U.S. Fish & Wildlife Service

Arcata Fisheries Data Series Report DS 2015-46

Fall Chinook Salmon Run Characteristics and Escapement for the Mainstem Klamath River, 2012

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December 2015

Funding for this study was provided by the Klamath River Fish Habitat Assessment Program administered by the Arcata Fish and Wildlife Office.

The Arcata Fish and Wildlife Office Fisheries Program reports its study findings through two publication series. The **Arcata Fisheries Data Series** was established to provide timely dissemination of data to local managers and for inclusion in agency databases. The **Arcata Fisheries Technical Reports** publishes scientific findings from single and multi-year studies that have undergone more extensive peer review and statistical testing. Additionally, some study results are published in a variety of professional fisheries journals.

key words: Area-Under-The-Curve, Carcass, Chinook, Egg Production, Escapement, Klamath, Mark-Recapture, Pre-Spawn Mortality, Salmon Spawner

The correct citation for this report is:

Gough, S.A., and N.A. Som. 2015. Fall Chinook Salmon Run Characteristics and Escapement for the Mainstem Klamath River, 2012. U.S. Fish and Wildlife Service. Arcata Fish and Wildlife Office, Arcata Fisheries Data Series Report Number DS 2015–46, Arcata, California.

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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 2012 spawning season to estimate escapement and characterize the age and sex composition and spawning success of the run. Using postmortem mark-recapture methods and an area-under-the-curve estimator, estimated spawning escapement for this section of the mainstem Klamath River in 2012 was 12,626 fish. Based on this estimate and age composition data from scale samples, spawning escapement by year-class was made up of 1,186 (9.4%) jacks (age-2) fish, 10,382 (82.2%) age-3 spawners, 1,058 (8.4%) age-4 spawners, and no (0.0%) age-5 spawners. An estimated 45.3% of the fish that spawned in the surveyed reach were of hatchery origin. The adult female–male ratio was 1.7:1. Pre-spawn mortality of females was 10.7%. Estimated egg deposition by adult females in the study area was 21.6 million.

Introduction

The Klamath River Basin (Figure 1) historically supported large runs of Chinook Salmon *Oncorhynchus tshawytscha*, Coho Salmon *O. kisutch*, and Steelhead *O. mykiss* (Leidy and Leidy 1984). 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.

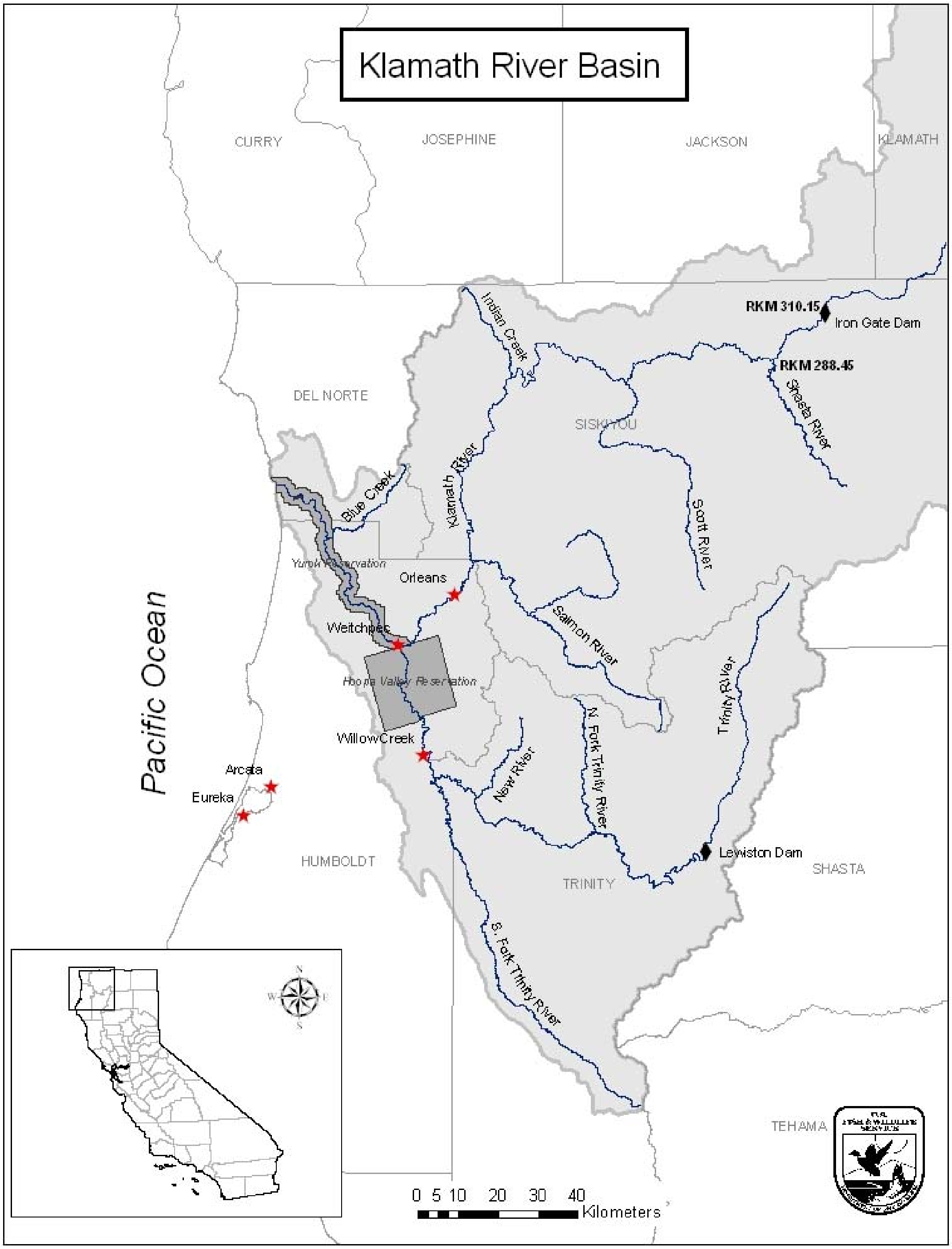


Figure 1. Klamath River Basin, northern California. The mainstem Klamath River carcass survey study area extends from Iron Gate Dam to the Shasta River confluence.

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 based on expanded redd counts assuming each redd equals one adult female and one adult male (Magneson 2008). This effort was initiated to supplement the other fall Chinook Salmon spawning escapement and harvest monitoring that had been initiated in the Klamath River Basin in 1978 (CDFW 2013). 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). From concurrent surveys in 2001 to 2004 and 2006, Petersen tag-recovery-based estimates and redd counts from IGD to the confluence of the Shasta River were compared. Estimates of successfully spawned adult females were 3.3 to 4.8 times higher than redd counts over this stretch of the river (Gough and Williamson 2012). We assumed Petersen estimates were the more accurate from 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.

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 effort required to complete the previously used mark-recapture protocol amidst this run's size projection would have been unfeasible given staffing, equipment, and time constraints needed to conduct the surveys. In response, we developed a methodology and protocol for an area-under-the-curve (AUC) escapement estimate. Incorporating weekly systematic sampling rates based on the anticipated number of carcasses, this new methodology allows the ability to complete weekly surveys regardless of run size.

The primary purpose of this project was to provide the Klamath River Technical Team (KRTT) a fall Chinook Salmon spawning escapement estimate 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. 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 for the less densely used spawning reaches to establish an estimate of escapement for the mainstem Klamath River (KRTT 2012). Accurate determination of the numbers of spawners within this reach is also needed for an ongoing outmigrant fry study

(Chamberlain and Williamson 2006) 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 is the 21.20-rkm section of mainstem Klamath River between IGD (the upper limit of anadromy) and the Shasta River confluence, and was divided into eight reaches (Figure 2; Table 1). Reaches were delineated based on previously mapped concentrations of redds with boundaries at distinguishable landmarks.

Methods

Data were collected in a cooperative effort between AFWO and the Yurok Tribal Fisheries Program (YTFP). Weekly surveys were conducted from October 10 through December 3, 2012, by one AFWO crew and one YTFP crew, each comprised of three members. Crews 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. Each crew surveyed their same respective bank throughout the survey season. 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 depth. We only recorded Secchi depth once per week since 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, depth, 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.

