcass recapture rates due to some redistribution associated with the elevated flows. The recapture rate of carcasses tracked for the pulse flow

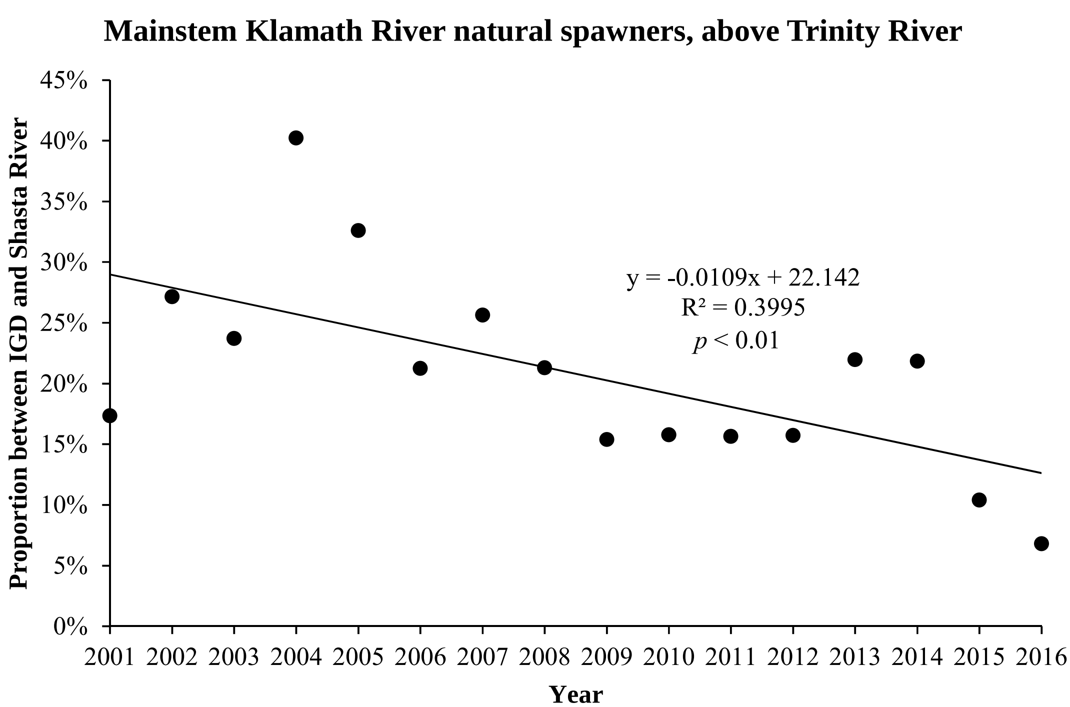
event was 22.7% compared to 34.8% for all carcasses over the entire survey season. We believe this difference between recapture rates was not large enough to indicate that carcasses left the survey area.

3. Most of the marked carcasses were too far upstream for them to travel far enough to leave the survey area. Seventy of the 75 carcasses marked before the pulse flow event were in the upper 13.3 km of the 21.2-km survey area. The furthest any of the recaptured carcasses travelled was 3.9 km downstream.

