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Fall Chinook Salmon Run Characteristics and Escapement in the Mainstem Klamath River below Iron Gate Dam, 2017

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Key words: Carcass, Chinook, Egg Production, Escapement, Hierarchical Latent Variables Model, Klamath, Mark–Recapture, Pre-Spawn Mortality, Redd, Salmon, Spawner, Spawning

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Abstract.— Adult fall Chinook Salmon *Oncorhynchus tshawytscha* carcasses and redds were surveyed on the mainstem Klamath River, from Iron Gate Dam to Wingate Bar during the 2017 spawning season to estimate annual escapement and characterize the age and sex composition and spawning success of the run. Surveys were conducted over 9 weeks, from October 11 to December 6. Using postmortem mark–recapture methods and a hierarchical latent variables model between Iron Gate Dam and the confluence with the Shasta River, the estimated spawning escapement for this 21.6-km section of the mainstem Klamath River was 4,740 fish. Based on this estimate and age composition data from scale samples, spawning escapement by year class was 1,749 (36.9%) age-2 (jacks and jills), 2,376 (50.1%) age-3, 550 (11.6%) age-4, and 65 (1.4%) age-5 spawners. The presence of jills (age-2 females) was unusually high in 2017 and they accounted for 8.2% of all female carcasses. Jacks (age-2 males) accounted for 53.4% of all male carcasses. An estimated 19.8% of the fish that spawned in the study area were of hatchery origin. The adult female–male ratio was 1.9:1 and pre-spawn mortality rate of females was 5.5%. Estimated egg deposition by females in the carcass study area was 4.9 million. The redd count in the 125.7-km section of the mainstem river between the Shasta River confluence and Wingate Bar was 478 in 2017. Redd counts over the previous 24-year history of this survey ranged from 243 (in 1993) to 3,456 (in 2014), although the downstream end of these past surveys was the Indian Creek confluence and was thus 11.2 km shorter. Estimated egg deposition in the redd study area was 1.2 million.

Introduction

Abundant runs of Chinook Salmon *Oncorhynchus tshawytscha* and steelhead *O. mykiss* and comparatively smaller runs of Coho Salmon *O. kisutch* were historically supported by the Klamath River Basin (Leidy and Leidy 1984; DOI et al. 2013; 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 (Hardy and Addley 2001; Moyle et al. 2008; Thorsteinson et al. 2011; DOI et al.

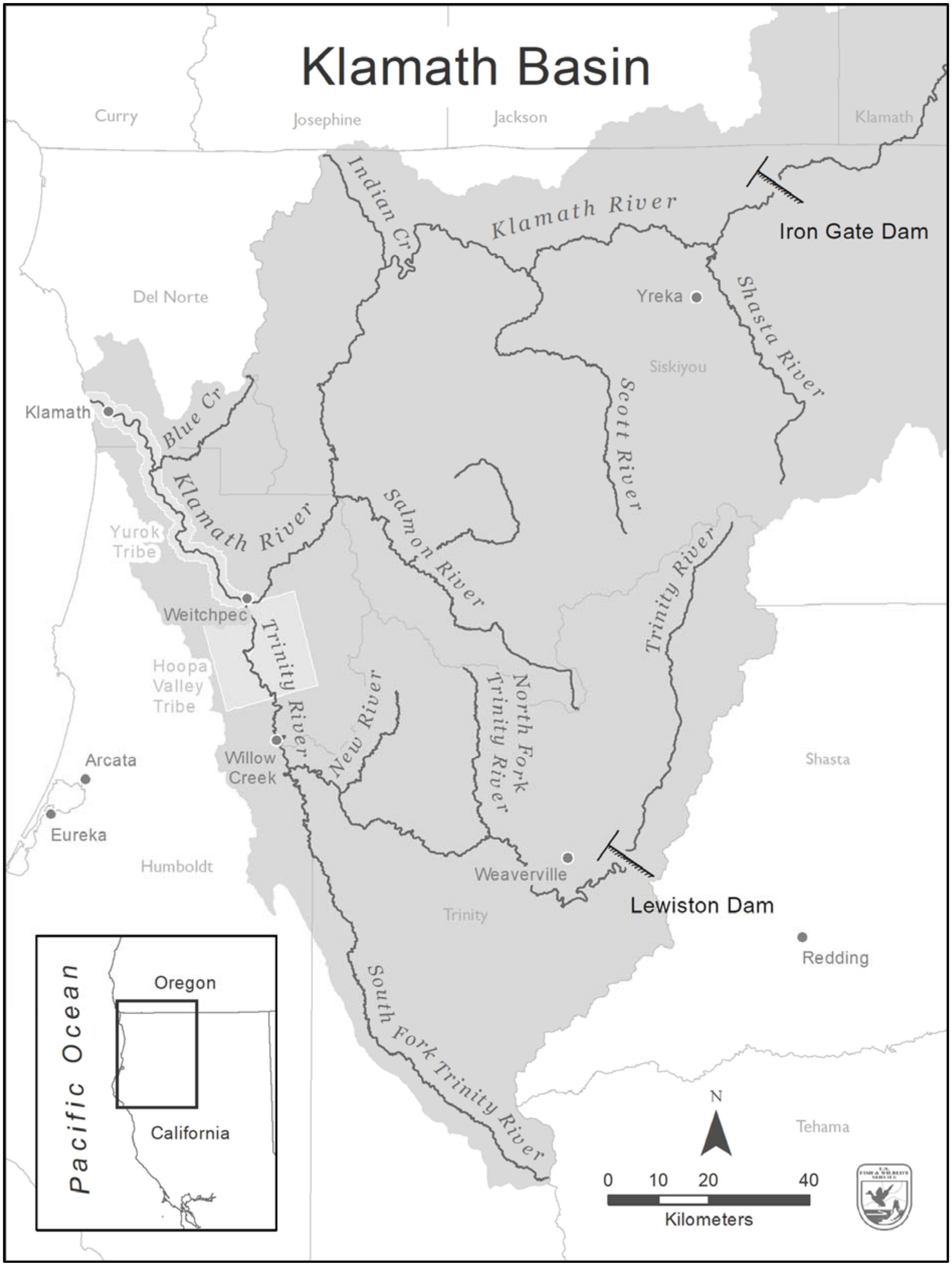

Figure 1. Klamath River Basin, northern California. The mainstem Klamath River carcass survey study area extends from Iron Gate Dam to the Shasta River confluence and the redd survey extends from the Shasta River to Indian Creek.

2013). These factors include overharvest, habitat alterations and loss from various land-use practices (e.g., dam construction, agricultural development, timber harvest, mining, etc.), reduced genetic integrity from hatcheries, environmental phenomena, and disease.

In response to concerns over declining salmon, the United States Congress enacted the Klamath River Fish and Wildlife Restoration Act (Public Law 99-552) in 1986 (USFWS 1991). Known as the 'Klamath Act', this legislation authorized the Secretary of the Interior to restore anadromous fish populations to optimum levels in the Klamath River Basin through the creation of the Klamath River Basin Conservation Area Restoration Program (KRBCARP). As part of the fishery resource monitoring program implemented under KRBCARP, the U.S. Fish and Wildlife Service (USFWS) Arcata Fish and Wildlife Office (AFWO) implemented redd surveys in 1993 to identify the distribution, abundance, and timing of fall Chinook Salmon spawning in the mainstem Klamath River between Iron Gate Dam [IGD; river kilometer (rkm) 310.1] and the confluence with Indian Creek (rkm 173.8). Escapement estimates were generated by expanding redd counts under the assumption that each redd represents one adult female and one adult male. 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 2018).

In 2001, AFWO 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 IGD and the Shasta River confluence (rkm 288.5). A postmortem tag-recovery study was conducted rather than the more common live tag–postmortem recovery or live mark–live recapture surveys since the opportunity to count, mark, or recover live fish (e.g., at a weir; Manly et al. 2005) was not available. 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. Consequently, only carcass surveys have been conducted in this section of the river since 2007.

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 not rely on estimates of carcass survey life and provide more precise carcass estimates, a hierarchical latent variables model was implemented in 2016 to estimate escapement.

The primary purpose of this project is to provide the Klamath River Technical Team (KRTT) with fall Chinook Salmon spawning escapement estimates for the mainstem Klamath River. 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 in the mainstem (KRTT 2018a). 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 2018b, PFMC 2018). Accurately determining the number of spawners within this reach is also needed for an ongoing outmigrant fry study (e.g., David et al. 2017) and for calibrating the Chinook Salmon production model, Stream Salmonid Simulator (S3; Perry et al. 2018). 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 mainstem Klamath River from IGD to Wingate Bar was divided into seven reaches (R1–R7) based on accessibility and distance that a single crew could survey for redds in a day (Figure 2; Table 1).

The carcass survey area (also Reach R1) consists of the 21.2-km section of mainstem Klamath River between the boat ramp across the river from the Iron Gate Hatchery (IGH) and the Shasta River confluence, and is further divided into eight smaller reaches (C1–C8; Figure 3; Table 2). Carcass survey reach delineation is based on previously mapped concentrations of redds with boundaries at distinguishable landmarks. The 0.4 km above Reach C1, between IGD (the upper limit of anadromy) and IGH, was not surveyed because it is not accessible and little spawning activity occurs in this section of the river.

The redd survey area (Reaches R2–R7) extends 125.7 km between the confluence with the Shasta River and Wingate Bar. Reach R1 was only surveyed for redds from 1993 to 2004 and 2006. The upper 2.7 km in Reach R2, from the Shasta River to Ash Creek, was not surveyed because past surveys revealed little to no spawning activity in this section of the river. For this report we assumed no redds were constructed in this short stretch of the river. Past years' redd surveys went to the confluence with Indian Creek (Reach R6); Reach R7 was added to the redd survey in 2017 because an increasing number of Chinook Salmon appeared to be spawning below the carcass survey reaches and further downstream in the mainstem.

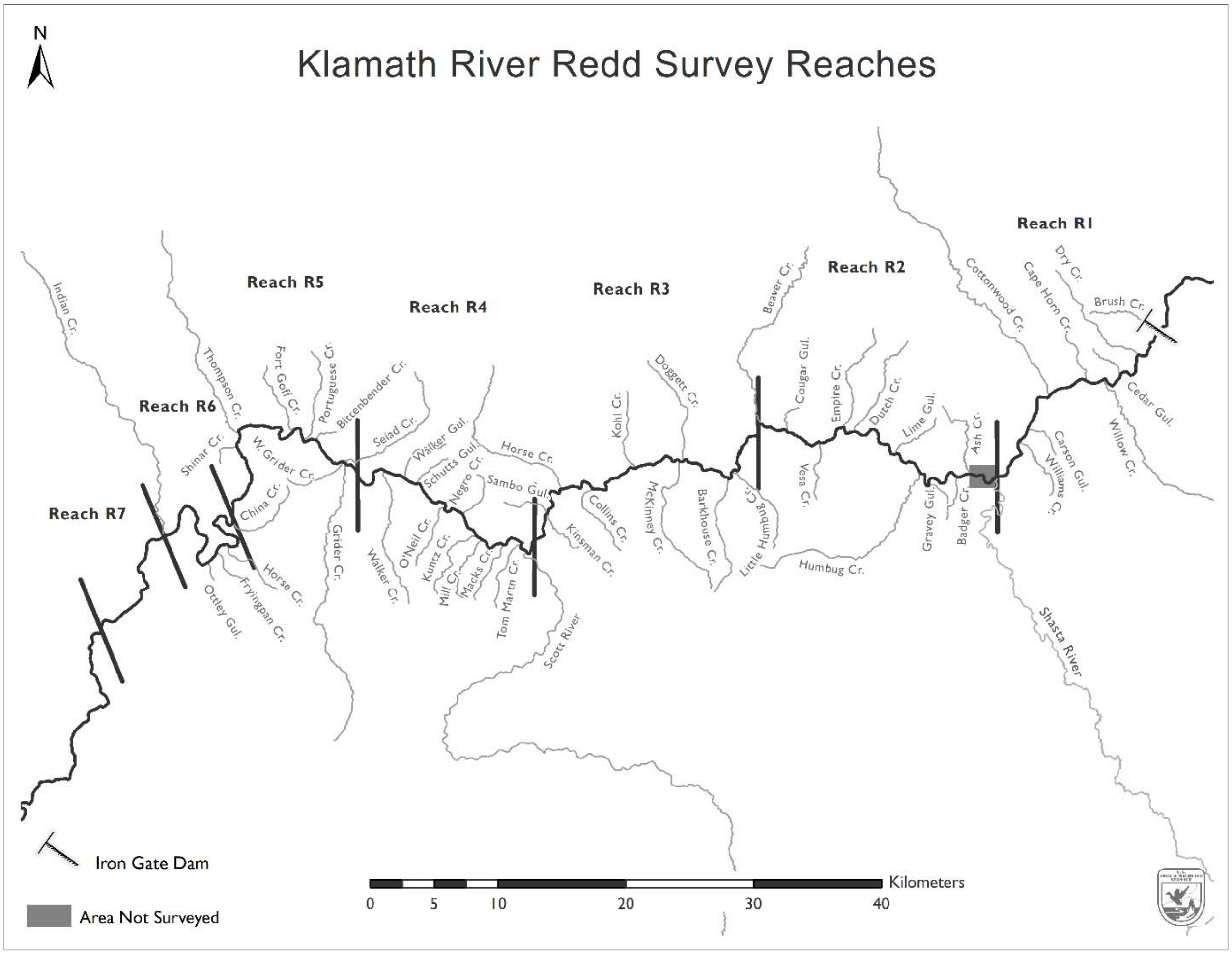

Figure 2. Mainstem Klamath River fall Chinook Salmon redd survey reaches. *Note*: Escapement in Reach R1 (Iron Gate Dam–Shasta River) is estimated from carcass mark-recapture survey data. The 2.7-km section between the Shasta River and Ash Creek was not surveyed because past surveys revealed a lack of spawning activity in this stretch of river.