The depth at which carcasses were recovered was estimated and recorded using a scale of 0 to 3:

- '0' = on the bank or floating at the surface;
- '1' = subsurface to 3 ft deep;
- '2' = 3 to 6 ft deep;
- '3' = over 6 ft deep.

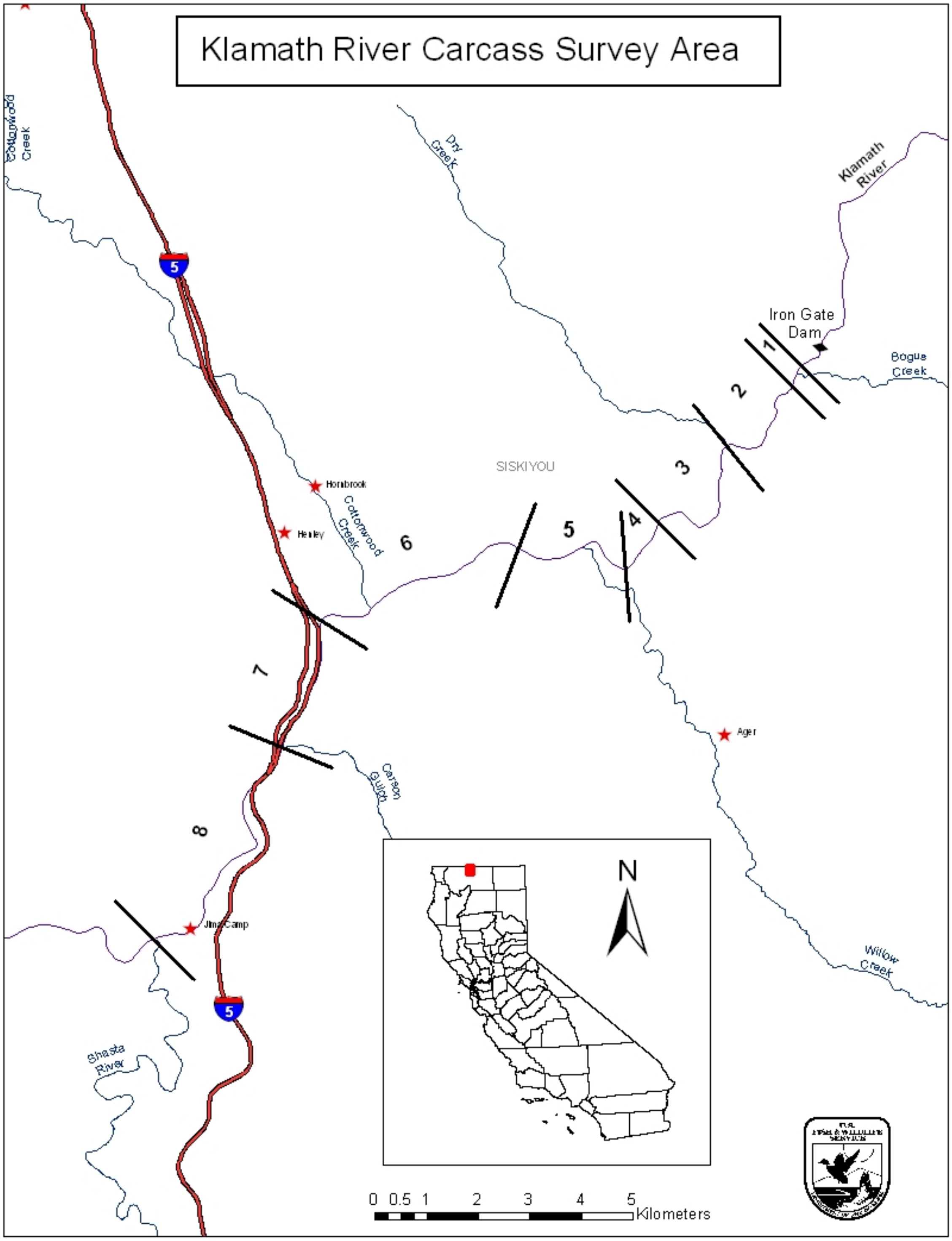


Figure 2. Klamath River carcass survey area from IGD to the Shasta River confluence with reaches delineated. Reach 1 begins at the first river access below IGD. Little to no spawning occurs between the dam and the access point.

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	(rkm)	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

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 rotten (N) 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 = rotten (decayed beyond D_2).

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-condition carcasses were believed to have expired more than one week prior to capture. Fork lengths were not recorded from N-condition carcasses.

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 male and female carcasses were assigned a spawning condition value based on a scale of 1 to 4 (Table 2). 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 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 can 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 (2013). The KRTT reviews data provided by various collaborators and jointly decides which method best represents the jack to adult proportions for each recovery 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 (2013) age composition analysis.

Table 2. Spawning condition scale used to assess spawning success in salmon carcasses

Condition	Female	Male
1	spawned out or less than one-third of eggs retained	flaccid strap-like gonads
2	partially spawned with one- to two-thirds of eggs retained	(not used)
3	unspawned or more than two-thirds of eggs retained	gonads solid and full
4	spawning condition could not be determined	spawning condition could not be determined

Escapement Estimate

Counts of carcasses were conducted weekly over the entire study area throughout the active spawning period. Every carcass was counted as long as surveys could be completed within the survey week. When the number of carcasses became too high for the crews to complete the survey within the work week, systematic sampling was employed to ensure completion. Sampling rates were derived using historic records of carcass data collection and the adult return apportioned to the mainstem Klamath River was projected according to historic spawning distribution patterns (CDFW 2013). When systematic sampling was employed, all carcasses were counted but carcass data (location, condition, etc.) was only taken on sampled carcasses. In 2012 a systematic sampling rate of 1-in-3 was used in Reaches 1 through 5 during Survey Weeks 5 and 6.

All sampled F_1- and D_2-condition carcasses were marked with uniquely numbered aluminum tags attached to a hog ring clamped around the lower jaw, allowing the fate of individual carcasses to be tracked over time and space. Tags were not applied to ad-clipped carcasses since removing the snout leaves the jaw poorly secured to the rest of the body. Tagged carcasses were replaced near the location and depth where they were found. N-condition carcasses were sampled, tallied, and replaced. Recaptured (previously tagged) carcasses were examined and the following data were recorded: reach, tag number, location, condition, and depth. Recaptured carcasses were replaced to allow the possibility of multiple recaptures.

An area-under-the-curve (AUC) estimator was used to estimate escapement in the study area, a widely used method for estimating salmon escapement (Manske and Schwarz 2000). We chose to adopt an AUC methodology because it allowed great flexibility for handling systematically sampled carcasses in some weeks (due to the large predicted run-size estimate, as described above) and missed weekly samples due to weather, river discharge, or logistical constraints. We used the most commonly applied AUC method, trapezoidal AUC, which linearly interpolates between observed counts (Millar et al. 2012).

AUC estimators generally require repeated counts of individuals, estimates of residence time, and estimates of observer efficiency (Hilborn et al. 1999). In our case, residence time is referred to as ‘carcass survey life’ and defined as the amount of time, in terms of weeks, from when a live fish expires (i.e., becomes a carcass) until the carcass decomposes to a state in which it is no longer intact or detectable. Though AUC methods are widely accepted and used by salmon managers (Millar et al. 2012), some have questioned the approach due to 1) the difficulty of obtaining estimates of residence time and observer efficiency and 2) lack of a clear way to incorporate the uncertainty in residence time and observer efficiency into final escapement estimates (Szerlong and Rundio 2008). In our analysis we address each of these critiques in the construction of our estimates. As described below, we compute data-driven estimates of carcass survey life and observer efficiency (i.e., error), and incorporate the variation of these estimates into our escapement estimates via a bootstrap approach (Manske and Schwarz 2000).

The assumptions of our estimation method include:

1. Carcass arrivals and departures occur between weekly surveys (not during), and carcass departures are permanent. Our trapezoidal AUC method further assumes that carcass arrivals between surveys occur uniformly.
2. Uniquely numbered tags are used to mark carcasses and recaptured tags are correctly identified.
3. Each fish that expires and becomes a carcass within the spatial domain of the survey is immediately available for capture.
4. Captures and departures are independent among carcasses and between surveys.
5. Mean carcass survey life was the same for both left and right river banks.
6. Mean carcass survey life was constant throughout the survey season.
7. Time wise, the survey length encompasses the entire arrival and departure period.