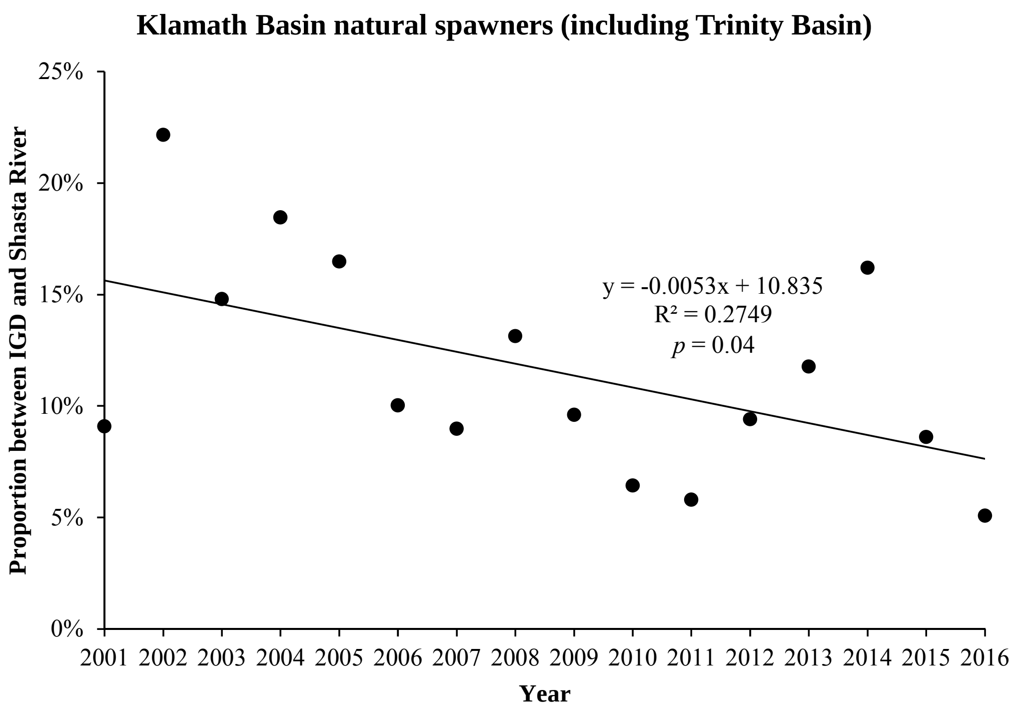
Low carcass movement and bank stranding following the pulse flow event may be attributed to the physical features of the Klamath River in this survey area. Large pools and eddies with slow-moving water even at elevated flows and sections of river banks lined with boulders provide depositories for moving carcasses to settle. Much of the river bank is steep or channelized which may have kept carcasses from being pushed up on to the banks and remaining there after the water level receded. We do not discount the possibility that carcasses may have been stranded in thick riparian areas and missed by the survey crews.

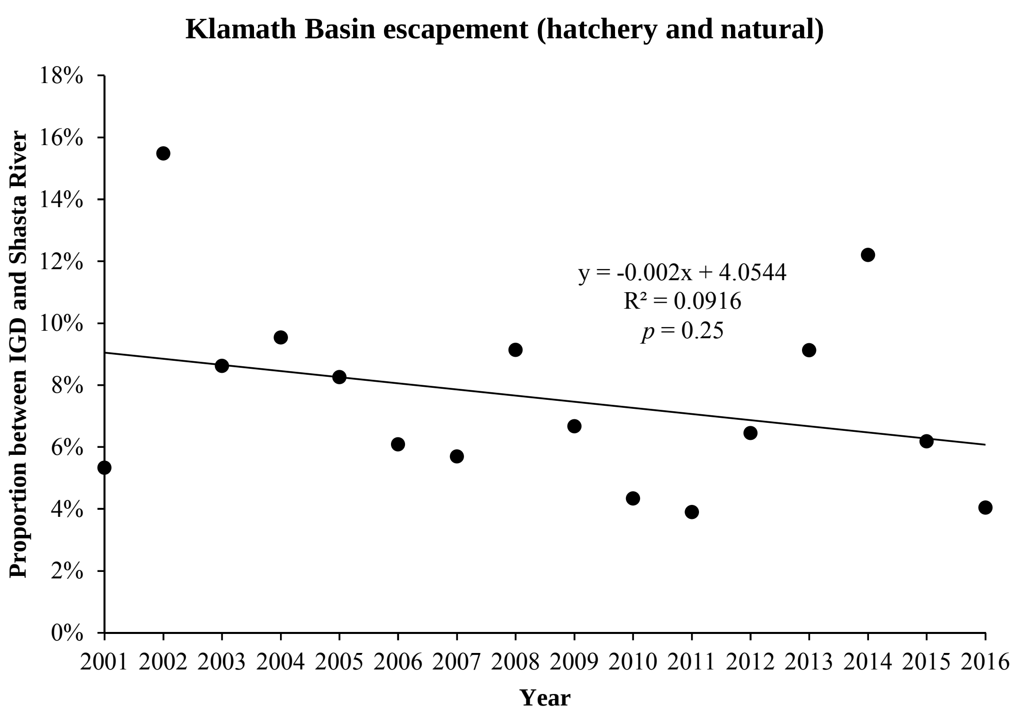
Appendix F. Proportions of fall Chinook Salmon adult spawners in the mainstem Klamath River from Iron Gate Dam to the Shasta River confluence within different scales of the Klamath River Basin, 2001–2016. Data compiled from KRTAT (2003a, 2003b, 2004), KRTAT (2005–2009), and KRTT (2010–2016, 2017b).