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

Reach	Rkm		Length	
	Upstream	Downstream	(km)	Upstream landmark
R1[a]	309.7	288.5	21.2	Boat ramp opposite Iron Gate Hatchery
R2[b]	288.5[e]	261.9	26.4	Shasta River confluence
R3[c]	261.9	234.3	27.6	Beaver Creek confluence
R4[b]	234.3	213.6	20.7	Blue Heron River Access
R5[c]	213.6	192.4	21.2	Seiad Bar
R6[d]	192.4	173.8	18.6	China Point River Access
R7[c]	173.8	162.6[f]	11.2	Indian Creek confluence

[a] redd surveys no longer conducted in Reach R1 (escapement in this reach estimated from carcass mark-recapture surveys by USFWS and the Yurok Tribe)

[b] surveyed by Karuk Tribe crew

[c] surveyed by USFWS crew

[d] Reach R6 was split at Gordon’s Ferry (rkm 185.0) and surveyed by Karuk Tribe and USFWS

[e] the section of river between Shasta River and Ash Creek (rkm 285.7) was not surveyed because past surveys revealed little to no evidence of spawning activity in this area

[f] Wingate Bar River Access

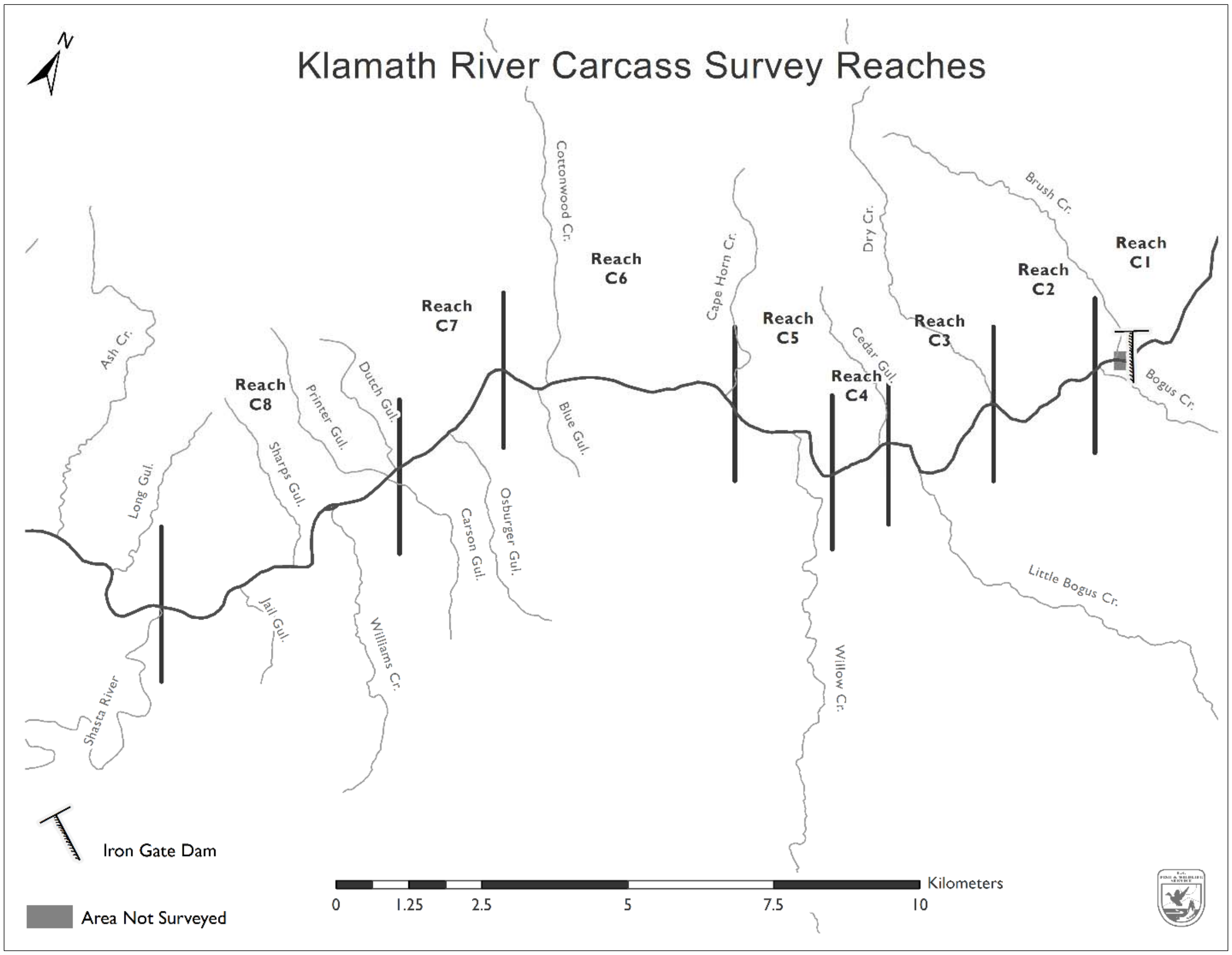

Figure 3. Klamath River carcass survey area from IGD (rkm 310.1) to the Shasta River confluence (rkm 288.5) with reaches delineated. The survey begins in Reach C1 at the first river access below IGD (rkm 309.7). Little to no spawning occurs between the dam and the access point.

Table 2. Reach boundaries and lengths in the Klamath River carcass survey study area. Downstream landmarks were the same as upstream landmarks of the next reach.

Reach	Rkm Upstream	Rkm Downstream	Length (km)	Upstream landmark
C1	309.7[a]	309.2	0.5	Boat ramp opposite Iron Gate Hatchery
C2	309.2	307.0	2.2	Riffle below USGS Gaging Station
C3	307.0	304.3	2.7	Dry Creek confluence
C4	304.3	303.2	1.1	First wooden foot bridge
C5	303.2	300.7	2.5	KRCE green wooden foot bridge
C6	300.7	296.4	4.3	Copco-Ager (Klamathon) Bridge
C7	296.4	293.8	2.6	Third (fallen) wooden foot bridge
C8	293.8	288.5[b]	5.3	Carson Creek confluence

[a] The 0.4 km immediately downstream of Iron Gate Dam (rkm 310.1) is not surveyed.

[b] Confluence with the Shasta River

Methods

Carcass Survey – Iron Gate Dam to the Shasta River

Carcass data were collected in a cooperative effort between AFWO and the Yurok Tribal Fisheries Program (YTFP). Weekly surveys were conducted from October 11 to December 6, 2017. 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 carcass study area (in Reach C8) 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 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; from covered with fungus and flesh softening to 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-condition carcasses were believed to have expired more than one week prior to capture. Fork lengths from N-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.

Spawning conditions were assigned to F_1- and D_2-condition female carcasses using the following codes:

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.

In previous reports from these projects, the term ‘jack’ referred to all age-2 (precocious) spawners, including males (true jacks) and females (jills). In 2017, an unusually high number of age-2 females (jills) was observed. Therefore, jacks and jills are referred to separately in this report. Sex-specific size cut-offs between adults and age-2 fish were decided after the sampling season based on scale-age data and length-frequency distributions compiled and analyzed by the KRTT (2018a). 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 (e.g., KRTT 2018a). 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 age composition analysis.

Escapement Estimate

Counts of carcasses were conducted weekly over the entire study area throughout the active spawning period. A systematic sampling rate of 1-in-2 was applied during the seventh survey week when we predicted that the number of carcasses would be too many for the crew to finish the survey. 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). Tags were also not applied to carcasses that had been damaged by scavengers. 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, 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 (Gough and Som 2017). 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 (i.e., those arriving since the prior survey) and weekly detection probabilities estimated from mark–recapture data. Weekly abundances are estimated by assuming that the weekly counts of fresh Chinook Salmon carcasses arise from a binomial distribution. All details regarding the development and application of this model can be found in Gough and Som (2017).

Age-Class Estimates

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

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

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 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 [i.e., under the 1-in-2 systematic sampling rate in the seventh survey week, each sampled carcass represented two carcasses with its attributes (e.g., ad-clip)].

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

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

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

Egg Deposition

Total egg deposition (N_e) in the carcass survey area was estimated by multiplying predicted egg production (n_e) by the estimate of adult females ($\hat{N}_{adult}$). 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 2017 mean egg production per female at IGH ($\bar{n}_e$ = 2,551; Pomeroy 2018) as a surrogate for mainstem spawning female Chinook Salmon. 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:

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

Redd Survey – Shasta River to Wingate Bar

Redd data were collected in a cooperative effort between AFWO and the Karuk Tribe. Weekly surveys were conducted from October 11 to November 30, 2017. Two crews, one AFWO and one Karuk, consisting of a rower and observer, surveyed the river by cataraft. Catarafts were rowed downstream and maneuvered in a zigzag pattern over spawning areas to count redds. Side channels were surveyed by foot and split channels by cataraft on alternating weeks. Crews surveyed the same reaches each week for consistency and familiarity with the river and to promote more accurate redd counts.

A GPS waypoint was taken at each lone redd or redd aggregation when observed for the first time during the season. The GPS waypoint, river kilometer, numbers of old and new redds, location of redd(s) in the channel, distance of redd(s) from bank, habitat type, and estimated age(s) of redd(s) were recorded on a data sheet each time a new redd or aggregation containing new redds was encountered. Only completed redds, identified by a pit and mound, were counted. Test redds (i.e., those without a completed pit and mound) were not included in the count. Only new redds (i.e., those observed for the first time) were summed across the survey weeks to produce the total redd count for the season.

Mean daily river discharge was obtained from USGS gaging stations 11516530, located in the Klamath River just downstream of IGD, and 11520500, located in the Klamath River near Seiad Valley.

Secchi disk depth was recorded each survey week in Reach R5 as measurement of water transparency, which can influence the observability of redds.

Adult and Age-2 Escapement Estimates

The total number of new redds in this survey was used to estimate the number of adult and jack (age-2 fish) fall Chinook Salmon spawners in the mainstem Klamath River between the Shasta River and Indian Creek. Assuming each redd represents one male and one female adult salmon, adult escapement (N_{adult}) was estimated by multiplying the total redd count (R) by two:

$$\widehat{N}_{adult} = 2R.$$

The age composition of mainstem Chinook Salmon from the IGD–Shasta River carcass survey (KRTT 2018a) was used as a surrogate for apportioning escapement by age class in the mainstem Klamath River below the Shasta River. In previous years, jack (age-2 fish) escapement (N_{jack}) was estimated in the following equation where P_{age2} is the jack proportion based on scale readings from the carcass survey:

$$\widehat{N}_{jack} = \frac{\widehat{N}_{adult}}{\left(1 - P_{age2}\right)} - \widehat{N}_{adult}\,.$$

An unusual abundance of jills (age-2 females) was observed in the mainstem Klamath River carcass survey (Iron Gate Dam–Shasta River) in 2017. To account for the presence of age-2 females we introduced an alternative method for estimating escapement from redd data in the mainstem river below the Shasta River.

To isolate redds constructed by *adult* (age-3+) females (R_a), we multiply the total redd count (R) by the proportion of adult females ($P_{f,a}$):

$$\widehat{R}_a = R * \widehat{P}_{f,a}.$$

Likewise, to isolate redds constructed by age-2 females (R_2), we multiply the redd count (R) by the proportion of age-2 females ($P_{f,2}$):

$$\widehat{R}_2 = R * \widehat{P}_{f,2}.$$

Assuming each redd also represents one adult male salmon (i.e., $R = N_{m,a}$), R_a was added to R to estimate adult escapement (N_a):

$$\widehat{N}_a = \widehat{R}_a + R.$$

We then use the age-2 male proportion ($P_{m,2}$) determined from the scale readings and the assumed adult male escapement ($N_{m,a}$; equal to R) to estimate jack escapement ($N_{m,2}$):

$$\widehat{N}_{m,2} = \frac{\widehat{N}_{m,a}}{\left(1 - \widehat{P}_{m,2}\right)} - \widehat{N}_{m,a}.$$

The total male *and* female age-2 escapement (N_2) estimate is then:

$$\widehat{N}_2 = \widehat{N}_{m,2} + \widehat{R}_2.$$

Egg Deposition

Total egg deposition (N_e) in the redd survey area was estimated by multiplying predicted egg production (n_e) by the total redd count (R):

$$\widehat{N}_e = n_e * R\,.$$

We used the 2017 mean egg production per female at IGH ($\bar{n}_e$ = 2,551; Pomeroy 2018) as a surrogate for mainstem spawning female Chinook Salmon.

Results and Discussion

Survey Conditions

River Discharge

In 2017, mean daily discharge in the mainstem Klamath River below IGD ranged between 1,000 and 1,270 ft^3/s throughout the entire redd and most of the carcass survey periods (Figure 4). Only during the last three carcass survey days was mean daily discharge higher, when it increased to 1,490 ft^3/s. Discharge near Seiad Valley ranged between 1,410 and 1,850 ft^3/s from the beginning of the redd survey period until November 19. Starting November 20, precipitation caused the mean daily discharge near Seiad Valley to increase to 3,630 ft^3/s, after which discharge then decreased to 2,420 ft^3/s by the end of the redd survey period. The highest discharge of the season coincided with the week when the redd survey was not conducted (calendar week 47). We believe that the changes in flow had little effect on the overall redd count.

Water Transparency

Secchi disk depth readings ranged between 2.4 and 3.0 m during the first eight weekly carcass surveys before dropping to 2.1 m during the last survey week when flows increased (Figure 4). We believe this range in transparency only minimally influenced carcass observation efficiency. Secchi disk depth readings ranged between 2.0 and 2.7 m during the first four redd survey weeks and between 1.2 and 1.5 m during the later surveys when flows were higher. The ability to see redds may have been negatively affected during those weeks with poorer transparency, but we believe that overall redd count was not compromised.

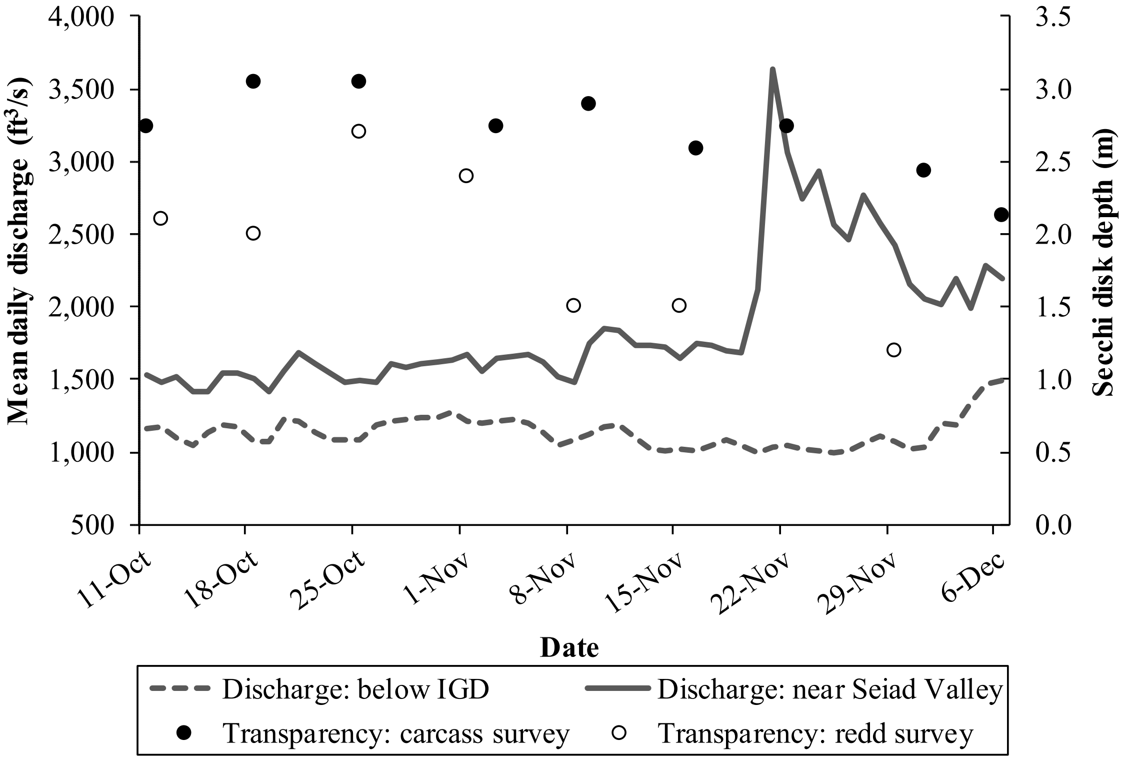

Figure 4. Mean daily discharge below Iron Gate Dam (USGS gaging station 11516530) and near Seiad Valley (USGS gaging station 11520500) from October 11 to December 6, 2017, and water transparency (Secchi disk depth) readings taken each survey week in Reaches C8 and R5.