The last assumption can be relaxed for the trapezoidal AUC methodology by combining periods of zero observed carcasses with weeks directly before and after the period of data collection. In regard to the carcass survey life estimates, early carcasses that arrive well before the first sample (but remain detectable) or carcasses that remain in the system long after the survey period would have their carcass survey life underestimated, though the consequences of this in our data are minor. First, the survey period commences and ends when carcasses counts are relatively small, at the tail ends of the spawning season. Second, the survey period encompasses the weeks when the vast majority of carcasses enter the system, and the average carcass survey life is unlikely to be effected by a small number of carcasses at each end of the survey season.

We used the following set of steps to create our estimate of total carcasses and its 95% confidence interval.

Step 1: Initial weekly estimates

To construct the annual estimates, we began by constructing a time series of weekly carcass estimates that account for observer error. We started with the weekly carcass counts and considered each week an individual mark-recapture experiment. Weekly counts were then adjusted by the recaptured fraction to construct weekly Chapman-type estimates of carcass abundance:

$$\widehat{N}_{i,b} = \frac{(M_{i,b} + 1)(C_{i,b} + 1)}{R_{i,b} + 1} - 1 \ ,$$

where *i* indexes week, *b* indexes river bank (left or right), *N* is carcass abundance, *M* is the total number of new carcass marks applied the prior week, *C* is the total number of carcasses counted, and *R* is the number of recaptured marks that were applied the previous week (Chapman 1951). Given the low numbers of marks available for recapture during each of Survey Weeks 2 and 3, we combined the numbers released and recaptured for those two weeks and assumed the observer error was constant among those weeks. Further, because no carcasses were marked and available for recapture during the very first week of the survey season, we assumed that observer error in Survey Week 1 was equal to that from Survey Weeks 2 and 3. In the few weeks where systematic sampling occurred, the number of recaptured carcasses was expanded by the systematic rate.

Step 2: Constructing season-wide estimate of carcass-weeks

This time series of weekly abundance estimates was then expanded to total carcass-weeks by summing over the product of differences in time between counts and the average of adjacent weekly counts, and then adding adjustments for non-zero counts in the first and last weeks of the survey season (Millar et al. 2012). In our case, subsequent surveys were one week apart, and given we used single-week time steps in the carcass survey life analysis described below, all time differences were set to one to obtain the following AUC estimate for each bank:

$$\widehat{AUC}_b = \sum_{i=2}^{n} \frac{\hat{N}_{i,b} + \hat{N}_{i-1,b}}{2}(t_i - t_{i-1}) + \frac{\hat{N}_{1,b}}{2} + \frac{\hat{N}_{n,b}}{2},$$

where n is the total number of survey weeks, t represents the numeric survey week, and N, i, and b are defined as above.

Step 3: Estimating carcass survey life

To estimate the average carcass survey life (the time that a carcass was available for sampling) over the season, we applied the methods of Pledger et al. (2009) for estimating stopover duration (i.e., residence time), which relies on maximum likelihood methods and uses mark-recapture histories. Sampling effort (full or systematic) was incorporated into the model for carcass survey life.

To implement the methods of Pledger et al. (2009), we began by constructing a matrix that summarizes the mark-recapture histories of all marked carcasses. Each individual carcass that was marked during the survey period contributes a row to this matrix, and the number of matrix columns is defined by the number of sampling occasions (e.g., the number of weeks the surveys were conducted). Each matrix cell consists of binary entries indicating which weeks each individual carcass was observed by the survey crew (a ‘1’ if observed, a ‘0’ if not observed).

The mark-recapture histories matrix represents the observed data, which is known to be incomplete due to imperfect detection. Another matrix was constructed in a similar fashion, but with perfect detection. By representing all weeks that individuals were available for detection, this matrix would also indicate the length of time individuals remained, or were present. The basis for estimating average survey life lies in translating the mark-recapture histories into presence histories, where presence is defined as the time period a carcasses was present and potentially observable by survey crews.

Pledger et al. (2009) construct the likelihood for stopover duration by first conditioning the probability of observed mark-recapture histories on the unobserved presence histories, and then derive the unconditional mark-recapture history probabilities by integrating over all possible presence histories. Their model is quite flexible, in that the probability a carcass remains in the system can be assumed constant over weeks, can be a function of covariates that vary over time, or can be a function of age (time since arrival). Given that carcasses decay and become unobservable over a period of time, we fit the version of the model that varies the probability a carcass remains in the system as a function of time since arrival.

Step 4: Computing estimate of total carcasses

The annual carcass estimate $\widehat{N}$ was computed by taking each $\widehat{AUC}_b$, dividing by average carcass survey life (SL), and then summing estimates across banks:

$$\widehat{N} = \sum_b \frac{\widehat{AUC}_b}{\overline{SL}} \ .$$

Step 5: Computing confidence intervals via bootstrapping

Given the array of data and estimates compiled to obtain our annual carcass estimate, we relied on a bootstrap procedure to estimate the sampling variability of our estimate. We applied the following bootstrap procedure 2,000 times and took the 2.5th and 97.5th percentiles of the resulting distribution of estimates as a 95% confidence interval for our annual carcass estimate.

5.1: Computing $R_{boot;i,b}$ and $\widehat{N}_{boot;\,i,b}$, parametric bootstrap of observer error data

As the number of marked carcasses recovered in each week represents a binomial experiment, we created a bootstrapped value for number of marked carcasses recovered in each week, for each bank, by drawing a random binomial variable with index parameter, $M_{i,b}$, and probability of success parameter, $R_{i,b}/M_{i,b}$

$$R_{boot;i,b} \sim Bin\left(M_{i,b}, \frac{R_{i,b}}{M_{i,b}}\right),$$

where *boot* indicates a bootstrapped value. After computing $R_{boot;i,b}$ for each bank and week, we substituted each $R_{boot;i,b}$ for $R_{i,b}$ in the equation from Step 1 to obtain $\widehat{N}_{boot;\,i,b}$ for each bank and week.

5.2: Computing $\widehat{AUC}_{boot;b}$

Each $\widehat{N}_{boot;\,i,b}$ was substituted for each $\widehat{N}_{i,b}$ in the equation from Step 2 to obtain $\widehat{AUC}_{boot;b}$.

5.3: Computing SL_{boot}

To obtain bootstrap estimates of carcass survey life, we applied a nonparametric bootstrap approach. We sampled, with replacement, the rows of the mark-recapture histories matrix to obtain a bootstrapped capture histories matrix. We applied the methods of Step 3 using this matrix to obtain SL_{boot}.

5.4: Computing $\widehat{N}_{boot}$

We substituted each $\widehat{AUC}_{boot;b}$ for $\widehat{AUC}_b$ and SL_{boot} for SL in the equation from Step 4 to obtain a bootstrapped estimate of the carcass total ($\widehat{N}_{boot}$).

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:

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

Individual age class estimates were calculated likewise:

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

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, Coho Salmon, and Steelhead. A proportion, varying with release group, of the juvenile Chinook Salmon produced at the hatchery are injected with a coded-wire tag (CWT) and adipose fin-clipped (ad-clip). CWT numbers 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 likely under-recognition 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 2013):

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

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 ($H_{code(i)}$):

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

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

Egg Deposition

The estimate of adult females, attained by multiplying the escapement estimate by the proportion of adults from scale analyses and the proportion of females from the adult female–male ratio, was multiplied by predicted egg production to derive total egg deposition (N_e) in the study area. 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 2012 average egg production (n_e = 3,402) per female at IGH as a surrogate for the mainstem spawning female Chinook Salmon (Pomeroy 2015). Escapement estimates of fully spawned females (F_{fs}) multiplied by 3,402 (n_e) were added to escapement estimates of partially spawned females (F_{ps}) multiplied by 1,701 (one-half of n_e) to yield total egg deposition in the study area:

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

Results and Discussion

Temporal and Spatial Distribution of Carcasses

A total 1,491 F_1- and D_2-condition carcasses were counted during 2012 surveys, of which 1,167 were tagged (Table 3). The peak of new carcass observations, which typically occurs from calendar week 44 to 46, occurred in calendar week 45. Carcass density was highest in the uppermost reach of the survey area and declined steadily downstream of Reach 2 (Figure 3).