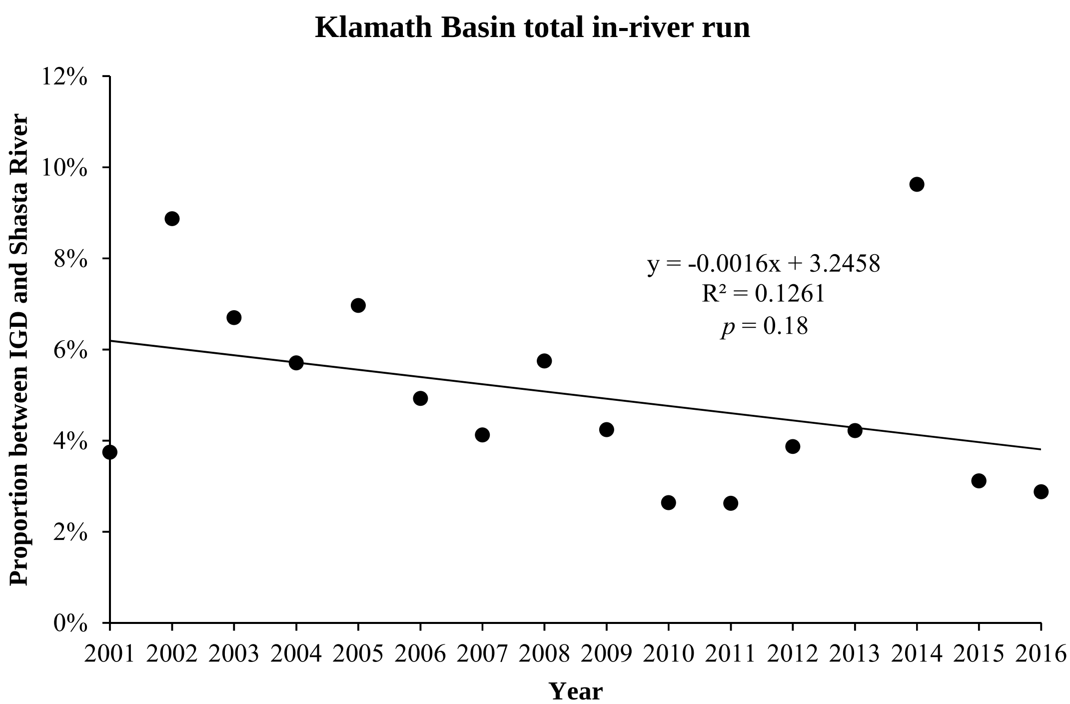


Appendix F (continued). Proportions of fall Chinook Salmon adult spawners in the mainstem Klamath River from Iron Gate Dam to the Shasta River confluence within different scales of the Klamath River Basin, 2001–2016. Data compiled from KRTAT (2003a, 2003b, 2004), KRTAT (2005–2009), and KRTT (2010–2016, 2017b).