Carcass Survey

Temporal and Spatial Distribution of Carcasses

A total of 1,222 F_1- and D_2-condition carcasses were counted during the 2017 surveys, of which 47 were counted in survey week 7 (calendar week 47) when a systematic sampling rate of 1-in-2 was implemented (Table 3). The peak of new carcass observations, which typically occurs in calendar weeks 44–46, occurred in calendar week 44 in 2017. Carcass density in Reach C1 was relatively low compared to previous years and in relation to the other reaches in 2017, but like previous years, carcass density was still highest in the upper reaches (C1C5; Figure 5).

Length Distribution

Mean fork lengths of adult females, jills, adult males, and jacks were 66.8, 54.0, 76.5, and 53.1 cm, respectively (Table 4). Adults were differentiated from jacks and jills using scale ages from 2017. From 2001 to 2016, a fork length was determined from length–frequency distributions to separate adults from jacks. For comparison purposes, the jack–adult male and jill–adult female size cut-offs in 2017 were 64 and 55 cm FL, respectively (Appendix A).

Table 3. Number of F_1- and D_2-condition fall Chinook Salmon carcasses observed by calendar week, Klamath River surveys, 2001–2017. 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	173	715	**898**	566	124	46	4	-	2,555
2015	5	16	70	**203**	133	99	39	14	1	-	580
2016	1	7	45	**84**	**84**	14	9	10	3	-	257
2017	8	42	145	**404**	388	185	94	2	1	-	1,269

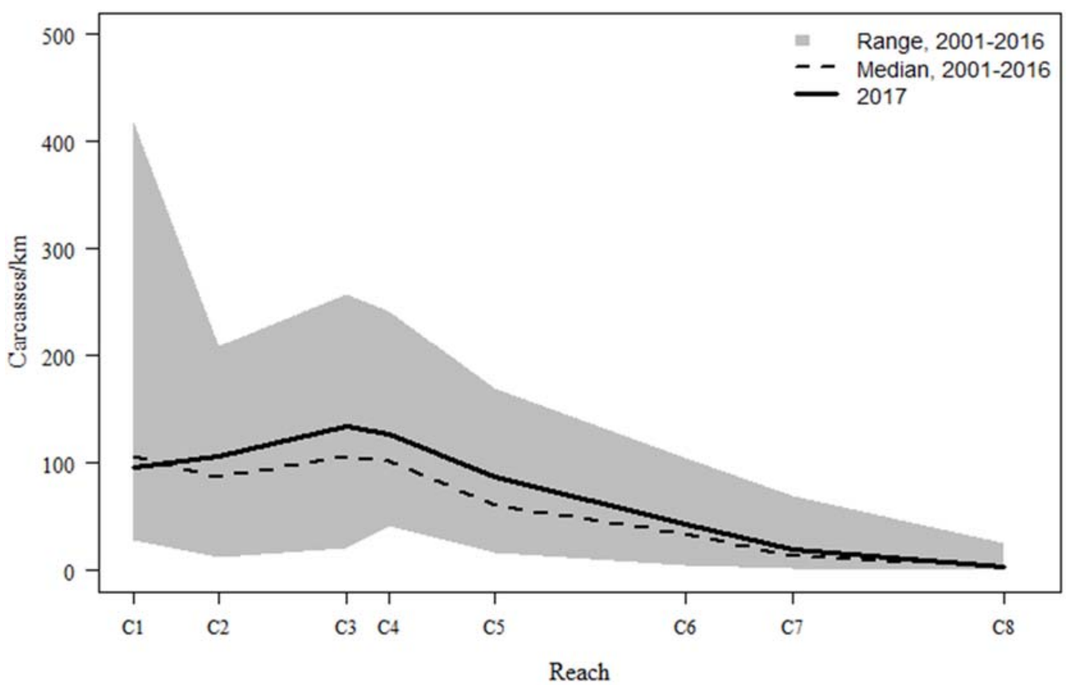

Figure 5. Fall Chinook Salmon carcass density (from *counts* of F_1- and D_2-condition carcasses only) by reach, 2017 Klamath River surveys compared to the range and median from 2001 to 2016. Reach C1 was not surveyed from 2002 to 2005.

Table 4. Mean fork lengths by year of fall Chinook Salmon carcasses, Klamath River surveys, 2001–2017.From 2001 to 2016, when age-2 females were few, the term 'jack' was used to refer to all age-2 fish, regardless of sex. Also, adults were distinguished from 'jacks' using annual fork-length size cutoffs from 2001 to 2016. In 2017, adults, jacks (i.e., true jacks), and jills were identified using scale ages.

Year	Jack–adult FL (cm) cut-off (jacks ≤)	Adult females FL (cm)		Adult males FL (cm)		Jacks FL (cm)	
		mean	s.d.	mean	s.d.	mean	s.d.
2001	63	76.3	6.3	85.4	9.6	53.8	6.3
2002	63	75.8	6.9	82.7	9.2	56.0	6.6
2003	55	76.9	7.8	87.0	10.2	48.0	5.4
2004	57	78.9	7.3	87.3	9.7	50.7	5.4
2005	52	73.7	7.6	83.3	9.7	47.0	4.3
2006	60	74.5	6.9	84.0	9.8	52.6	5.7
2007	51	66.6	5.3	77.2	10.0	46.5	3.5
2008	59	76.8	6.4	84.0	12.0	53.4	4.9
2009	58	73.2	5.7	83.0	8.4	51.6	4.1
2010	61	78.9	6.3	85.4	9.2	55.8	4.5
2011	63	76.6	7.2	84.2	9.9	56.6	4.4
2012	58	71.0	4.9	78.0	8.0	51.7	4.4
2013	57	75.1	6.7	81.4	9.9	51.4	4.3
2014	60	75.8	6.3	83.1	9.9	54.1	4.7
2015	54	71.3	6.0	80.6	9.2	49.8	3.7
2016	55	73.0	6.3	79.4	10.4	49.5	5.1
2017	64[a],55[b]	66.8	6.0	76.5	7.6	53.1[a],54.0[b]	4.7[a],5.1[b]

[a] true jacks (age-2 males)
[b] jills (age-2 females)

Adult Female–Male Ratio

The percentage of females among handled adult carcasses, identified by scale age, was 65.4% (adult female–male ratio = 1.9:1) in 2017 (Figure 6). Between 2001 and 2016, when adults were identified by size, the percentage of females ranged from 51.8% (adult female–male ratio = 1.1:1) to 72.9% (2.7:1). 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). Reach C8 did not have a large enough sample size (n = 2) to include in this inference. Compared to adult Chinook Salmon that returned to IGH, the percentage of returning adults that were female was 6.7% higher in the mainstem (Appendix C).

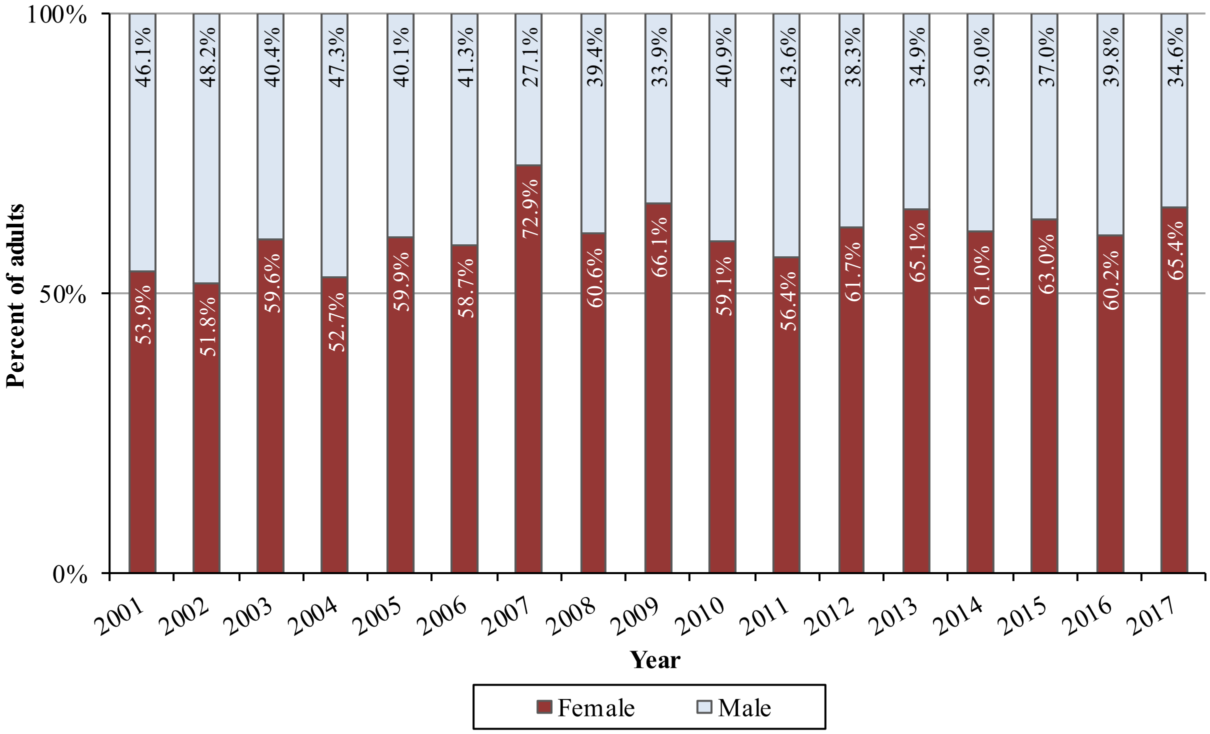

Figure 6. Female and male proportions of adult fall Chinook Salmon carcasses, Klamath River surveys, 2001–2017.Adults were distinguished from jacks using a fork length size cutoff in 2001–2016. In 2017, adults were identified using scale ages.

Pre-spawn Mortality

Pre-spawn mortality was 5.5% in 2017 (Figure 7). Fully spawned individuals made up 92.5% 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 8.3%. 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 2017 was highest during the first two survey weeks (Figure 8; Appendix D).

Escapement Estimates and Age Composition

The mainstem spawning escapement estimate in this study area for 2017 was 4,740 Chinook Salmon (95% CI: 3,955–6,564; Table 5). Uniquely numbered jaw tags were applied to 1,161 carcasses. The estimated weekly recapture rates for carcasses captured one week after tagging ranged from 0.28 to 0.40. The first three recapture weeks of mark–recapture data were combined, as were the last two 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 (79.4%) of carcasses in 2017 were found in the first five survey reaches, indicating that most

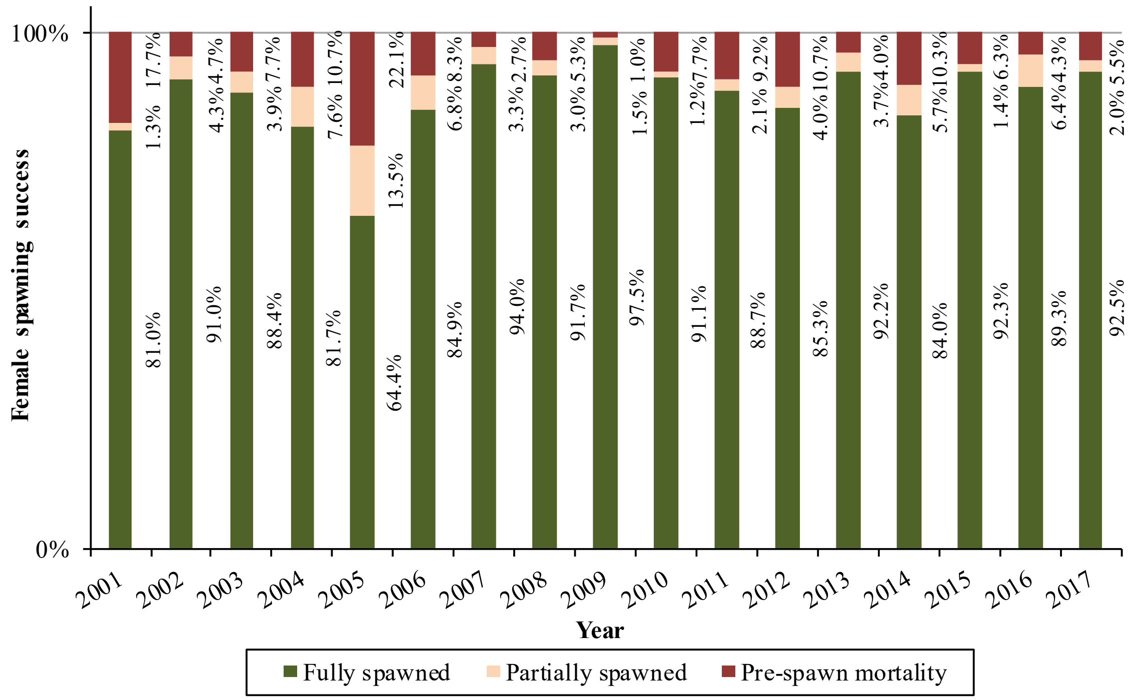

Figure 7. Spawning success of female fall Chinook Salmon based on F_1- and D_2-condition carcasses, Klamath River surveys, 2001–2017.

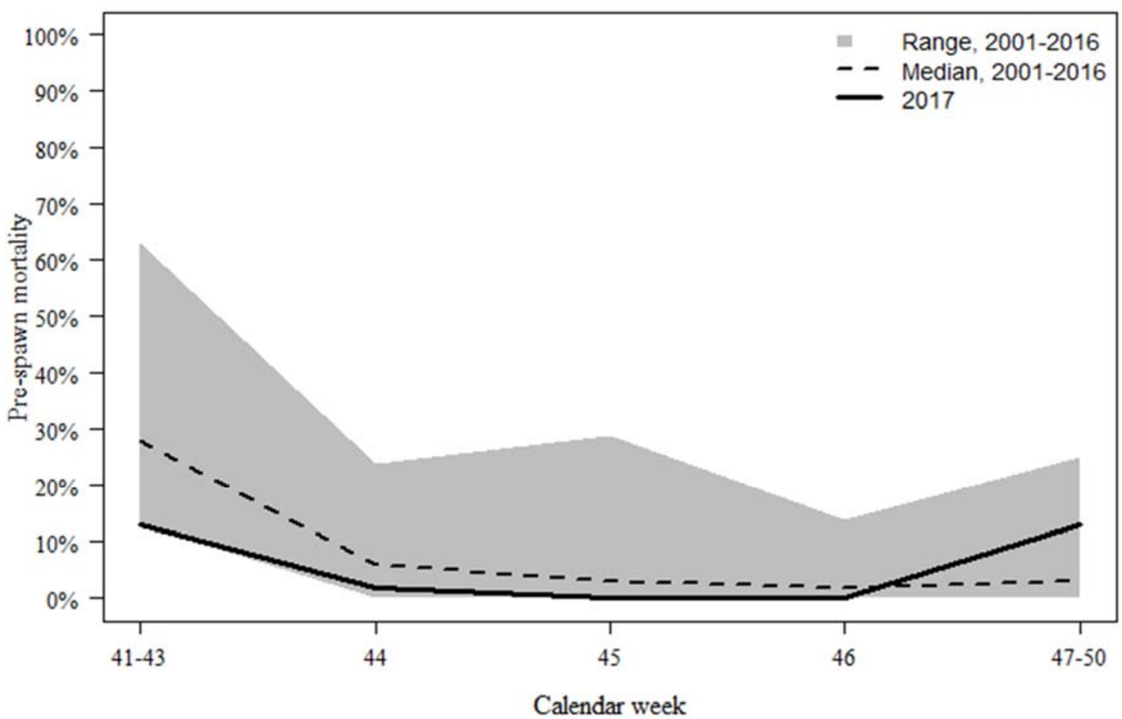

Figure 8. Weekly pre-spawn mortality from F_1-condition female fall Chinook Salmon carcasses, 2017 Klamath River surveys compared to the range and median from 2001 to 2016. Calendar weeks 41–43 and 47–50 were combined since sample sizes were typically low in calendar weeks 41, 42, 48, 49, and 50, if surveyed.