Length Distribution

The 2012 jack–adult size cut-off (58 cm FL) was determined after the sampling season by the KRTT (2013; Figure 4; Table 4). Of the 119 measured fish less than or equal to 58 cm FL, none were female. Mean fork lengths of adult females, adult males, and jacks were 71.0 cm, 78.0 cm, and 51.7 cm, respectively (Table 4).

Adult Female–Male Ratio

The percentage of females among handled adult carcasses was 63.6% in 2012 (adult female–male ratio = 1.7:1; Figure 5). The percentage of females ranged from 51.8% (adult female–male ratio = 1.1:1; in 2002) to 72.9% (adult female–male ratio = 2.7:1; in 2007) in 2001 to 2011. These ratios likely underestimate 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 mobilization of males is supported by our observed decrease in the female–male ratio moving downstream within the study area (Appendix A). Adult females were more abundant than males in reaches 1 through 5, while males were more abundant in reaches 6 through 8. Compared to adult Chinook Salmon returning to IGH in 2001 to 2012, 0.1% to 11.4% more females were observed among mainstem carcasses each year (Appendix B).

Table 3. Number of F1- and D2-condition fall Chinook Salmon carcasses captured by calendar week, Klamath River surveys, 2001 to 2012. Annual peak counts are in bold font. Dashes indicate no survey conducted.

Year	Calendar week 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

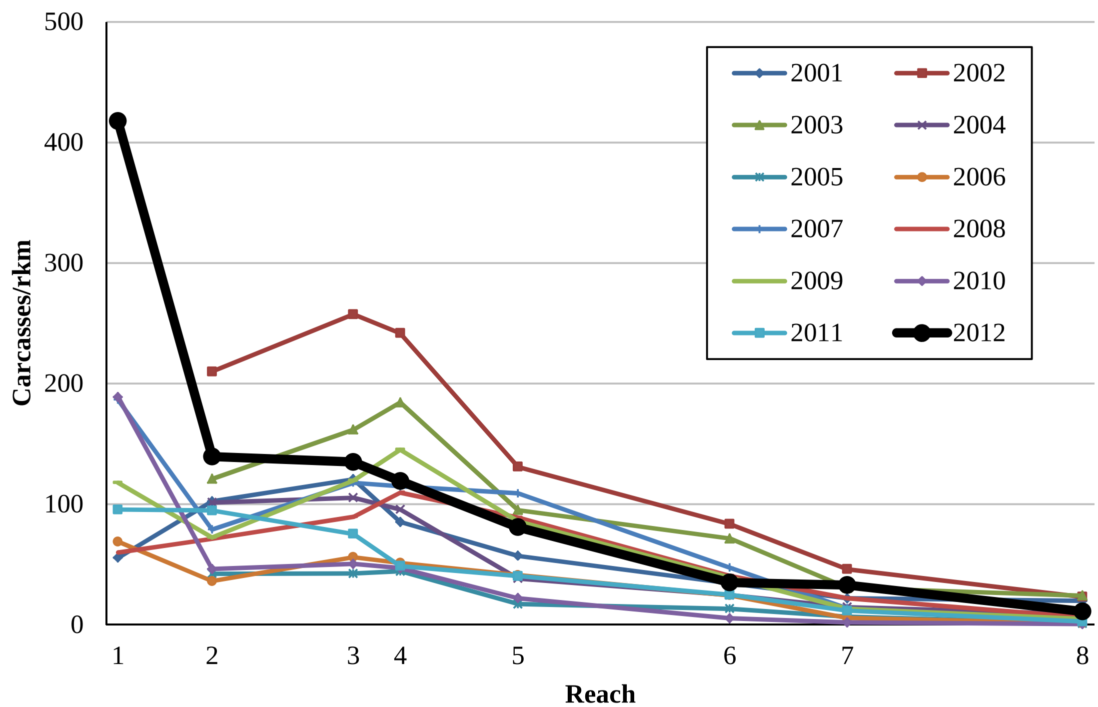


Figure 3. Fall Chinook Salmon carcass density (F1- and D2-condition only) by reach, Klamath River surveys, 2001 to 2012. Reach 1 was not surveyed in 2002 to 2005.

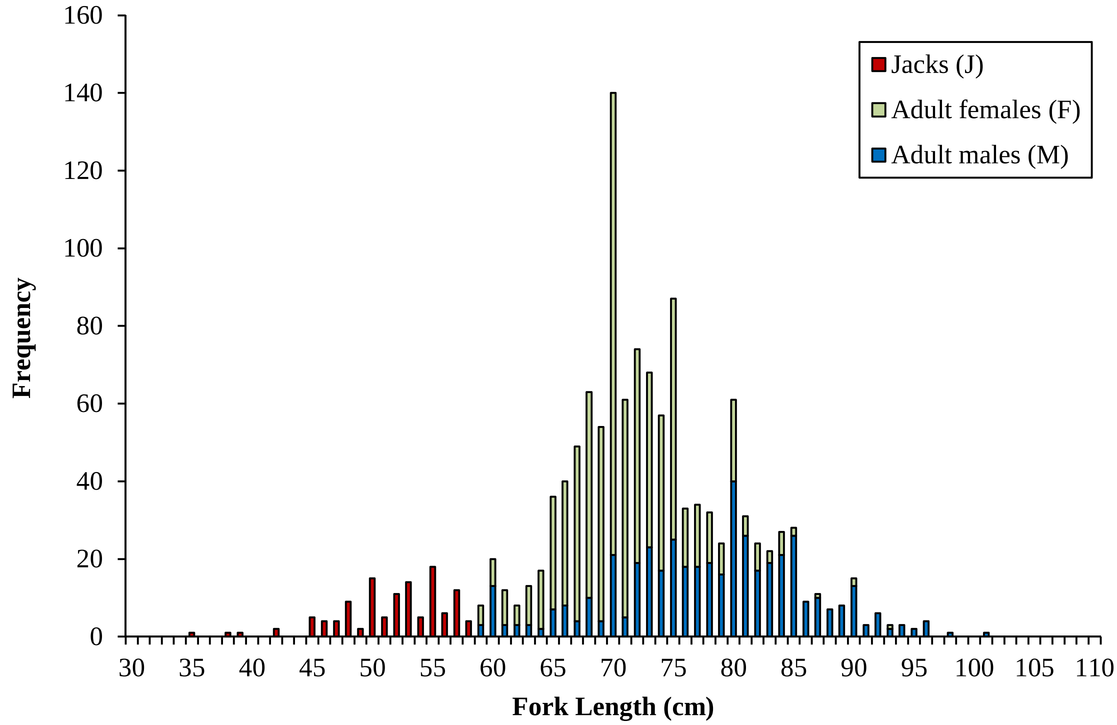


Figure 4. Length-frequency of F_1- and D_2-condition fall Chinook Salmon spawners from the mainstem Klamath River survey, 2012 [n = 1,315 (n_F = 737; n_M = 459; n_J = 119)].

Table 4. Mean fork lengths by year of mainstem Klamath River fall Chinook Salmon carcasses, 2001 to 2012.

