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Fall Chinook Salmon Run Characteristics and Escapement for the Main-Stem Klamath River, 2001-2010

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Abstract. Adult fall-run Chinook salmon (*Oncorhynchus tshawytscha*) carcasses were surveyed on the mid-Klamath River during spawning seasons 2001 through 2010 to estimate annual escapement using postmortem tag-recovery statistical methods and to characterize the age and sex compositions and spawning success of the runs. The study area consisted of eight consecutive reaches extending 21.2 river km from Iron Gate Dam downriver to the Shasta River confluence. A focus of this study was to improve what we believed to be negatively-biased estimates of escapement generated using redd counts. Unstratified Petersen carcass tag-recovery methods yielded 3.3 to 4.8 successfully spawned females per observed redd based on redd count data collected concurrently with carcass surveys. Based on Kimura-adjusted scale readings and unstratified Petersen escapement estimates, jacks (age-2 fish) represented less than 10% of the total annual escapement estimates for six of the ten survey years, with the greatest observed proportion of jacks occurring in 2006 (16%) and 2008 (17%). Low jack abundance in 2005 was indicative of low returns of age-3 adults in 2006 and age-4 adults in 2007 and similarly, low jack abundance in 2007 was indicative of low returns of age-3 adults in 2008 and age-4 adults in 2009. Despite low escapement estimates of adults in 2006, the abundance of jacks was relatively high, portending higher returns of 3-year old spawners in 2007 and 4-year old spawners in 2008. A similar pattern of low estimated escapement comprised of a relatively high abundance of jacks was observed in 2008, which was indicative of an abundance of 3-year old spawners in 2009 and 4-year old spawners in 2010. Pre-spawn mortalities of females ranged from about 22% in 2005 to 1% in 2009. Annual egg deposition by adult females calculated from unstratified Petersen estimates ranged from estimated highs of 24.5 and 25.0 million in 2002 and 2003, down to 5.7 and 4.7 million in 2006 and 2010.

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, overharvest, and land-use practices causing habitat loss, blockages, and degradation.

The primary purpose of this project was to provide the Klamath River Technical Advisory Team (KRTAT) fall Chinook salmon escapement estimates for the designated survey area to more accurately reflect the magnitude of spawning in the main-stem Klamath River. KRTAT 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. Redd surveys were also concurrently conducted in the survey area as an alternative method for comparison. This information, along with age-structured hatchery escapement and inriver harvest estimates, is then used to project ocean stock abundance and develop harvest management alternatives for the next season. 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 calibration of the Stream Salmonid Simulator, or SSS, Chinook salmon production model that is currently under production to replace SALMOD (Bartholow et al. 2002). In addition, carcass survey data are used to estimate annual age class proportions, jack–adult ratios, adult female–male ratios, female spawning success/pre-spawn mortality, fork length distributions, proportions of naturally spawning hatchery-origin fish, and egg deposition.

Beginning in 1993, main-stem Klamath River fall Chinook salmon spawning escapement was estimated based on expanded redd counts (assumes each redd equals one adult female and one adult male; Magneson 2008). Redd surveys were conducted weekly on the 136-river kilometer (rkm) reach between Iron Gate Dam (IGD; rkm 310.15) and the confluence of Indian Creek (rkm 173.85) in Happy Camp, California (Figure 1). In 2001, we initiated a statistical-based 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 288.45). The abundance of spawners in this reach was assumed to be sufficient to allow escapement to be estimated using a tag-recovery estimator. 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 mark, count, or estimate the number of live fish (e.g., at a weir; Manly et al. 2005).