Table 5. Fall Chinook Salmon escapement estimates, Klamath River surveys, 2001–2017. AUC =area-under-the-curve; HLVM = hierarchical latent variables model.

Year	Escapement estimate	95% confidence limits		Estimator
		Lower	Upper	
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
2017	4,740	3,955	6,564	HLVM

spawning activity occurred in the upper 9.0 km of the 21.2 km of surveyed area. Few, if any, of 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.

Six hundred forty-one scale samples were collected from carcasses and analyzed in 2017 to estimate the age composition of the mainstem spawning escapement. Based on age-composition estimates (KRTT 2018a) and the total escapement estimate, age-2 fish represented 36.9% ($\widehat{N}_2$ = 1,749) of the total escapement (Table 6). The proportion of males designated as jacks by the fork length cut-off was 4.5% higher than that determined to be 2-year olds by scale aging. The proportion of females designated as jills by the fork length cut-off was 1.1% lower than that determined to be 2-year olds by scale aging. The majority (50.1%) of the 2017 run returning to the study area were age-3 fish ($\widehat{N}_3$ = 2,376).

Adult Chinook Salmon spawners in the mainstem Klamath River between IGD and the Shasta River confluence accounted for 76.5% of natural-area adult spawners in the mainstem Klamath River above Wingate Bar, 21.6% in the Klamath River Basin above the Trinity River, and 16.2% in the entire Klamath River Basin in 2017 (Table 7). In the entire Klamath River Basin, fall Chinook Salmon adult spawners in the mainstem Klamath River

Table 6. Fall Chinook Salmon spawning escapement estimates (and percent of total run) for each age class, Klamath River surveys, 2001–2017. Note: Adults are ages 3–5.

	Age				
Year	2	3	4	5	Adults [a]
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
2017	1,749 (36.9%)	2,376 (50.1%)	550 (11.6%)	65 (1.4%)	2,991

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

between IGD and the Shasta River confluence accounted for 10.1% of total adult escapement (hatchery and natural spawners) and 9.4% of the total adult in-river run (hatchery and natural spawners plus in-river harvest) in 2017. The proportion of natural spawners in the IGD–Shasta study area has trended downward over the 17-year history of these surveys at all these scales, but only significantly above Indian Creek ($p < 0.01$) and above the Trinity River ($p = 0.02$; Appendix E). 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); 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. Evidence supporting this hypothesis include 1) a downward trend in the number of hatchery-origin Chinook Salmon that returned to IGH from 2001 to 2017 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 2017 (Appendix F). A number of larger-scale environmental factors may have also affected the population dynamic and determining the cause will require further investigations.

Table 7. 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, 2001–2017. Data compiled from KRTAT (2003–2004), KRTAT (2005–2009), and KRTT (2010–2017, 2018a).

Year	Mainstem Klamath R. natural spawners IGD to Indian Cr.[b]	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%
2017	76.5%	21.6%	16.2%	10.1%	9.4%

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

[b] IGD to Wingate Bar in 2017

Hatchery Fish Contribution

Snout samples were collected from 60 F_1- and D_2-condition ad-clipped carcasses encountered in 2017. Of these, CWTs from all 60 snouts were recovered and, of these, 56 were decoded (4 CWTs were lost; Appendix G). All CWTs recovered were from fish from Brood Years 2012–2015 with production multipliers that ranged from 4.00 to 4.05. The estimated proportion of hatchery-origin spawners in the study area was 19.8% (n = 939; 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 2016.

Consistent with previous years, the proportion of hatchery-origin Chinook Salmon in 2017 was highest in Reach C1 (91.8%; 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 C2 to Reach C8, ranging between 0.0% and 26.8%.

Table 8. Hatchery composition of fall Chinook Salmon spawning escapement in the mainstem Klamath River from IGD to the Shasta River confluence, based on carcass surveys, 2001–2017. See Appendix G 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
2017	19.8%	4,740	939

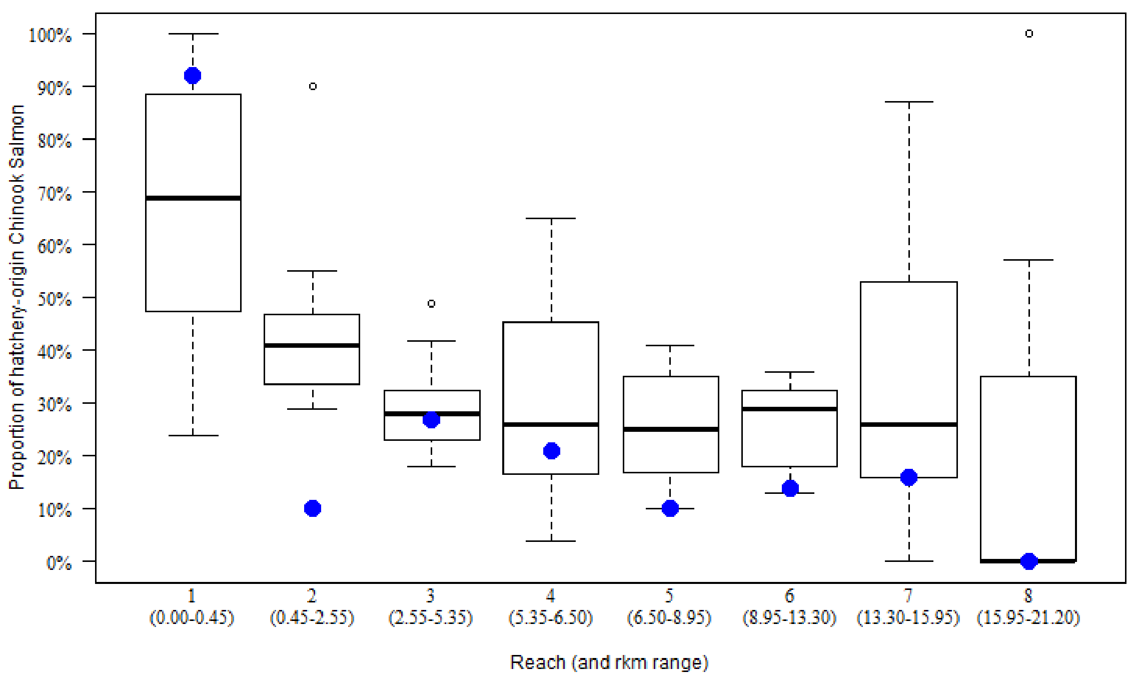

Figure 9. Box plot of proportions of hatchery-origin Chinook Salmon carcasses by reach, Klamath River surveys, 2007–2017. Data from 2017 are represented with solid circles.

Egg Deposition

Egg deposition in the carcass survey study area was estimated to be 4.9 million from 1,957 female Chinook Salmon in 2017 (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).

Redd Survey

Redd Counts and Distribution

Four hundred seventy-eight redds were observed between the Shasta River confluence and Wingate Bar in 2017 (Reaches R2–R7; Table 10). This count is the third lowest in the history of the survey and 2.6 times less than the previous 24-year mean (1,242; Figure 10; Figure 11; Appendix H). When only Reaches R2–R6 are considered, the redd count in 2017 is the fifth lowest on record.

Peak counts of new redds occurred during CW 43 and 44 in 2017 (Table 10). This is consistent with previous years' peak counts of new redds, which typically occurred in CW 43 or 44 (mid to late October; Romberger and Bell 2017). The highest concentration of redds was in Reach 6 (10.4 redds/km) and the lowest was in Reach 3 (2.5 redds/km; Appendix I).

Table 9. Egg deposition (N_e) by fall Chinook Salmon in the Klamath River from the carcass survey between IGD and the Shasta River confluence, 2001–2017. F_{fs} and F_{ps} are escapement of fully and partially spawned females and $\bar{n}_e$ is the mean number of eggs produced per female at IGH.

Year	$\hat{F}_{fs}$	$\hat{F}_{ps}$	$\bar{n}_e$	$\hat{N}_e$
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
2017	1,916	41	2,551	4,900,000

Table 10. Weekly summary of mainstem Klamath River fall Chinook Salmon redd counts 2017. NS = no survey.

Calender week	Survey dates	Reach							Total
		R1[d]	R2[a]	R3[b]	R4[a]	R5[b]	R6[c]	R7[e]	
41	Oct. 11-13	NS	0	3	0	11	17	5	36
42	Oct. 17-19	NS	14	15	10	24	43	1	107
43	Oct. 24-26	NS	30	17	21	11	42	2	123
44	Oct. 31-Nov. 2	NS	6	12	5	20	78	2	123
45	Nov. 7-9	NS	12	21	21	14	9	NS	77
46	Nov. 14-16	NS	6	1	0	0	5	NS	12
47	Nov. 21-23	No Survey (Thanksgiving week)							
48	Nov. 28-30	NS	0	0	0	0	0	NS	0
Reach Total		-	68	69	57	80	194	10	478
Percent of Total		-	14.2%	14.4%	11.9%	16.7%	40.6%	2.1%	
Redd Density		-	2.6/km	2.5/km	2.8/km	3.8/km	10.4/km	0.89/km	

[a] surveyed by Karuk Tribe crew
[b] surveyed by USFWS crew
[c] reach split and surveyed by Karuk Tribe and USFWS crews
[d] Reach 1 not surveyed for Redds
[e] In 2017 below Indian Creek was surveyed for redds to asses spawning downstream

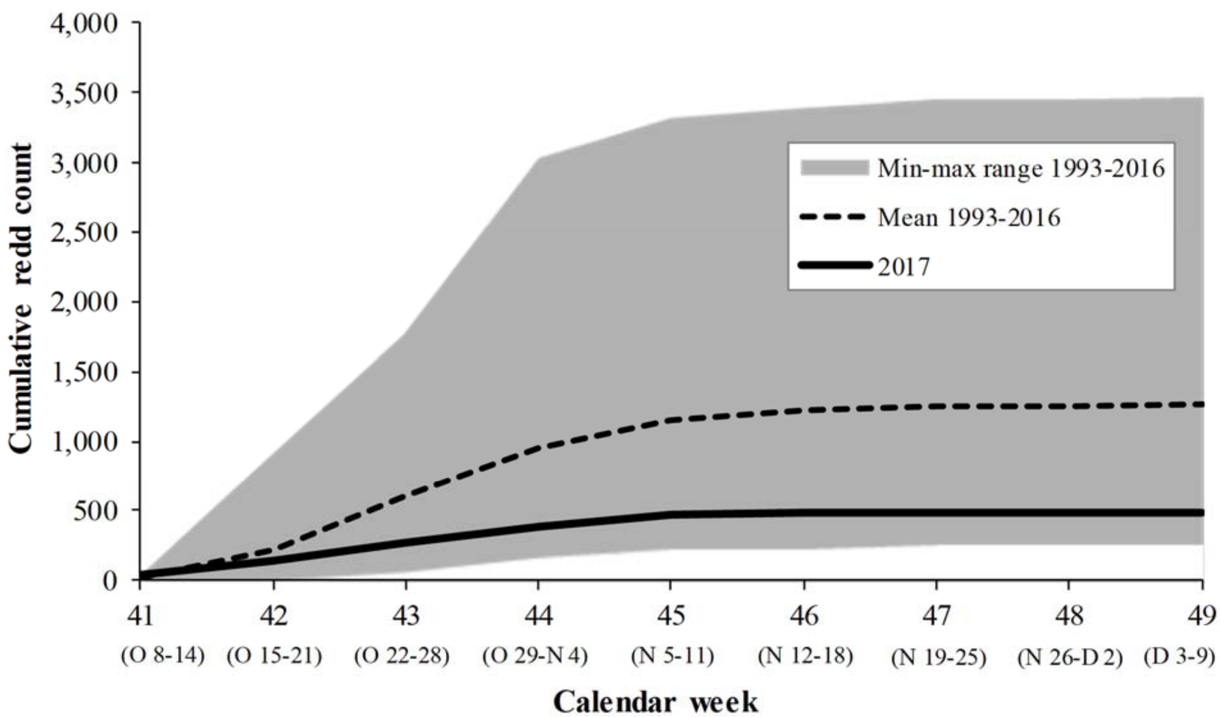

Figure 10. Cumulative Chinook Salmon redd counts by calendar week, 2017 Klamath River surveys compared to the range and mean from 1993 to 2016.

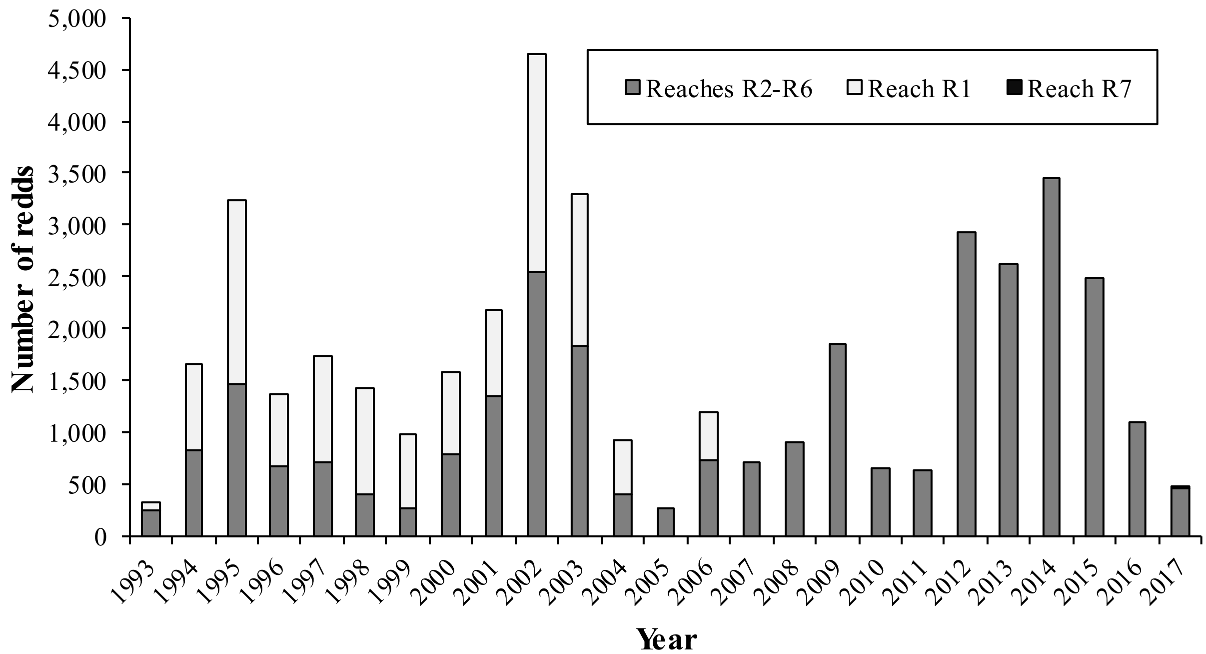

Figure 11. Mainstem Klamath River fall Chinook Salmon redd counts, 1993–2017. Reach R1 was surveyed from 1993 to 2004 and in 2006. Reach R7 was only surveyed in 2017.