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

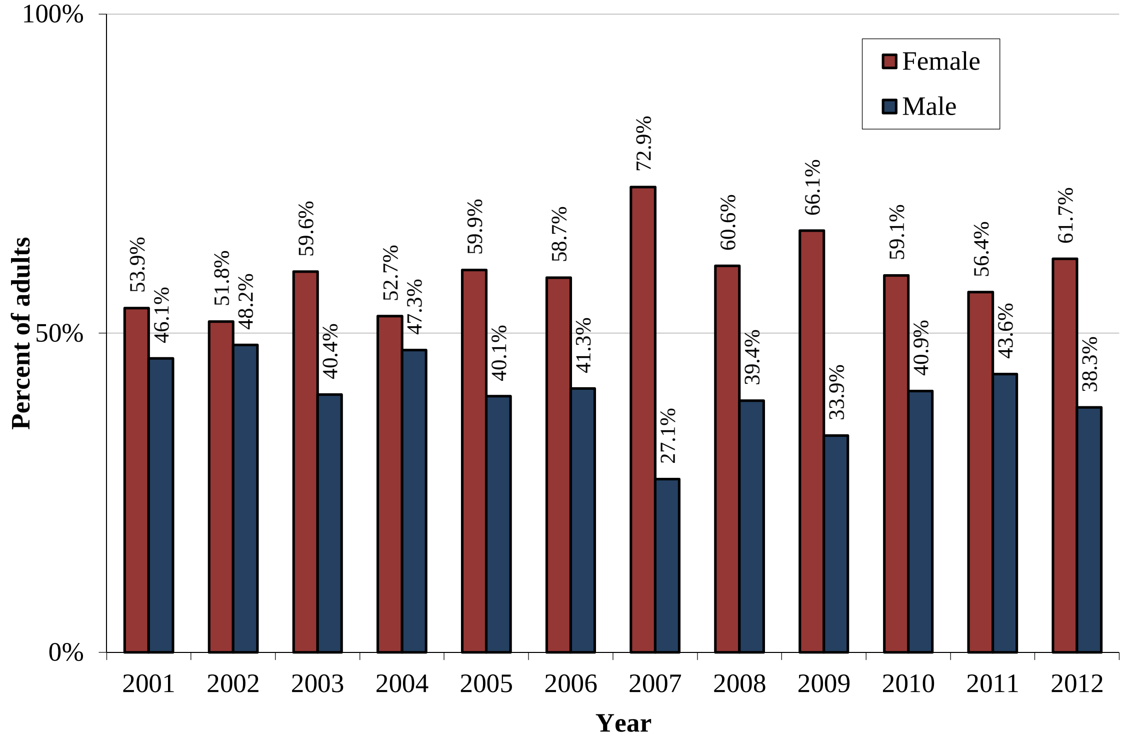


Figure 5. Female and male proportions of adult fall Chinook Salmon carcasses in the mainstem Klamath River, 2001 to 2012.

Pre-spawn Mortality

Pre-spawn mortality was 10.7% in 2012 (Figure 6). Pre-spawn mortality in previous years' surveys ranged from 1.0% (in 2009) to 22.1% (in 2005). Fully spawned individuals made up 85.3% of F_1- and D_2-condition female adult carcasses. Partially spawned individuals made up 4.0% of F_1- and D_2-condition female adult carcasses.

Consistent with the trend observed in previous years, pre-spawn mortality is generally highest at the beginning of the surveys and decreases as the season progresses (Figures 7 and 8). We only used natural pre-spawn mortality in this analysis. The survey crews also noted 28 F_1- and D_2-condition roe-stripped females, presumably by fishermen, that we did not include in the evaluation of spawning success since their opportunity to spawn was prevented.

Escapement Estimates and Age Composition

The mainstem spawning escapement estimate in this study area for 2012 was 12,626 fish (95% CI: 9,592–16,721; Table 5). Each bank was analyzed independently due to differences in catch, tagging rates, and recapture rates. The estimated escapement for the left bank was 6,868 (95% CI: 5,099–8,877), and the estimated escapement for the right bank was 5,758 (95% CI: 4,197–8,634). Of the 324 carcasses tagged on the

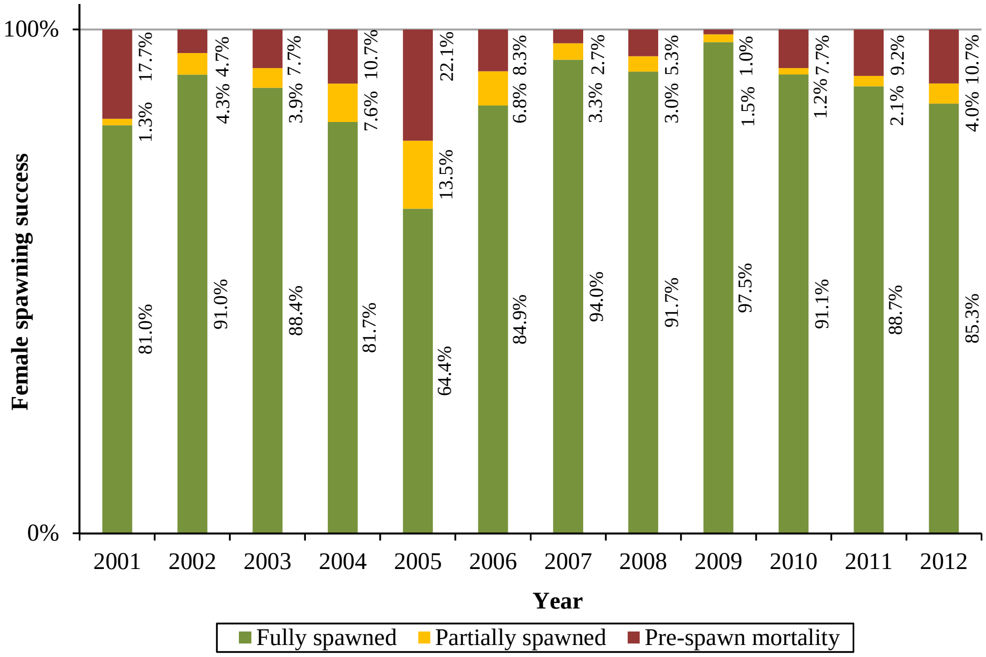


Figure 6. Spawning success of female fall Chinook Salmon based on F_1- and D_2-condition carcasses, Klamath River surveys, 2001 to 2012.

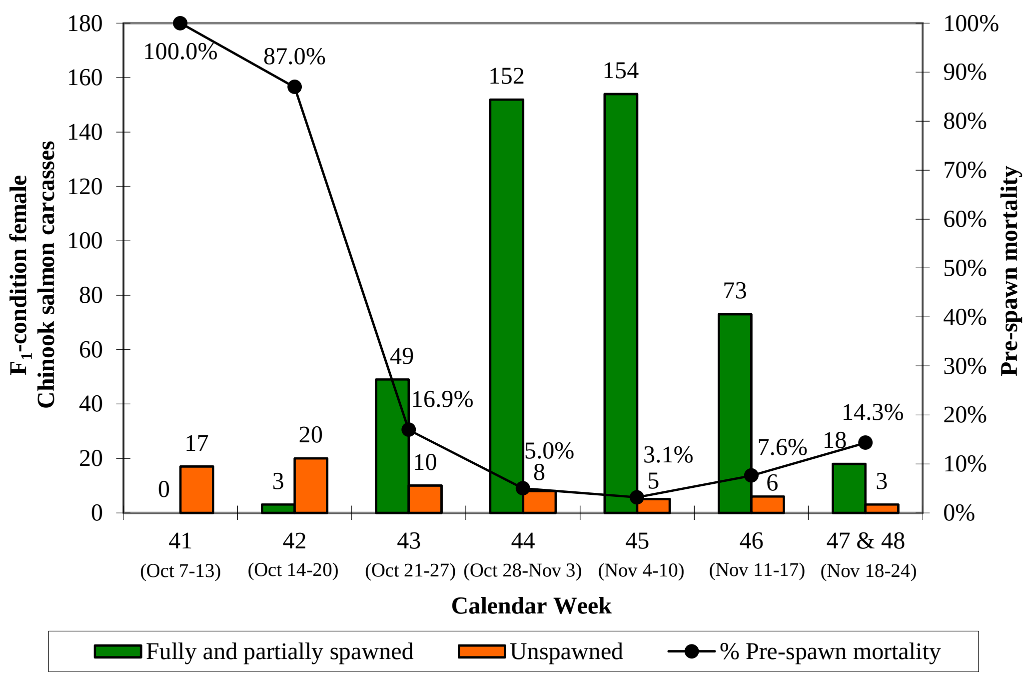


Figure 7. Weekly pre-spawn mortality from F_1-condition female fall Chinook Salmon carcasses, Klamath River survey, 2012. Only F_1-condition carcasses were included since we can assume only those fish expired the week they were found. Calendar weeks 47 and 48 were combined since sample sizes were low.