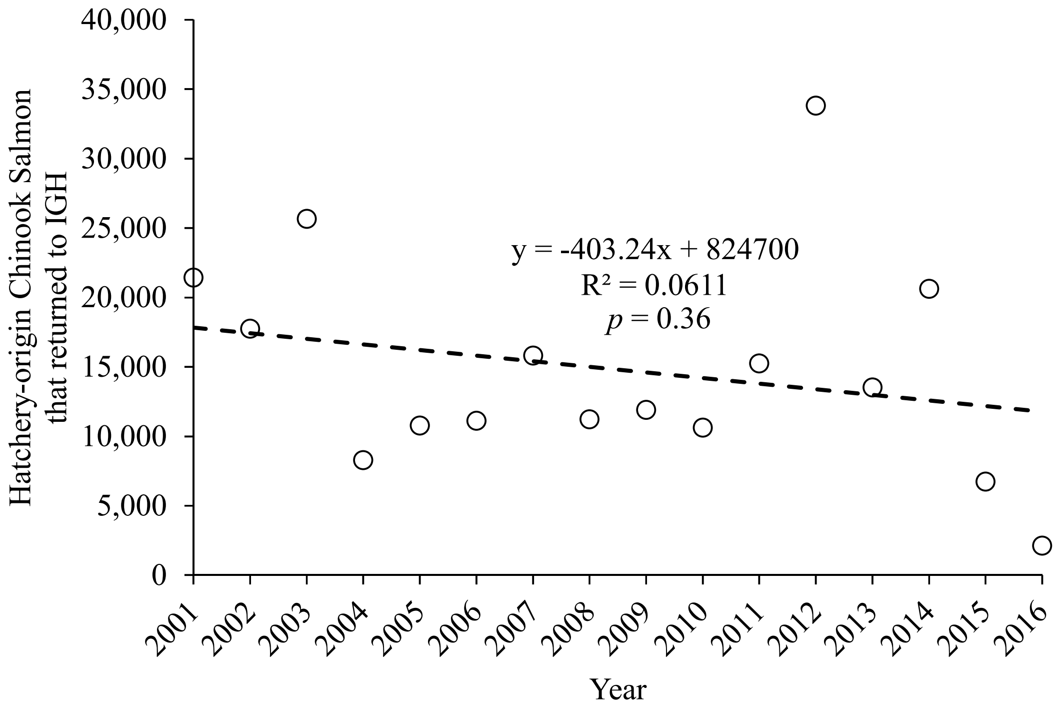


Appendix F (continued). Proportions of fall Chinook Salmon adult spawners in the mainstem Klamath River from Iron Gate Dam to the Shasta River confluence within different scales of the Klamath River Basin, 2001–2016. Data compiled from KRTAT (2003a, 2003b, 2004), KRTAT (2005–2009), and KRTT (2010–2016, 2017b).