In Reaches R2 and R4, redds were unevenly distributed with small aggregations of typically less than 10 redds (Appendix I). Reach R3 was characterized by redds more evenly distributed with most spawning locations each having between one and five redds. In Reach R5, a relatively large aggregation of 40 redds was about 1 km upstream of the confluence with Grider Creek followed by a few aggregations of 10 or less redds as well as some areas with a single redd. Reach R6 contained the single largest aggregation of redds (44; about 0.5 km downstream of Woods Creek) in this survey year and aggregations of 20 or less redds interspersed. Reach R7 had one aggregation of 6 redds near the confluence with Curly Jack Creek and three more areas with just one or two redds each. See Appendix I for maps of redd distribution by reach.

Escapement Estimates

Scale ages from mainstem Klamath River carcasses revealed that 53.4% of males and 8.2% of females were age-2 (KRTT 2018a). After multiplying the redd count by the age-2 female (jill) proportion, 439 redds were estimated to have been constructed by adult females and 39 by jills. Assuming each redd represents one adult male salmon, the total adult escapement was estimated to be 917 (439 adult females and 478 adult males). After applying the surrogate age-2 male (jack) proportion, the total age-2 escapement was estimated to be 587 (548 jacks and 39 jills).

Egg Deposition

Using the mean number of eggs produced per female at IGH ($\bar{n}_e$ = 2,551), egg deposition in the redd survey study area was estimated to be 1.2 million from the 478 redds counted in 2017.

Acknowledgements

We particularly thank the Karuk Tribe Department of Natural Resources and Yurok Tribal Fishery Program for their annual participation in this survey. Data were collected by AFWO personnel: Savannah Bell, Sterling Fulford, Sylvia Gwozdz, Michael Macon, Christian Romberger, and Brianna Walsh. Data were collected by Karuk Tribe personnel: Ken Brink, Sonny Mitchell, Mike Polmateer, and Clayton Tuttle. Data were collected by YTFP personnel: Rocky Erickson, Troy Fletcher Jr., and Gilbert Myers. We also thank Erik Kenas for cartographic support, and Bill Pinnix from AFWO for his editorial review of this report.

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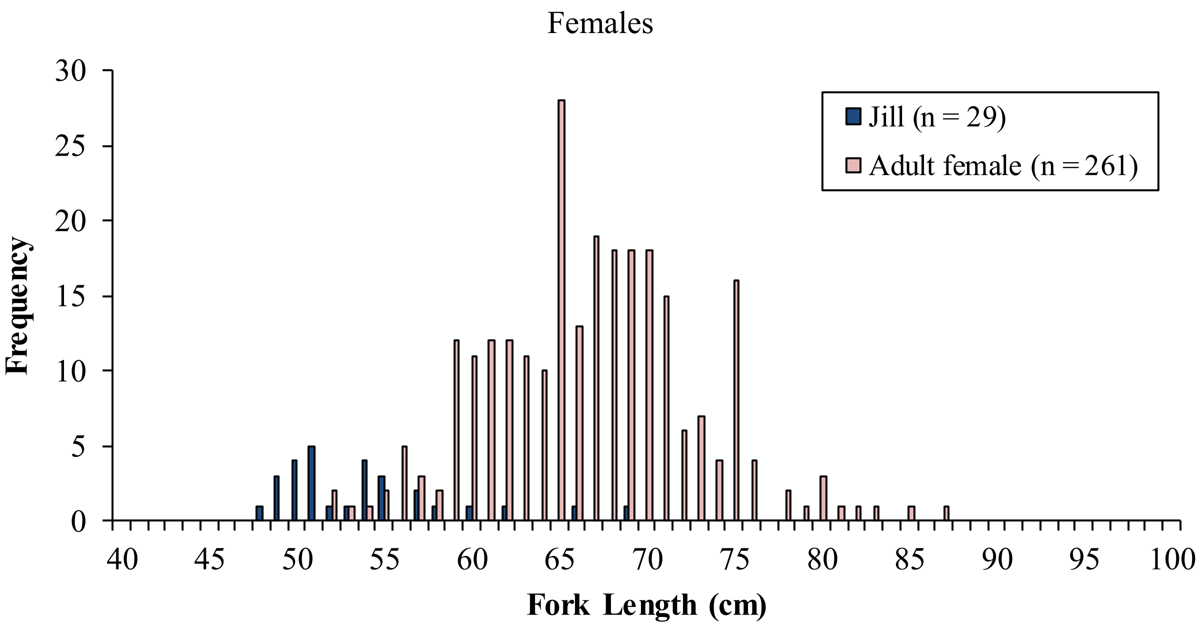
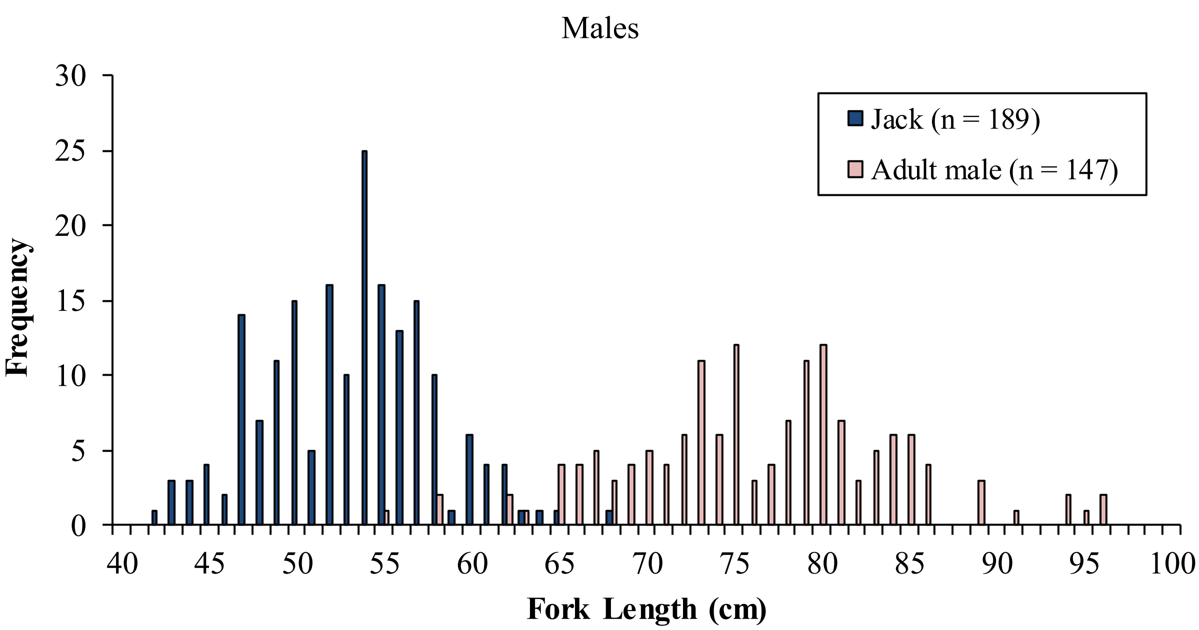
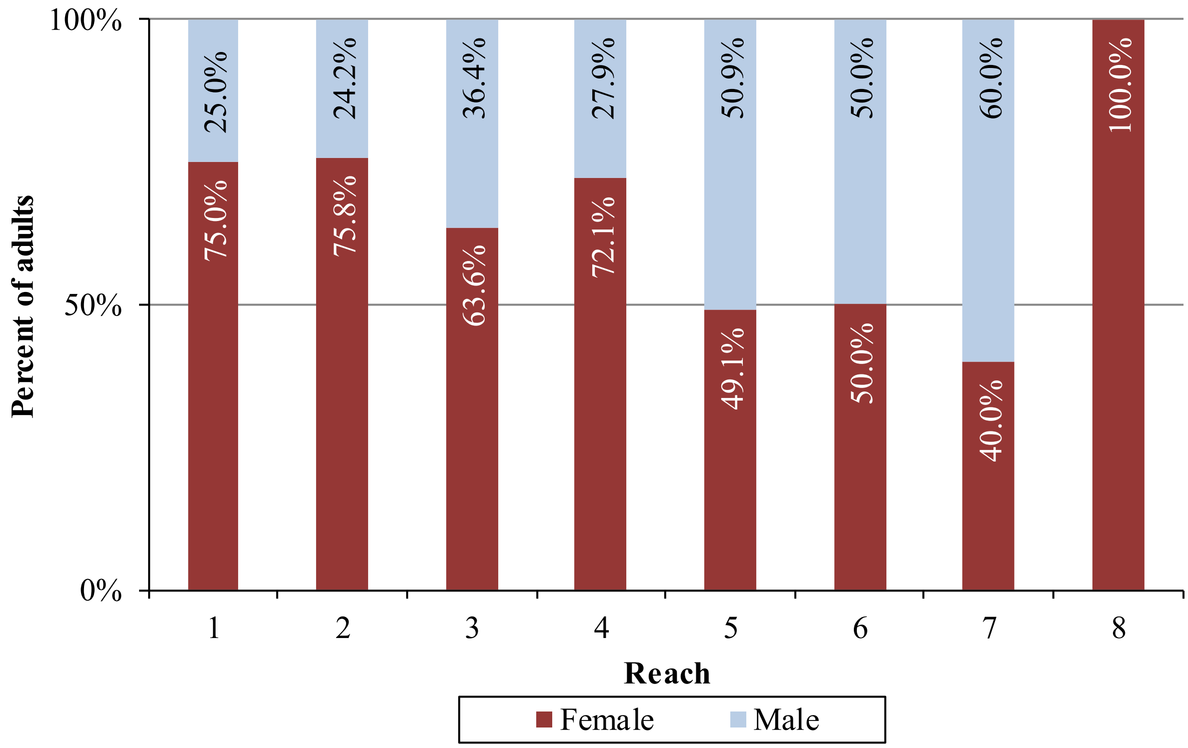
Appendices

Appendix A. Length-frequency of F_1- and D_2-condition fall Chinook Salmon carcasses, Klamath River surveys, 2017.n = 244 (n_F = 261; n_{Jill} = 29; n_M = 147; n_{Jack} = 189).





Appendix B. Proportions of adult female and male Chinook Salmon carcasses by reach, Klamath River surveys, 2017.

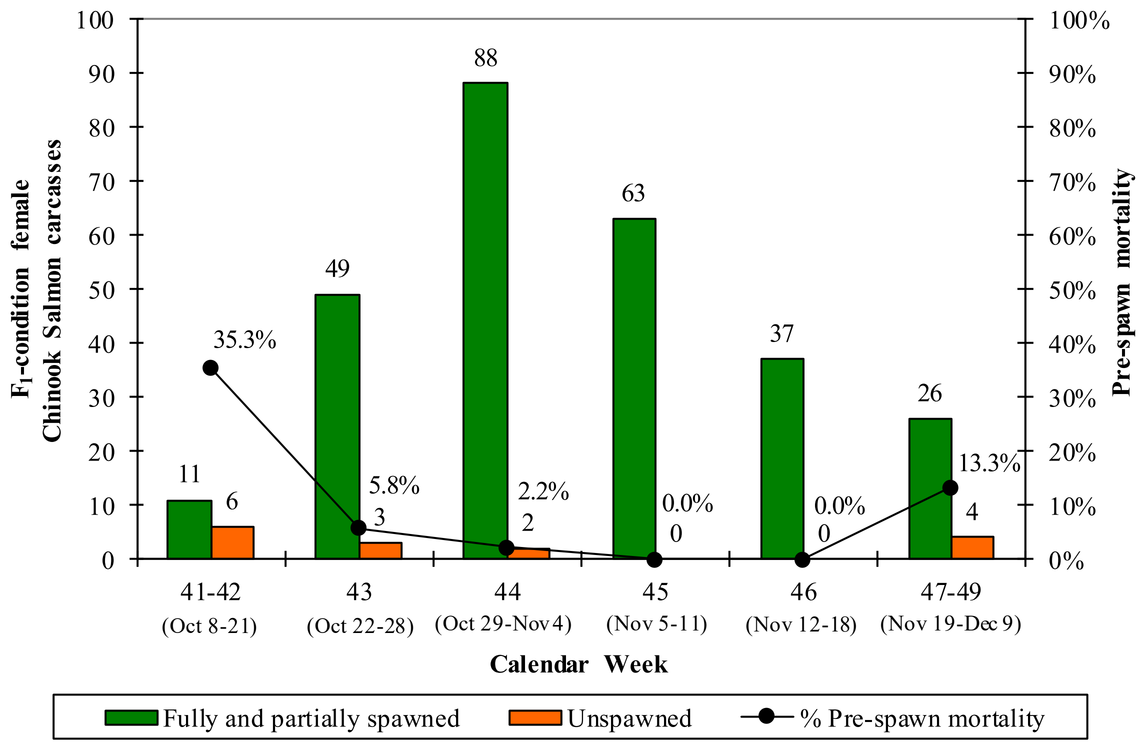


Appendix C. Proportions of female and male Chinook Salmon returning to IGH and the mainstem Klamath River, 2001–2017. IGH adult proportions were determined by first subtracting the jack percentage from the male percentage. Proportions of adult females and males were then recalculated from the remaining adult numbers. IGH data compiled from CDFG (2003), Hampton (2005), Richey (2006, 2007), Chesney (2007–2009), Chesney and Knechtle (2010–2017), and Giudice and Knechtle (2018).