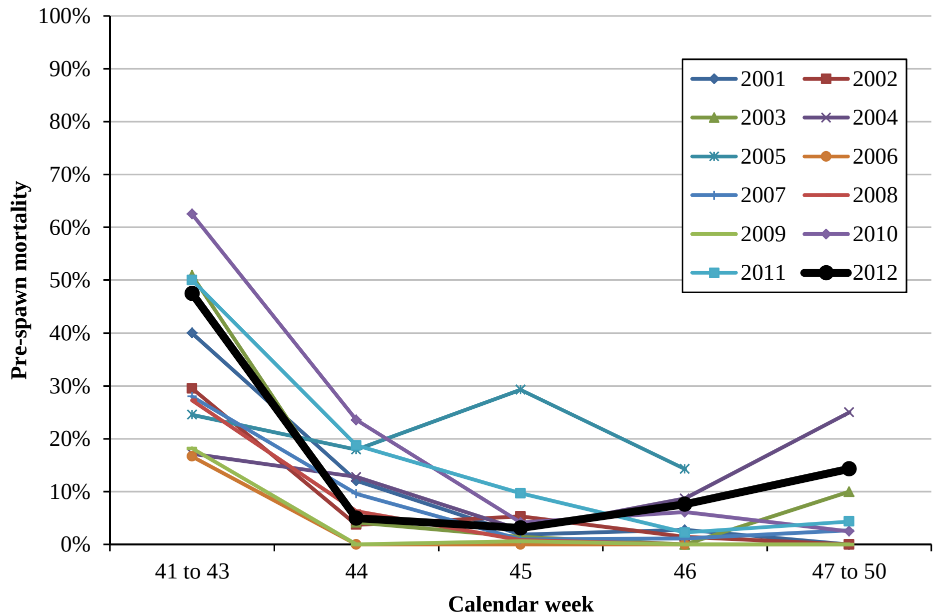


Figure 8. Weekly pre-spawn mortality from F_1-condition female fall Chinook Salmon carcasses, Klamath River surveys, 2001 to 2012. Calendar weeks 41 to 43 and 47 to 50 were combined since sample sizes were typically low in calendar weeks 41, 42, 48, 49, and 50, if surveyed.

Table 5. Fall Chinook Salmon escapement estimates, Klamath River surveys, 2001 to 2012.

	Escapement	95% confidence limits		
Year	estimate	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

right bank, five (1.5%) were recaptured on the left bank. Of the 842 carcasses tagged on the left bank, 11 (1.3%) were recaptured on the right bank. Since the number and proportion of carcasses that mobilized across the river was small and the proportions of carcasses that crossed over were almost the same for both banks, recapture rates were calculated with all recaptures remaining associated with the bank on which they were tagged. The estimated weekly recapture rates ranged from 0.24 to 0.69 on the left bank and from 0.15 to 0.57 on the right. The estimated carcass survey life of carcasses was 2.3 weeks (95% CI: 1.8–3.1).

We assumed that males leaving the survey area after spawning (see Adult Female–Male Ratio section) did not significantly bias the escapement estimate. The majority (90.3%) of all carcasses were found in the first six survey reaches, indicating that most spawning activity occurred in the upper 13.3 rkm of the 21.2-rkm study area. Few, if any, of those male fish likely migrated or drifted downstream more than 7.9 rkm after spawning to leave the study area. Of the few males that spawned in the two downstream-most reaches, any that left the study area after spawning could have only minimally affected the escapement estimate.

Secchi depths ranged from 8 to 10 feet. We believe this small range in visibility had only minimal influence on observation efficiency. Flows below IGD were about 1,000 cfs most of the season with two small one-day ‘spikes’ to 1,150 cfs on October 23 and 1,170 on November 1 and one large five-day ‘spike’ that peaked at 1,620 cfs on November 21. These flow variations, particularly the last one, may have negatively affected observation efficiency the week during or following the events.

Eight hundred forty-three scale samples were collected from carcasses and analyzed in 2012 to estimate the age composition of the mainstem spawning escapement. Based on age composition estimates (KRTT 2013) and the total escapement estimate, jacks (age-2 fish) represented 9.4% ($\widehat{N}_{jacks}$ = 1,186) of the total escapement (Table 6). The 2012 adult escapement estimate was made up of 10,382 3-year olds (82.2%), 1,058 4-year olds (8.4%), and no 5-year olds (0.0%). The proportion of fish designated as jacks by the fork length cut-off was 0.1% lower than that determined to be 2-year olds by scale aging. Following the large return of age-2 fish in 2011, the 2009 brood year also contributed a notably large return of age-3 fish in 2012.

Chinook Salmon adult spawners in the mainstem Klamath River between IGD and the Shasta River confluence accounted for 62.8% of natural-area adult spawners in the mainstem Klamath River above Indian Creek, 15.7% of natural adult spawners in the Klamath River Basin above the Trinity River, and 9.4% of natural adult spawners in the entire Klamath River Basin in 2012 (Table 7). In the entire Klamath River Basin, fall Chinook Salmon adult spawners in the mainstem Klamath River between IGD and the Shasta River confluence accounted for 6.4% of total adult escapement (hatchery and natural spawners) and 3.9% of the total adult in-river run (hatchery and natural spawners plus in-river harvest) in 2012.

Table 6. Fall Chinook Salmon spawning escapement estimates (and percent of total run) for each age class, Klamath River surveys, 2001 to 2012 Note: Adults are ages 3 through 5.

Year	Age				
	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

[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

Table 7. 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 to 2012. Data compiled from Magneson (2008), KRTAT (2003a, 2003b, 2004, 2005, 2006, 2007, 2008, 2009), and KRTT (2010, 2011, 2012, 2013).

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%

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

Hatchery Fish Contribution

From the 179 F_1- and D_2-condition ad-clipped carcasses encountered in 2012, 170 snout samples were collected, 157 CWTs were recovered, and 155 CWTs were decoded. Production multipliers from known CWT numbers ranged from 4.01 (24.9% tag rate; codes 068711, 068714, and 068716 from Brood Year 2009) to 12.17 (8.2% tag rate; code 068795 from Brood Year 2010). The estimated proportion of hatchery-origin spawners in the study area was 45.3% (n = 5,726) in 2012 (Table 8). 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 2011.

Consistent with previous years, the reach-wise proportion of hatchery-origin Chinook Salmon in 2012 was highest in Reach 1 (89.4%; Figure 9). 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 from Reach 2 to Reach 8, ranging from 25.7% to 48.6%.

Table 8. Hatchery composition of fall Chinook Salmon spawning escapement in the mainstem Klamath River, IGD to the Shasta River confluence, based on carcass surveys, 2001 to 2012. Note: Data only from F_1- and D_2-condition carcasses were used. See Appendix C for an explanation of the different methods used in estimating annual hatchery composition.

Year	Estimated hatchery-origin proportion	Escapement estimate	
		Total	Hatchery only
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

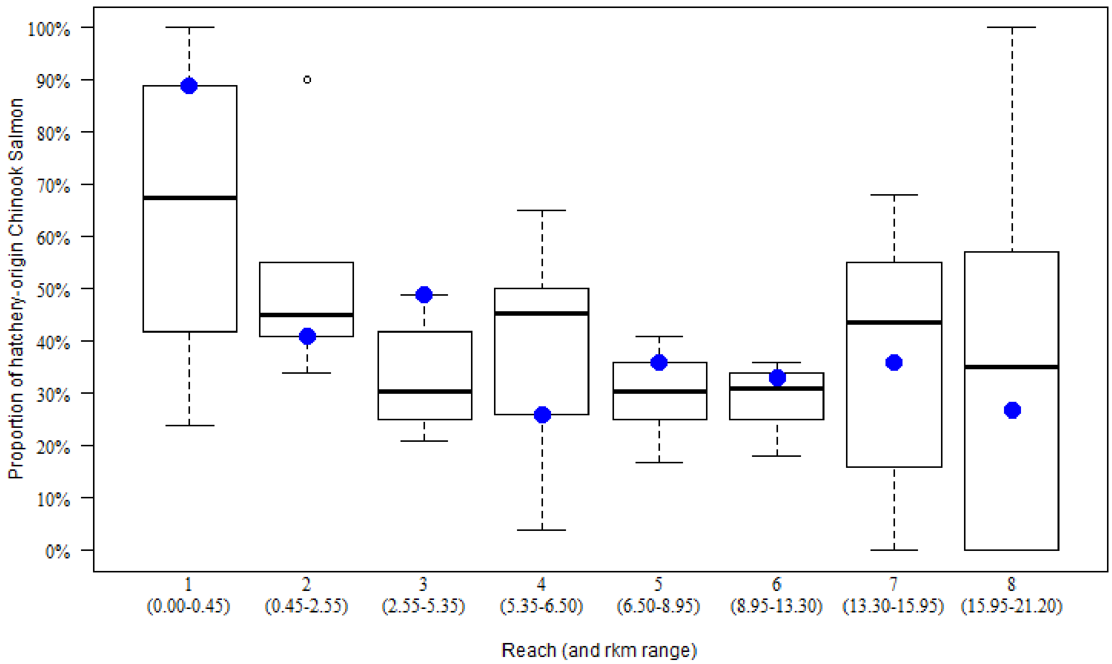


Figure 9. Box plot of proportions of hatchery-origin Chinook Salmon carcasses by reach, Klamath River, 2007 to 2012. Data from 2012 is marked with solid circles.