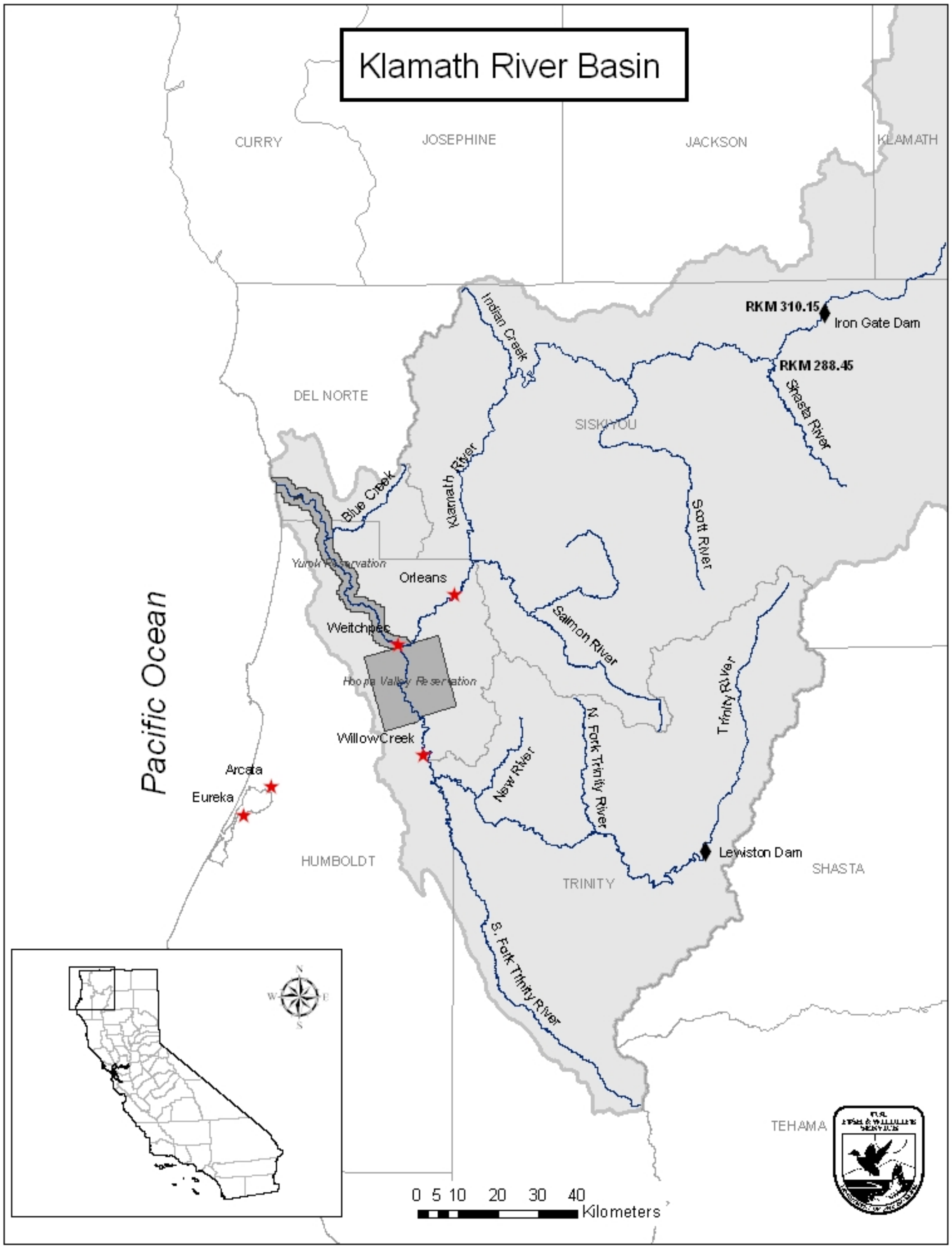

Figure 1. Klamath River Basin, northern California. The main-stem Klamath River carcass survey study area extends from IGD to the Shasta River confluence.

Study Area

The survey area was the 21.20 rkm section of main-stem Klamath River between IGD (the upper limit of anadromy) and the Shasta River confluence, divided into eight reaches (Table 1; Figure 2). Reaches were delineated based on previously mapped concentrations of redds and ended at distinguishable landmarks.

Methods

Surveys

Data were collected in a cooperative effort between the U.S. Fish and Wildlife Service Arcata Fish and Wildlife Office (AFWO) and the Yurok Tribal Fisheries Program (YTFP). Weekly surveys were conducted from the second week of October through the third week of November from 2001 through 2010. In 2001, 2009, and 2010, surveys continued through the end of November and in 2007, which had an atypically late and prolonged spawning season, surveys continued until December 12.