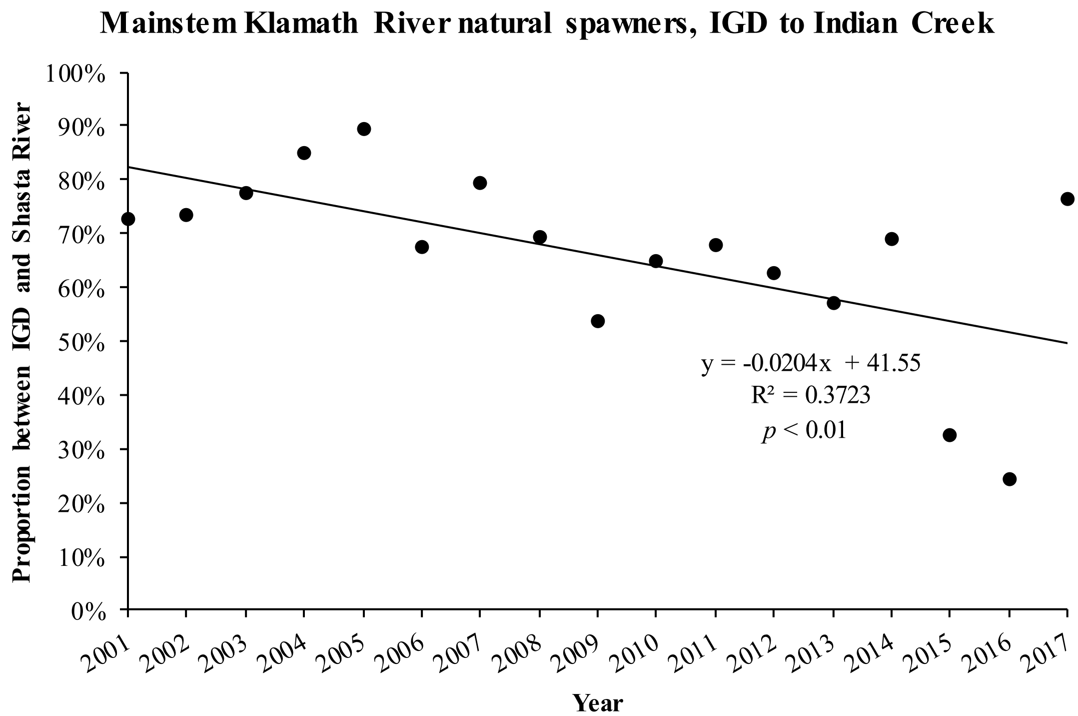
	IGH returns					Mainstem carcasses	
	Overall [a]			Adults		Adults	
Year	Female	Male	Jacks	Female	Male	Female	Male
2001	49.1%	50.9%	2.1%	50.1%	49.9%	53.9%	46.1%
2002	48.9%	51.1%	5.2%	51.6%	48.4%	51.8%	48.2%
2003	51.3%	48.7%	0.9%	51.8%	48.2%	59.6%	40.4%
2004	46.0%	54.0%	8.8%	50.4%	49.6%	52.7%	47.3%
2005	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%
2017	41.1%	58.9%	30.0%	58.7%	41.3%	65.4%	34.6%

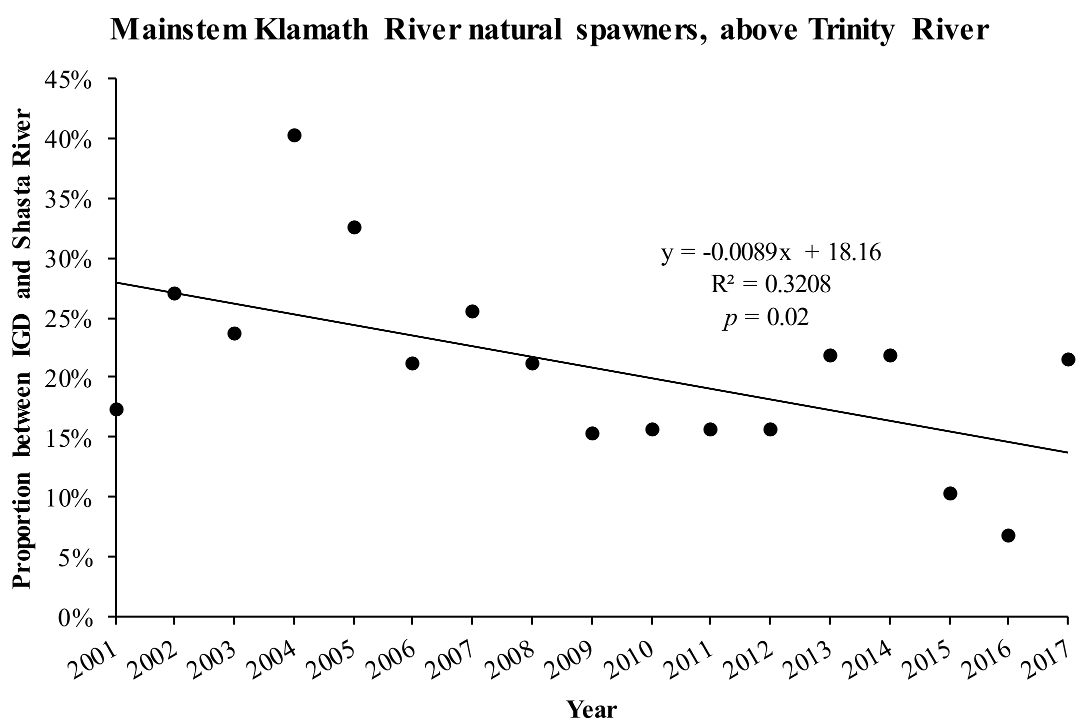
[a] Female and male proportions were calculated prior to distinguishing jacks and therefore total 100%

Appendix D. Weekly pre-spawn mortality from F_1-condition female fall Chinook Salmon carcasses, Klamath River surveys, 2017. Only F_1-condition carcasses were included since we can assume only those fish expired the week they were found. Calendar weeks 41–42 and 47–49 were combined since sample sizes were low.

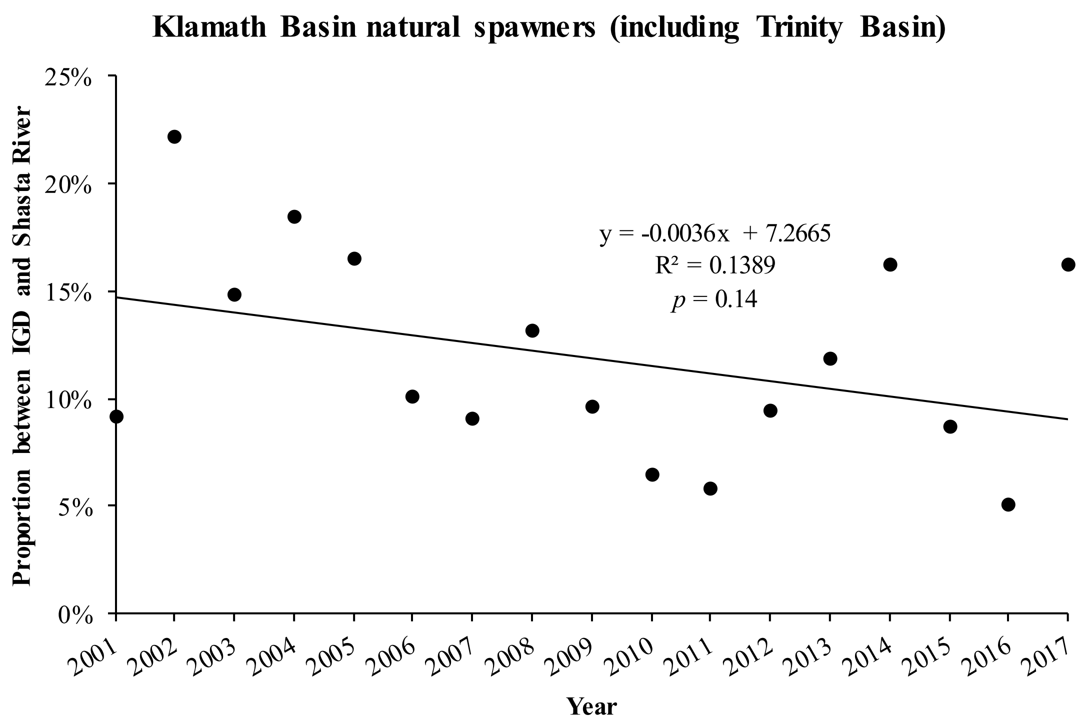


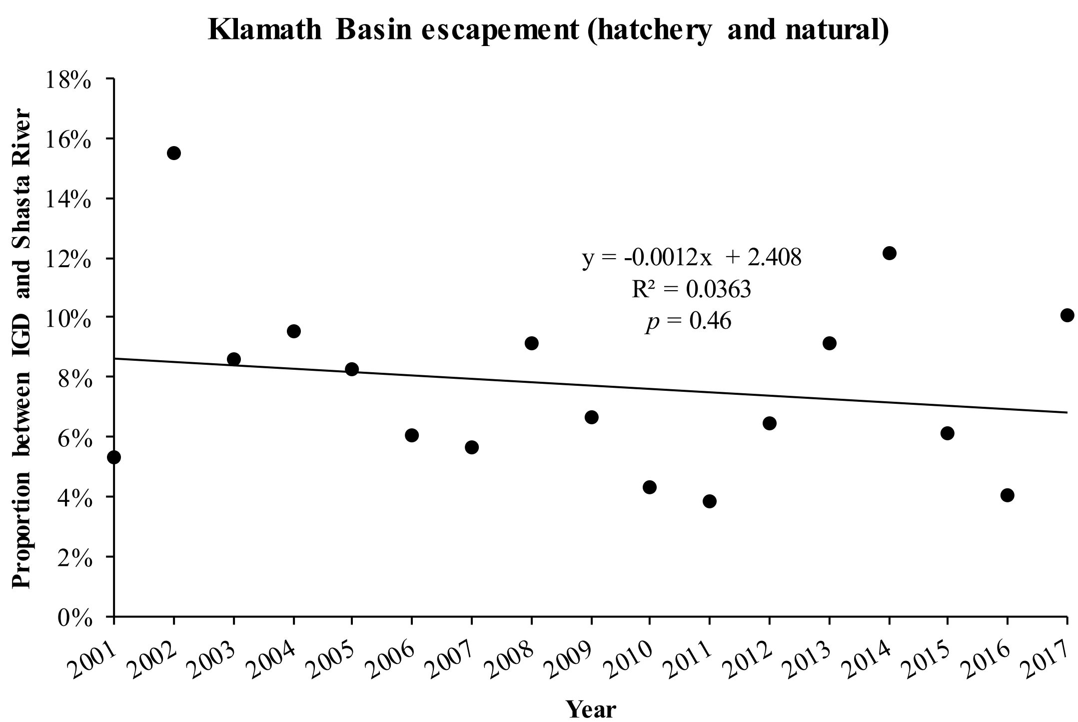
Appendix E. Proportions of fall Chinook Salmon adult spawners in the mainstem Klamath River from Iron Gate Dam to the Shasta River confluence within different scales of the Klamath River Basin, 2001–2017. Data compiled from KRTAT (2003–2004), KRTAT (2005–2009), and KRTT (2010–2017, 2018a).



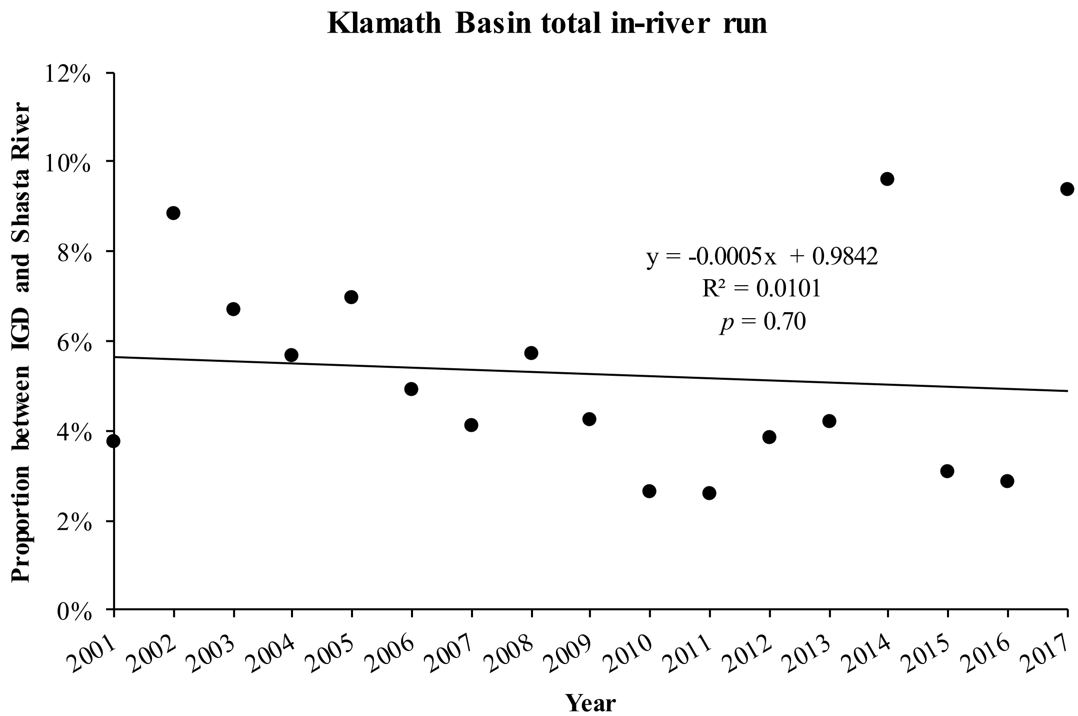


Appendix E (continued). Proportions of fall Chinook Salmon adult spawners in the mainstem Klamath River from Iron Gate Dam to the Shasta River confluence within different scales of the Klamath River Basin, 2001–2017. Data compiled from KRTAT (2003–2004), KRTAT (2005–2009), and KRTT (2010–2017, 2018a).