Egg Deposition

Egg deposition in the study area was estimated to be 21.6 million from 6,497 females in 2012 (Table 9). 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).

Acknowledgements

We particularly thank the Yurok Tribal Fishery Program for their annual participation in the carcass survey. Data were collected by AFWO personnel: Jordan Green, Josh Pieratt, Samuel Rizza, and Nick Van Vleet. Data were collected by YTFP personnel: Jamie Holt, Rocky Erickson, and Luke Walker. This report was reviewed by Michael O'Farrell (National Marine Fisheries Service) and Joseph Polos (AFWO).

Table 9. Egg deposition (N_e) of fall Chinook Salmon from Klamath River carcass surveys, 2001 to 2012. 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. Data for 2001 to 2011 does not match what was reported in Gough and Williamson (2012) and Gough (2014). Annual female egg production as measured at IGH were used in this table whereas the mean egg production by adult female Chinook Salmon in the Klamath River (n_e = 3,634) as determined by Allen and Hassler (1986) was used in the mentioned reports. As a result egg deposition estimates below range from 22% lower to 4% higher than what was previously reported.

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

Literature Cited

Allen, M.A., and T.J. Hassler. 1986. Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates (Pacific Southwest) -- Chinook Salmon. U.S. Fish and Wildlife Service, Biological Report 82(11.49). U.S. Army Corps of Engineers, TR EL–82–4. 26 p.

CDFG (California Department of Fish and Game). 2003. Chinook and Coho salmon recovery at Iron Gate Hatchery, October 7, 2002 to January 3, 2003. Klamath River Project, Yreka, California. 19 p.

CDFW (California Department of Fish and Wildlife). 2013. Klamath River basin fall Chinook Salmon spawner escapement, in-river harvest and run-size estimates, 1978–2012. California Department of Fish and Wildlife, Arcata, California. 13 p.

Chamberlain, C.D., and S.C. Williamson. 2006. Klamath River salmonid emigrant trapping catch, mortality, and external health indicators – 2004. U.S. Fish and Wildlife Service, Arcata Fish and Wildlife Office, Arcata, California. 102 p.

Chapman, D.G. 1951. Some properties of the hypergeometric distribution with applications to zoological censuses. University of California Publications in Statistics 1, 131–160.

Chesney, D. 2007. Recovery of fall-run Chinook and Coho salmon at Iron Gate Hatchery, 2006. California Department of Fish and Game, Klamath River Project, Yreka, California. 22 p.

Chesney, D. 2008. Recovery of fall-run Chinook and Coho salmon at Iron Gate Hatchery, 2007. California Department of Fish and Game, Klamath River Project, Yreka, California. 21 p.

Chesney, D. 2009. Recovery of fall-run Chinook and Coho salmon at Iron Gate Hatchery, 2008. California Department of Fish and Game, Klamath River Project, Yreka, California. 22 p.

Chesney, D., and M. Knechtle. 2010. Recovery of fall-run Chinook and Coho salmon at Iron Gate Hatchery, September 25, 2009 to December 15, 2009. California Department of Fish and Game, Klamath River Project, Yreka, California. 21 p.

Chesney, D., and M. Knechtle. 2011. Recovery of fall-run Chinook and Coho salmon at Iron Gate Hatchery, September 24, 2010 to December 15, 2010. California Department of Fish and Game, Klamath River Project, Yreka, California. 19 p.

Chesney, D., and M. Knechtle. 2012. Recovery of fall-run Chinook and Coho salmon at Iron Gate Hatchery, October 4, 2011 to December 12, 2011. California Department of Fish and Game, Klamath River Project, Yreka, California. 21 p.

Chesney, D., and M. Knechtle. 2013. Recovery of fall-run Chinook and Coho salmon at Iron Gate Hatchery, September 26, 2012 to December 6, 2012. California Department of Fish and Wildlife, Klamath River Project, Yreka, California. 20 p.

DeVries, D.R., and R.V. Frie. 1996. Determination of age and growth. Pages 483-512 *in* B.R. Murphy and D.W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Gough, S.A., and S.C. Williamson. 2012. Fall Chinook Salmon run characteristics and escapement for the main-stem Klamath River, 2001–2010. U.S. Fish and Wildlife Service, Arcata Fish and Wildlife Office, Arcata Fisheries Technical Report Number TR 2012–14, Arcata, California.

Gough, S.A. 2014. Fall Chinook Salmon run characteristics and escapement for the mainstem Klamath River, 2011. U.S. Fish and Wildlife Service, Arcata Fish and Wildlife Office, Arcata Fisheries Data Series Report Number DS 2014–35, Arcata, California.

Hampton, M. 2005. Recovery of Chinook and Coho salmon at Iron Gate Hatchery, October 4, 2004 to December 20, 2004. California Department of Fish and Game, Klamath River Project, Yreka, California. 24 p.

Hardy, T.B., and R.C. Addley. 2001. Evaluation of interim instream flow needs in the Klamath River: Phase II Final Report. Institute for Natural Systems Engineering, Utah Water Research Laboratory, Utah State University, Logan, Utah. 304 p.

Harris, N., P. Petros, and W. Pinnix. 2012. Juvenile salmonid emigration monitoring on the mainstem Trinity River, California, 2009. Yurok Tribal Fisheries Program, Hoopa Valley Tribal Fisheries Department, and U.S. Fish and Wildlife Service, Arcata Fish and Wildlife Office, Arcata Fisheries Data Series Report Number DS 2012–27, Arcata, California. 52 p.

Healey, M.C. 1991. Life history of Chinook Salmon (*Oncorhynchus tshawytscha*). Pages 311–393 *in* C. Groot and L. Margolis, editors. Pacific salmon life histories. University of British Columbia Press, Vancouver, British Columbia, Canada.

Hilborn, R., B.G. Bue, and S. Sharr. 1999. Estimating spawning escapements from periodic counts: a comparison of methods. Canadian Journal of Fisheries and Aquatic Sciences 56:888–896.

KRTAT (Klamath River Technical Advisory Team). 2003a. Klamath River fall Chinook age-specific escapement, 2001 run. Available from the Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220–1384. 15 p.

KRTAT (Klamath River Technical Advisory Team). 2003b. Klamath River fall Chinook age-specific escapement, 2002 run. Available from the Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220–1384. 15 p.

KRTAT (Klamath River Technical Advisory Team). 2004. Klamath River fall Chinook age-specific escapement, 2003 run. Available from the Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220–1384. 16 p.

KRTAT (Klamath River Technical Advisory Team). 2005. Klamath River fall Chinook age-specific escapement, river harvest, and run size estimates, 2004 run. Available from the Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220–1384. 16 p.

KRTAT (Klamath River Technical Advisory Team). 2006. Klamath River fall Chinook age-specific escapement, river harvest, and run size estimates, 2005 run. Available from the Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220–1384. 16 p.

KRTAT (Klamath River Technical Advisory Team). 2007. Klamath River fall Chinook age-specific escapement, river harvest, and run size estimates, 2006 run. Available from the Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220–1384. 17 p.

KRTAT (Klamath River Technical Advisory Team). 2008. Klamath River fall Chinook age-specific escapement, river harvest, and run size estimates, 2007 run. Available from the Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220–1384. 17 p.

KRTAT (Klamath River Technical Advisory Team). 2009. Klamath River fall Chinook Salmon age-specific escapement, river harvest, and run size estimates, 2008 run. Available from the Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220–1384. 20 p.

KRTT (Klamath River Technical Team). 2010. Klamath River fall Chinook Salmon age-specific escapement, river harvest, and run size estimates, 2009 run. Available from the Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220–1384. 18 p.

KRTT (Klamath River Technical Team). 2011. Klamath River fall Chinook Salmon age-specific escapement, river harvest, and run size estimates, 2010 run. Available from the Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220–1384. 21 p.

KRTT (Klamath River Technical Team). 2012. Klamath River fall Chinook Salmon age-specific escapement, river harvest, and run size estimates, 2011 run. Available from the Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220–1384. 19 p.