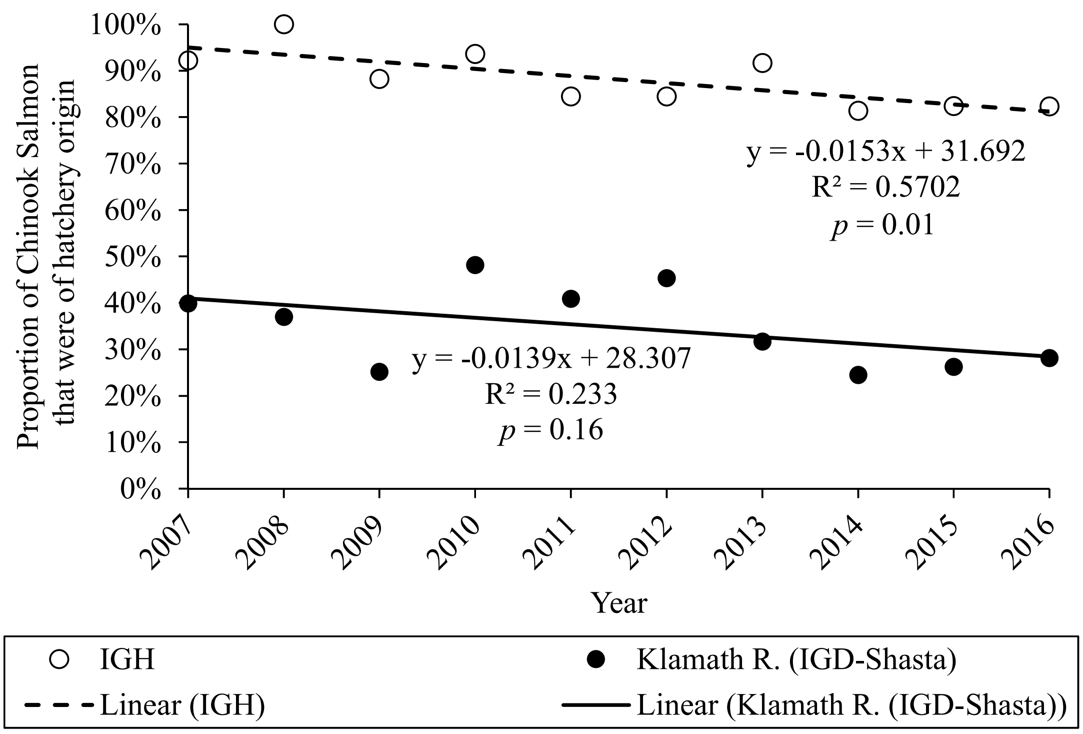


Appendix G. Numbers of hatchery-origin Chinook Salmon that returned to Iron Gate Hatchery (IGH) from 2001 to 2016 (A) and the proportion of Chinook Salmon that were of hatchery origin that returned to Iron Gate Hatchery and the Iron Gate Dam–Shasta River (IGD–Shasta) study area of the Klamath River from 2007 to 2016 (B).

A)



B)



Appendix H. Hatchery composition of fall Chinook Salmon in the mainstem Klamath River, IGD to the Shasta River confluence, based on carcass surveys from 2001 to 2016. Data from 2001 to 2010 does not match what was reported in Gough and Williamson (2012). Only data from F_1- and D_2-condition carcasses were used in this table whereas data from carcasses of all conditions were used in the mentioned report. As a result hatchery proportion estimates below are 1.0–2.8 times greater (difference: 0.2% lower to 19.5% higher). The adjustment was made for a better comparison with 2011–2016 results. Data from 2011 to 2016 is presented in a separate table since a different methodology was used to calculate hatchery composition.

Year	Total carcass capture	Ad-clip carcass capture [a]	Proportion of hatchery-produced fish with ad-clip at IGH	Estimated capture of hatchery-origin carcasses	Estimated hatchery-origin proportion [b]	Escapement estimate	
						Total	Hatchery only
	C	$Adobs$	$P(AD\,\vert H)_{IGH}$	$\hat{H}$	$\hat{P}(H)$	$\hat{N}$	$\hat{N}_H$
2001	1,125	5	3.76%	133	11.8%	7,828	925
2002	2,343	13	3.98%	333	14.2%	14,394	2,043
2003	1,664	4	5.73%	63	3.8%	12,958	489
2004	897	1	9.01%	11	1.2%	4,715	58
2005	386	8	7.78%	103	26.6%	4,585	1,222
2006	551	8	6.27%	125	22.7%	3,587	815
2007	1,237	23	4.66%	493	39.8%	5,523	2,201
2008	1,046	24	6.20%	387	37.0%	4,894	1,810
2009	1,153	20	6.90%	290	25.1%	4,427	1,112
2010	472	20	8.80%	227	48.1%	2,572	1,238

[a] In 2002, 2003, 2006, and 2007 there were high discrepencies between banks in ad-clip detections. For these years AD_{obs} was predicted by expanding ad-clipped carcass capture from the bank with the higher number proportionately by the capture of all carcasses on each bank.

[b] $\hat{P}(H) = \hat{H}/C$

Year	Total carcass capture	Ad-clip carcass capture	Snout samples from ad-clip carcasses	CWTs recovered	CWTs decoded	Estimated capture of hatchery-origin carcasses	Estimated hatchery-origin proportion	Escapement estimate	
								Total	Hatchery only
	C	AD_{obs}	AD_{sample}	AD_{cwt}	AD_{code}	$\hat{H}$	$\hat{P}(H)$	$\hat{N}$	$\hat{N}_H$
2011	761	77	75	75	69	311	40.9%	4,880	1,995
2012 [c]	1,491	140	131	124	122	676	45.3%	12,626	5,726
2013	1,188	100	97	86	86	376	31.7%	7,358	2,329
2014 [c]	2,555	111	107	101	100	626	24.5%	16,720	4,096
2015	580	40	37	35	32	152	26.2%	2,507	657
2016	257	18	16	16	16	72	28.1%	746	210

[c] systematic sampling rates have not yet been applied to ad-clip and CWT values (AD_{obs}, AD_{sample}, AD_{cwt}, and AD_{code})