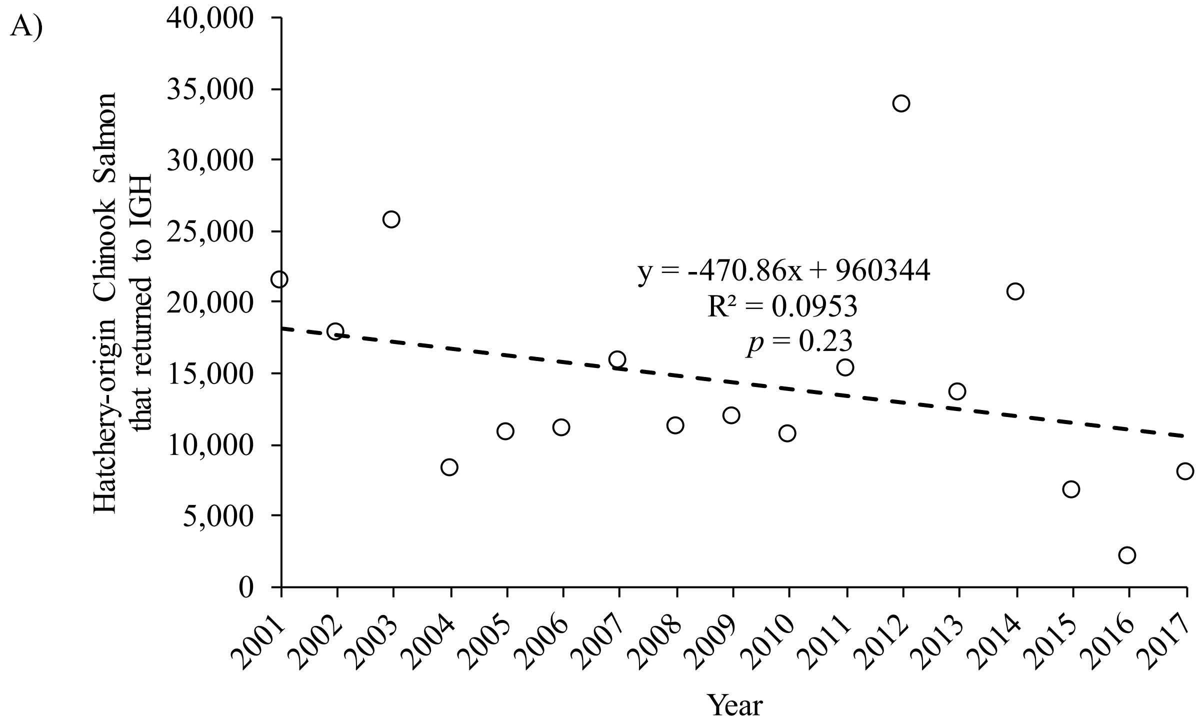


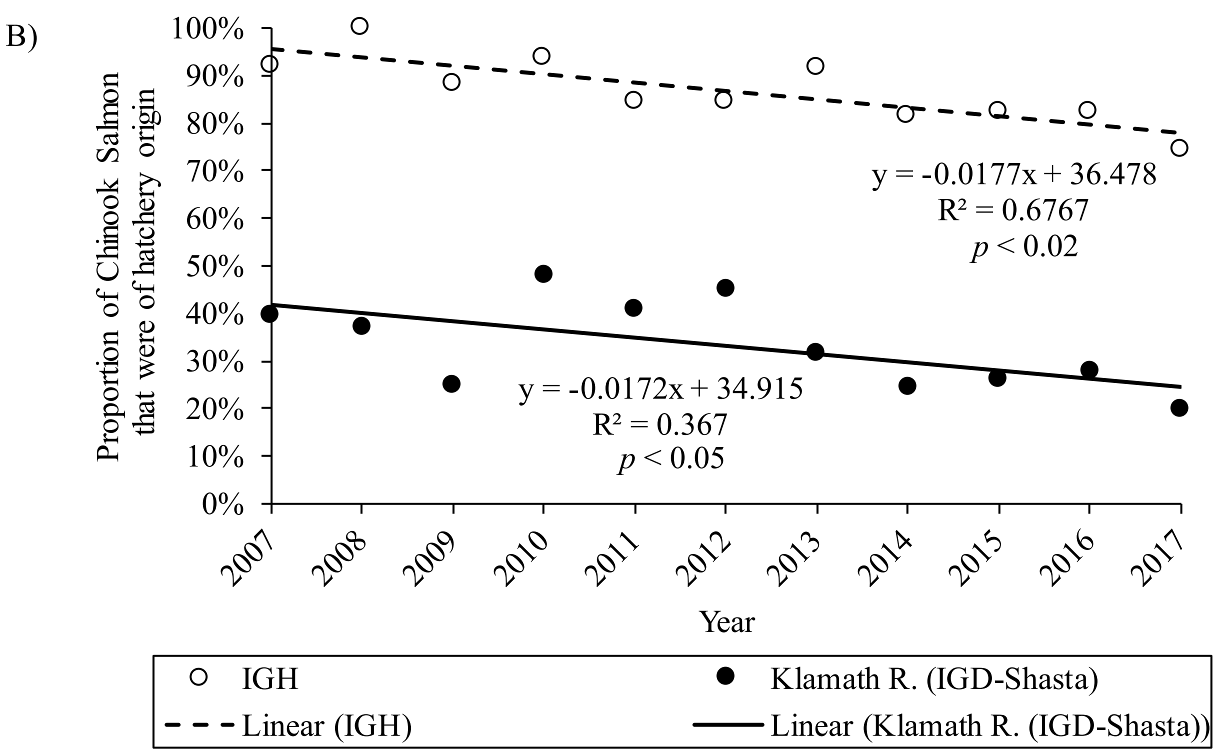


Appendix E (continued). Proportions of fall Chinook Salmon adult spawners in the mainstem Klamath River from Iron Gate Dam to the Shasta River confluence within different scales of the Klamath River Basin, 2001–2017. Data compiled from KRTAT (2003–2004), KRTAT (2005–2009), and KRTT (2010–2017, 2018a).



Appendix F. Numbers of hatchery-origin Chinook Salmon that returned to Iron Gate Hatchery (IGH) from 2001 to 2017 (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 2017 (B).





Appendix G. Hatchery composition of fall Chinook Salmon in the mainstem Klamath River, IGD to the Shasta River confluence, based on carcass surveys from 2001 to 2017. 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 2011–2017 results. Data from 2011 to 2017 are 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	$Adobs$	$P(AD\mid H)_{IGH}$	$\hat{H}$	$\hat{P}(H)$	$\hat{N}$	$\hat{N}_H$
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 [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
2017	1,262	60	60	60	56	249	19.8%	4,740	939

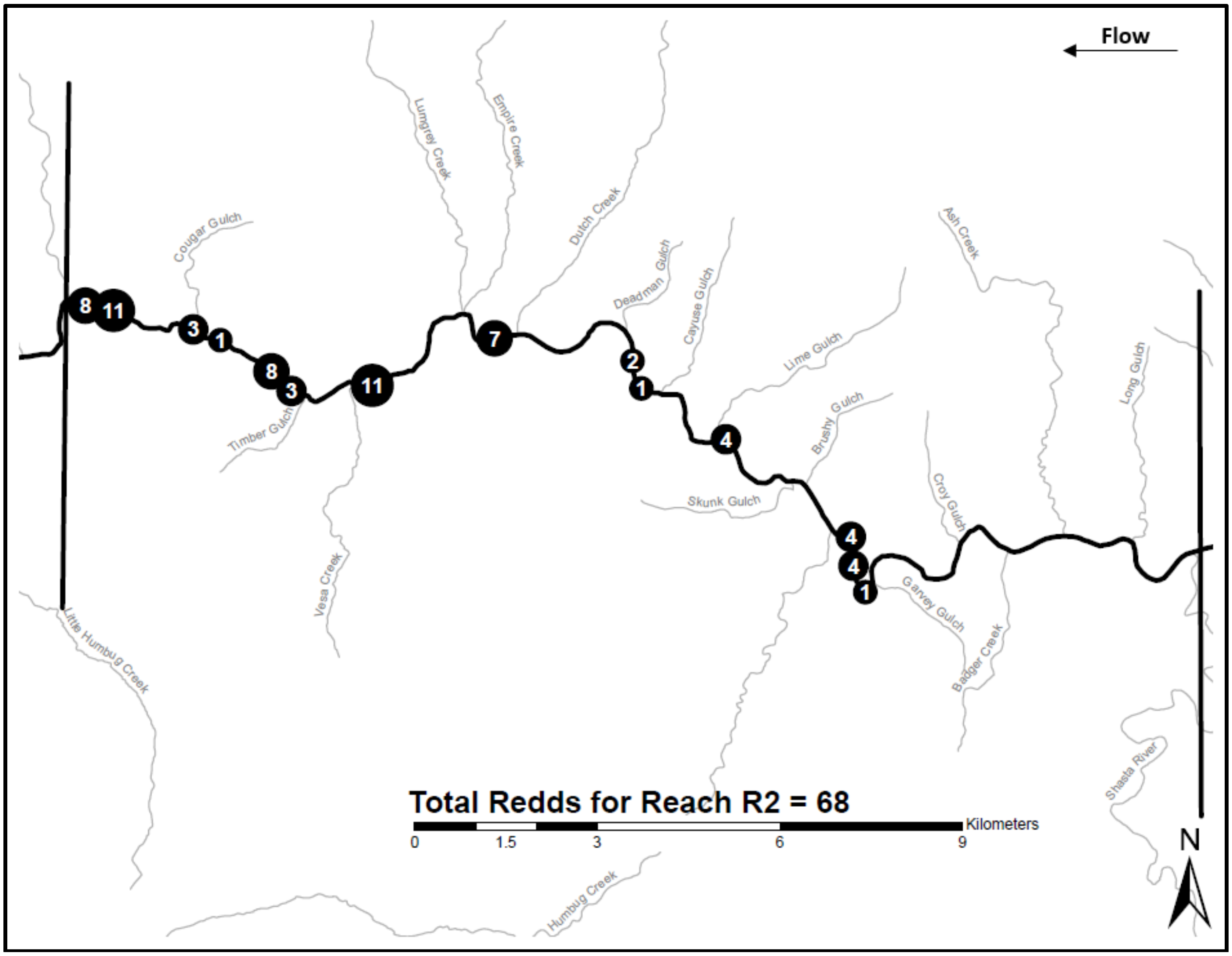
[c] systematic sampling rates have not yet been applied to ad-clip and CWT values (AD_{obs}, AD_{sample}, AD_{cwt}, and AD_{code})

Appendix H. Summary of annual mainstem Klamath River fall Chinook Salmon redd counts by reach, 1993–2017. R1 = Iron Gate Dam to Shasta River, R2 = Shasta River to Beaver Creek (note: the 2.7-km section from the Shasta River to Ash Creek was not surveyed and was assumed to have no redds), R3 = Beaver Creek to Blue Heron river access, R4 = Blue Heron river access to Seiad Bar, R5 = Seiad Bar to China Point, R6 = China Point to Indian Creek; Ns = no survey.

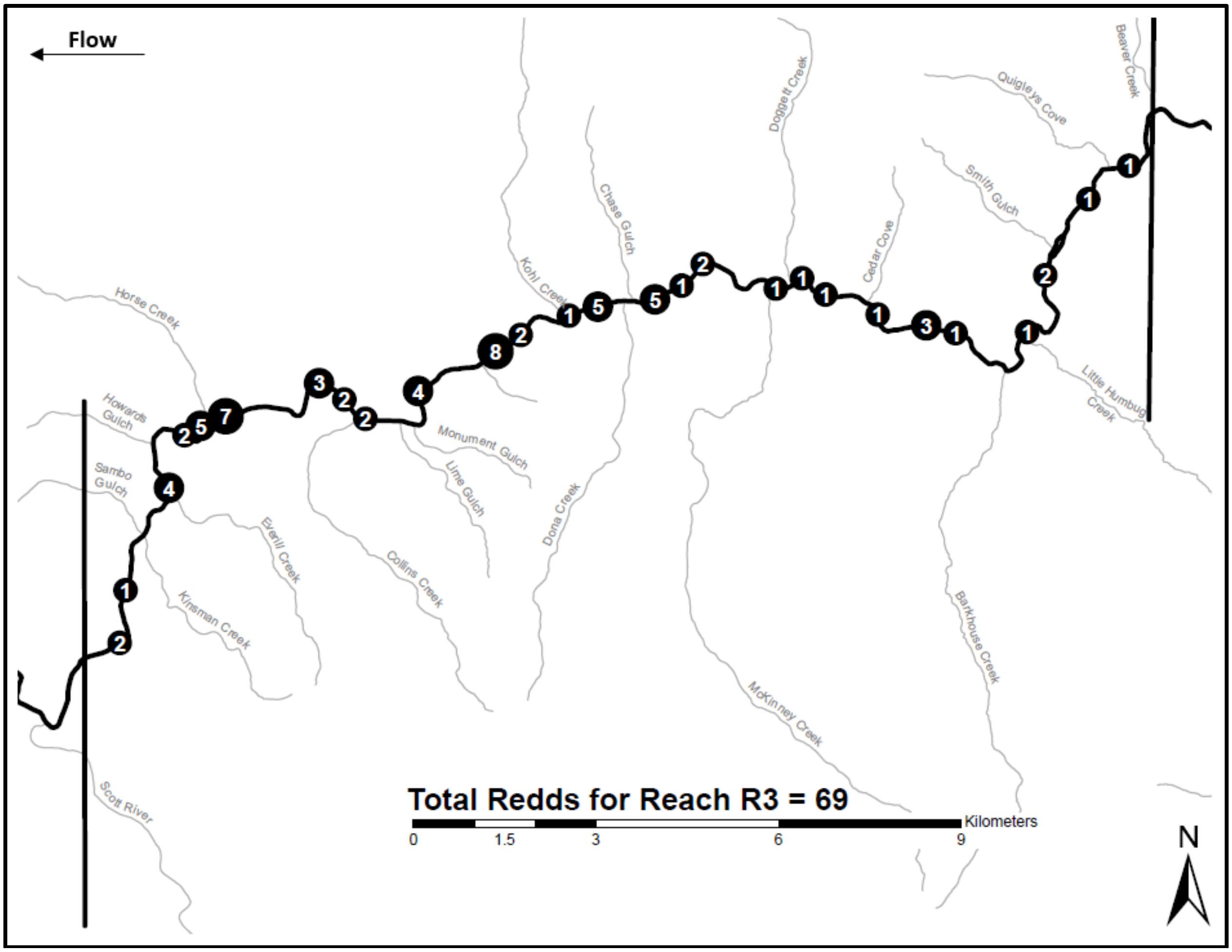
		Reach							
Year	Survey dates	R1	R2	R3	R4	R5	R6	R7	Total
1993	Oct 25 - Nov 18	87	38	56	31	31	87	-	330
1994	Oct 17 - Nov 18	831	109	178	159	119	260	-	1,656
1995	Oct 16 - Dec 1	1,779	187	410	172	215	473	-	3,236
1996	Oct 21 - Nov 15	704	64	151	40	200	213	-	1,372
1997	Oct 16 - Nov 14	1,020	76	162	162	62	257	-	1,739
1998	Oct 14 - Nov 19	1,010	82	126	42	39	116	-	1,415
1999	Oct 13 - Nov 19	723	69	62	28	38	69	-	989
2000	Oct 16 - Nov 22	789	208	196	164	42	180	-	1,579
2001	Oct 15 - Dec 14	830	269	435	220	140	278	-	2,172
2002	Oct 10 - Dec 6	2,113	566	726	441	311	495	-	4,652
2003	Oct 14 - Dec 3	1,472	343	484	292	285	426	-	3,302
2004	Oct 11 - Dec 3	513	117	134	55	48	49	-	916
2005	Oct 18 - Nov 17	-	39	40	46	28	115	-	268 [a]
2006	Oct 16 - Nov 29	453	57	117	146	71	342	-	1,186
2007	Oct 16 - Nov 29	-	89	136	138	65	284	-	712 [a]
2008	Oct 15 - Dec 4	-	147	135	170	92	354	-	898 [a]
2009	Oct 14 - Dec 4	-	201	345	342	218	734	-	1,840 [a]
2010	Oct 13 - Dec 2	-	87	57	148	61	293	-	646 [a]
2011	Oct 12 - Dec 1	-	34	105	72	92	328	-	631 [a]
2012	Oct 10 - Nov 28	-	230	555	348	490	1,309	-	2,932 [a]
2013	Oct 22 - Dec 5	-	253	582	468	406	902	-	2,611 [a]
2014	Oct 7 - Dec 4	-	314	877	652	548	1,065	-	3,456 [a]
2015	Oct 6 - Dec 3	-	298	421	734	240	799	-	2,492 [a]
2016	Oct 4 - Dec 1	-	112	173	124	241	447	-	1,097 [a]
2017	Oct 10 - Nov 30	-	68	69	57	80	194	10	478 [a,b]