KRTT (Klamath River Technical Team). 2013. Klamath River fall Chinook Salmon age-specific escapement, river harvest, and run size estimates, 2012 run. Available from the Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220–1384. 18 p.

Leidy, R.A., and G.R. Leidy. 1984. Life stage periodicities of anadromous salmonids in the Klamath River Basin, northwestern California. U.S. Fish and Wildlife Service, Division of Ecological Services, Sacramento, California. 21 p.

Magneson, M. 2008. Mainstem Klamath River fall Chinook Salmon spawning survey 2007. U.S. Fish and Wildlife Service, Arcata Fish and Wildlife Office, Arcata Fisheries Data Series Report DS 2008–14, Arcata, California. 23 p.

Manly, B.F.J., T.L. McDonald, and S.C. Amstrup. 2005. Introduction to the handbook. Pages 1–21 *in* Handbook of capture-recapture analysis. S.C. Amstrup, T.L. McDonald, and B.F.J. Manly, editors. Princeton University Press, Princeton, New Jersey.

Manske, M., and C.J. Schwarz. 2000. Estimates of stream residence time and escapements based on capture-recapture data. Canadian Journal of Fisheries and Aquatic Sciences 57:241–246.

McNeil, W.J. 1964. Redd superimposition and egg capacity of Pink Salmon spawning beds. Journal of the Fisheries Research Board of Canada 21:1385-1396.

Millar, R.B., S. McKechnie, and C.E. Jordan. 2012. Simple estimators of salmonid escapement and its variance using a new area-under-the-curve method. Canadian Journal of Fisheries and Aquatic Sciences 69(6):1002–1015.

Mohr, M.S., and W.H. Satterthwaite. 2013. Coded wire tag expansion factors for Chinook Salmon carcass surveys in California: Estimating the numbers and proportions of hatchery-origin fish. San Francisco Estuary and Watershed Science, 11(4). jmie_sfews_13364. Retrieved from: http://escholarship.org/uc/item/3471w9mv.

Neilson, J.D., and G.H. Geen. 1981. Enumeration of spawning salmon from spawner residence time and aerial counts. Transactions of the American Fisheries Society 110:554–556.

Nelson, S.M., G. Reed, E.N. Bray, E. Guzman, and M. Bigelow. 2012. Hyporheic water quality and salmonid egg survival in the San Joaquin River. Technical Memorandum Number 86–68220–12–03, U.S. Department of the Interior, Bureau of Reclamation, Denver, Colorado.

O’Farrell, M. 2012. Personal communication. Klamath ocean harvest model outputs for PFMC alternatives for the 2012 ocean salmon fishery. National Marine Fisheries Service, Southwest Fisheries Science Center, Santa Cruz, California.

PFMC (Pacific Fishery Management Council). 2012. Preseason Report II: proposed alternatives and environmental assessment Part 2 for 2012 ocean salmon fishery regulations. Regulation Identifier Number 0648–XA921, Portland, Oregon. 69 p.

PSMFC (Pacific States Marine Fisheries Commission). 2013. Pacific salmonid coded-wire tag release database. Regional Mark Processing Center, PSMFC. Gladstone, Oregon. http://www.rmpc.org.

Pledger, S., M. Efford, K.H. Pollock, J.A. Collazo, and J.E. Lyons. 2009. Stopover duration analysis with departure probability dependent on unknown time since arrival. Pages 349–363 *in* D.L. Thomson, E.G. Cooch, and M.J. Conroy, editors. Modeling demographic processes in marked populations: Environmental and Ecological Statistics, Volume 3. Springer, New York, New York.

Pomeroy, K. 2015. Personal communication. California Department of Fish and Wildlife, Iron Gate Hatchery, Hornbrook, California.

Richey, J. 2006. Recovery of fall-run Chinook and Coho salmon at Iron Gate Hatchery, 2005. California Department of Fish and Game, Klamath River Project, Yreka, California. 23 p.

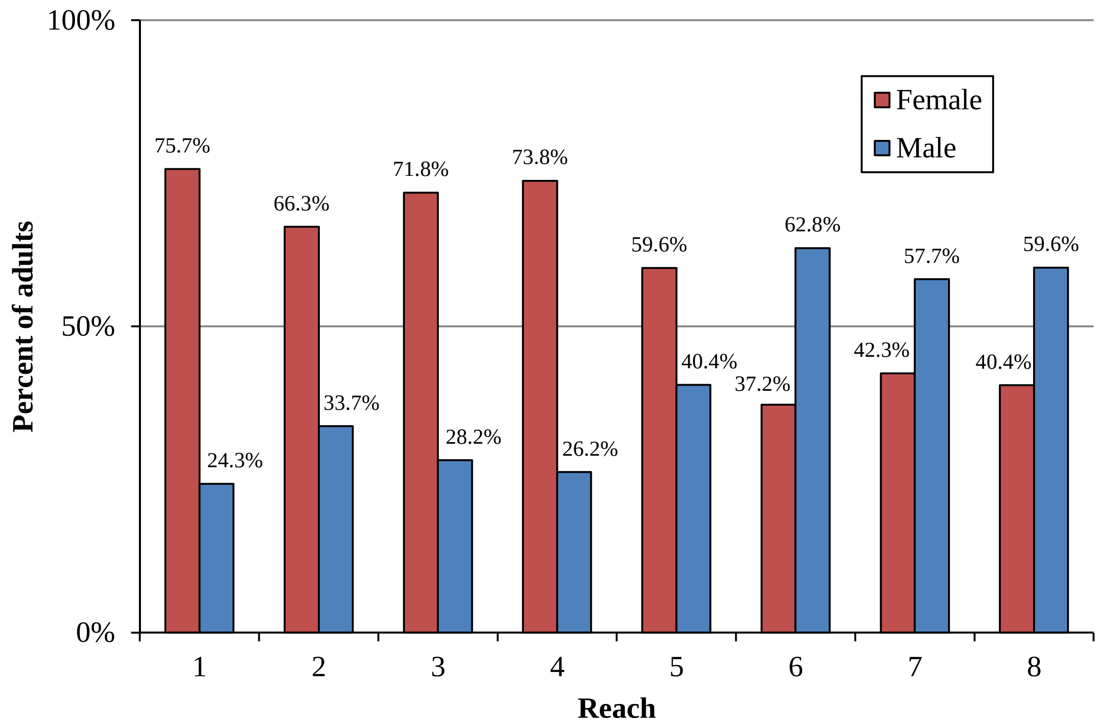
Richey, J. 2007. Recovery of fall-run Chinook and Coho salmon at Iron Gate Hatchery, October 6, 2003 to December 31, 2003. California Department of Fish and Game, Klamath River Project, Yreka, California. 21 p.

Szerlong, R.G., and D.E. Rundio. 2008. A statistical modeling method for estimating mortality and abundance of spawning salmon from a time series of counts. Canadian Journal of Fisheries and Aquatic Sciences 65:17–26.

West Coast Chinook Salmon Biological Review Team. 1997. Review of the status of Chinook Salmon (*Oncorhynchus tshawytscha*) from Washington, Oregon, California, and Idaho under the U.S. Endangered Species Act. NOAA Technical Memorandum NMFS–NWFSC–35. 448 p.

Appendices

Appendix A. Proportions of adult male and female Chinook Salmon carcasses by reach in the mainstem Klamath River, IGD to the Shasta River confluence, 2012.



Appendix B. Proportions of female and male Chinook Salmon returning to IGH and the mainstem Klamath River, 2001 to 2012. 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 isolated adult numbers. IGH data compiled from CDFG (2003), Hampton (2005), Richey (2006, 2007), Chesney (2007, 2008, 2009), Chesney and Knechtle (2010, 2011, 2012, 2013), and Pomeroy (2015).

	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%

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

Appendix C. Hatchery composition of fall Chinook Salmon in the mainstem Klamath River, IGD to the Shasta River confluence, based on carcass surveys, 2001 to 2012. Data for 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 to 2.8 times greater (difference: 0.2% lower to 19.5% higher). The adjustment was made for a better comparison with 2011 and 2012 results. Data from 2011 and 2012 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	Escapement estimate: Hatchery only
	C	AD_{obs}	$P(AD\|H)_{IGH}$	$\hat{H}$	$\hat{P}(H)$	$\hat{N}$	$\hat{N}_H$
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	Escapement estimate: 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	1,491	179	170	157	155	676	45.3%	12,626	5,726