[a] Reach R1 not surveyed

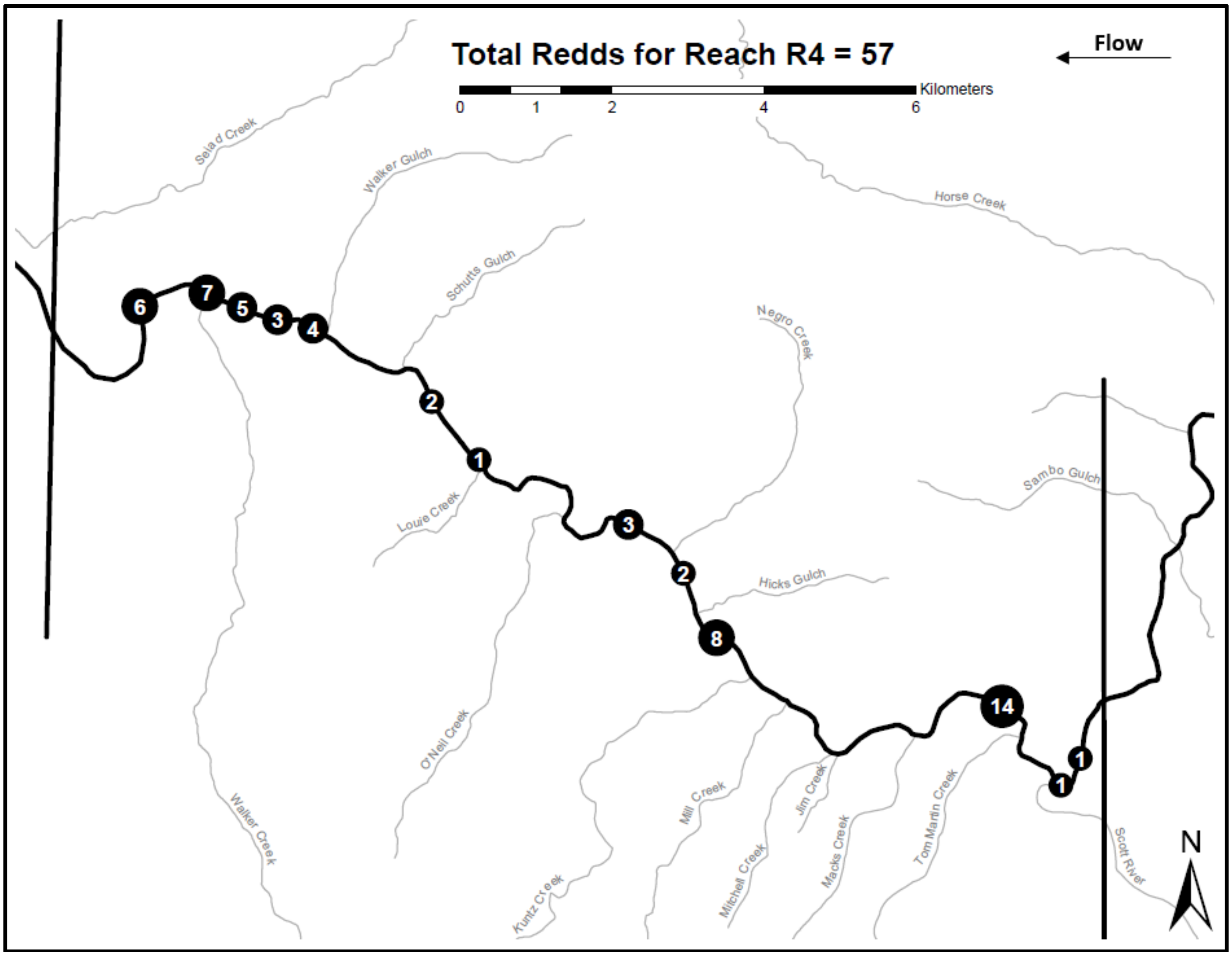
[b] Includes redds counted in Reach R7, which was added to the survey in 2017



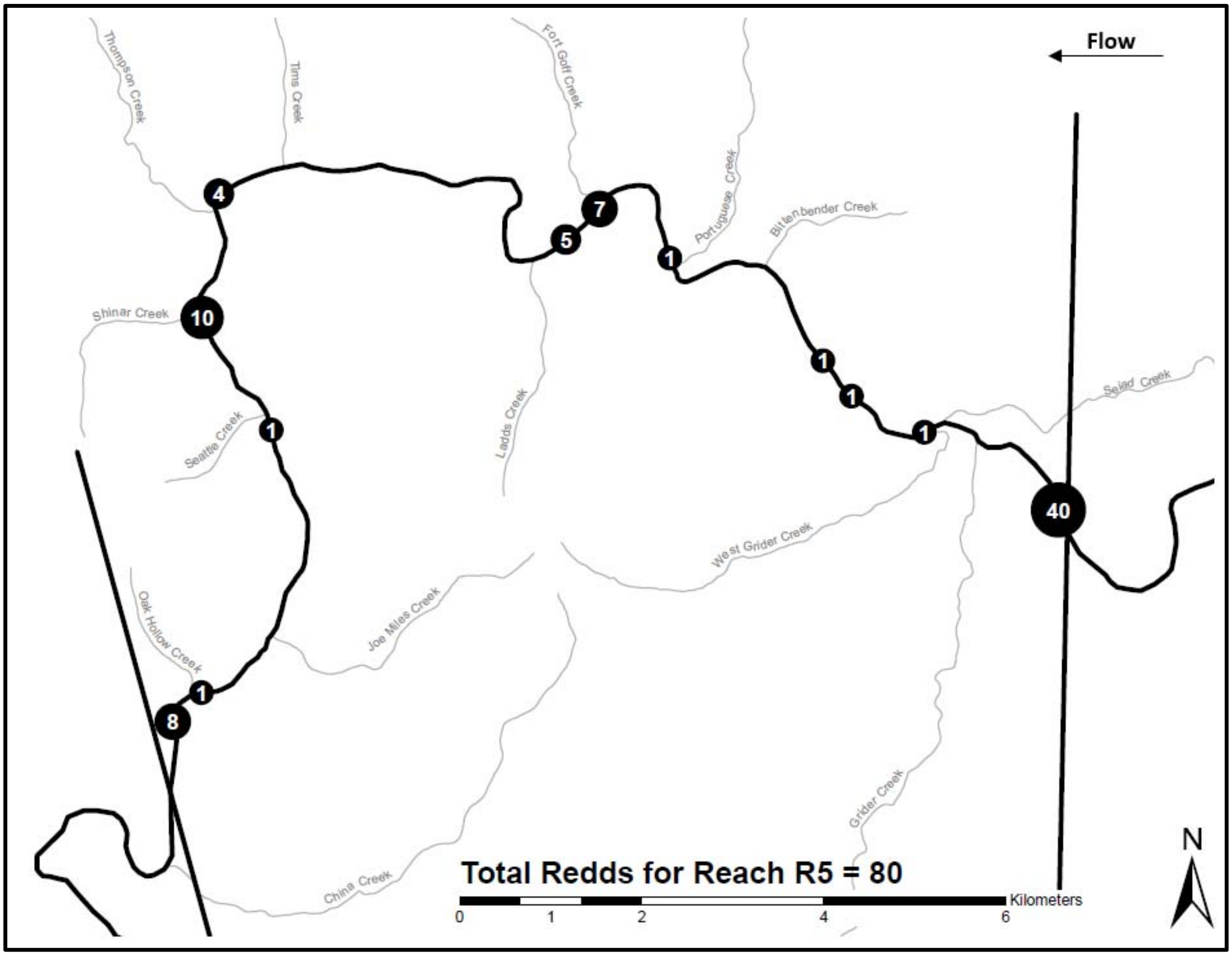
Appendix I. Redd count distribution in the mainstem Klamath River within survey reaches R2–R7 (shown separately) located between the Shasta River and Indian Creek, 2017. Redds are binned to the nearest 0.5 rkm.



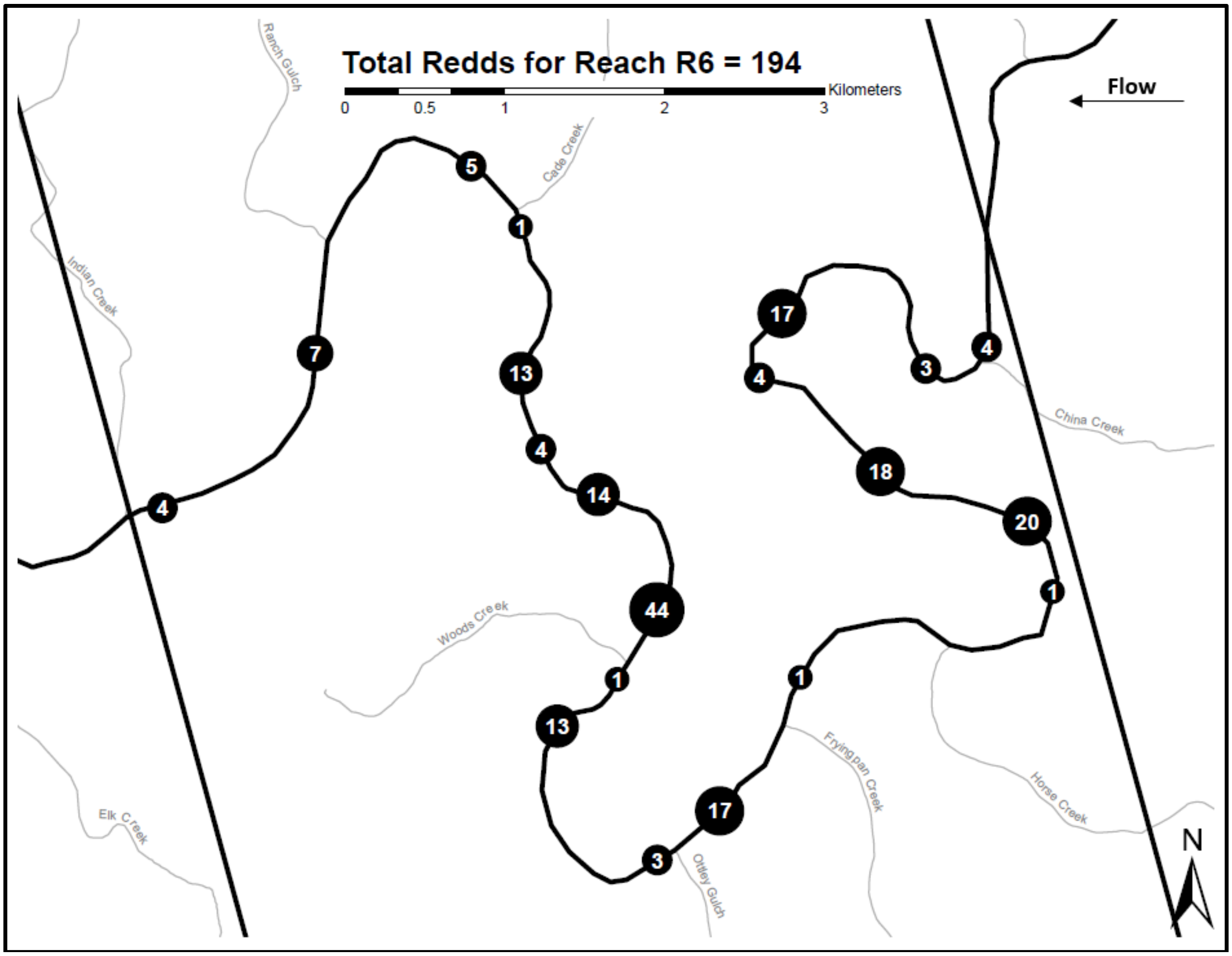
Appendix I (continued). Redd count distribution in the mainstem Klamath River within survey reaches R2–R7 (shown separately) located between the Shasta River and Indian Creek, 2017. Redds are binned to the nearest 0.5 rkm.



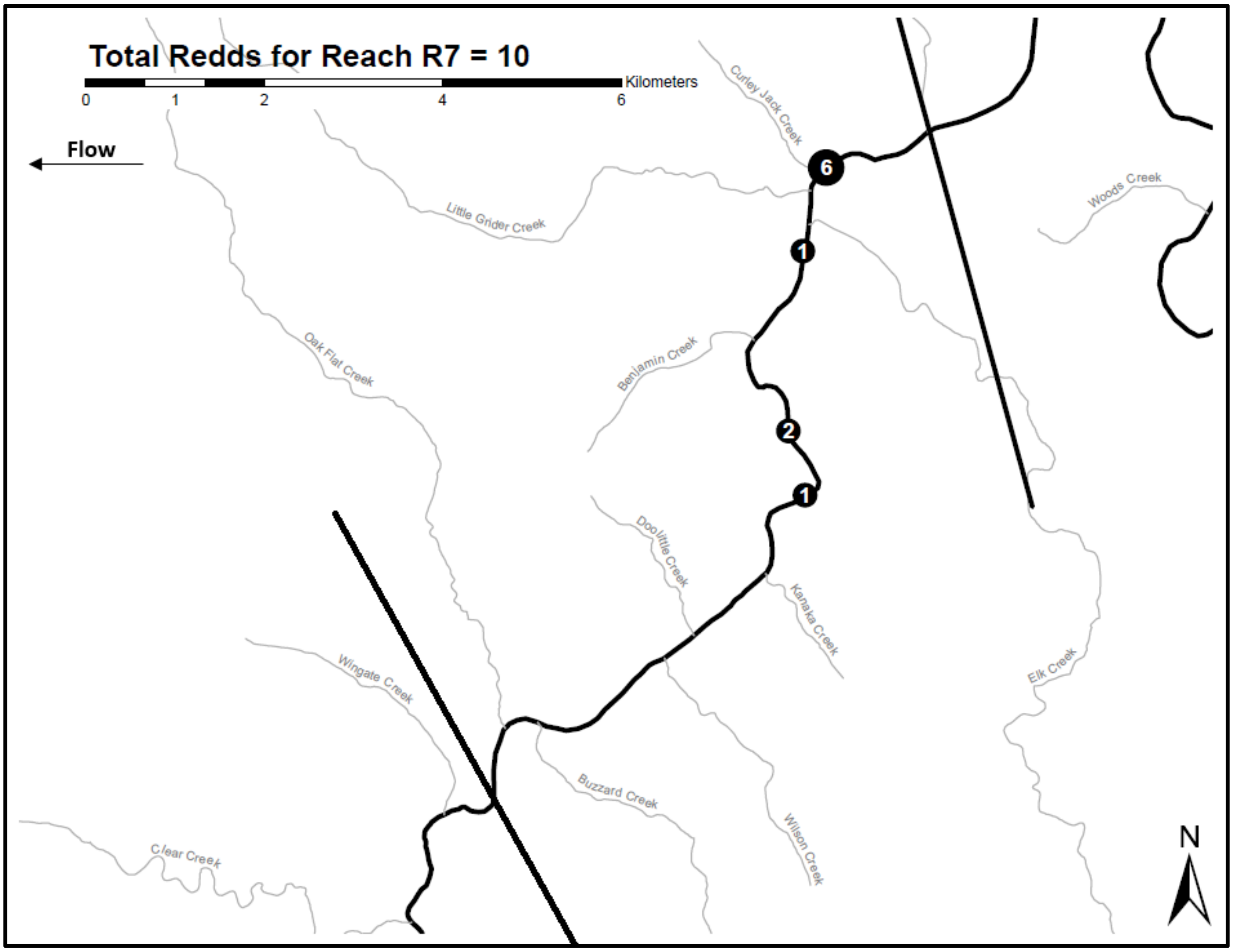
Appendix I (continued). Redd count distribution in the mainstem Klamath River within survey reaches R2–R7 (shown separately) located between the Shasta River and Indian Creek, 2017. Redds are binned to the nearest 0.5 rkm.



Appendix I (continued). Redd count distribution in the mainstem Klamath River within survey reaches R2–R7 (shown separately) located between the Shasta River and Indian Creek, 2017. Redds are binned to the nearest 0.5 rkm.



Appendix I (continued). Redd count distribution in the mainstem Klamath River within survey reaches R2–R7 (shown separately) located between the Shasta River and Indian Creek, 2017. Redds are binned to the nearest 0.5 rkm.



Appendix I (continued). Redd count distribution in the mainstem Klamath River within survey reaches R2–R7 (shown separately) located between the Shasta River and Indian Creek, 2017. Redds are binned to the nearest half rkm.