Surveys were conducted by two three-person crews, one AFWO and one YTFP, oaring downstream in inflatable catarafts along opposite banks of the river. Each crew, consisting of a rower, a data recorder, and a carcass handler, searched the river for carcasses from their respective bank to the center of the river. Each crew surveyed their same respective bank throughout the survey season. Side channels were walked or floated to look for carcasses. The following information was recorded for each survey: survey week, date, reach(es) surveyed, surveyors' names, predominant weather of the day, discharge at USGS Gage 11516530 below IGD, and weekly Secchi disk depth.

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

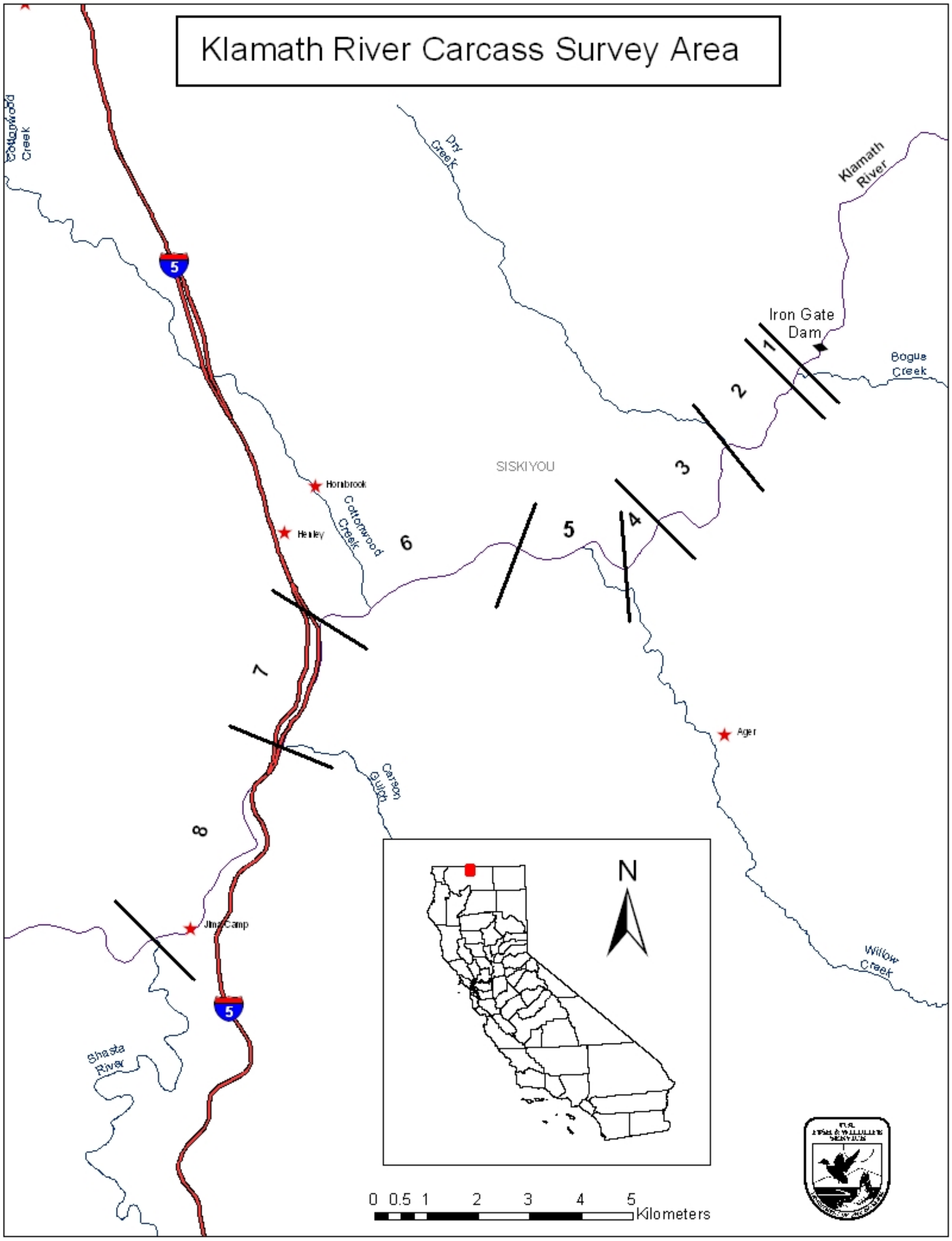

Figure 2. Klamath River carcass survey area from IGD to the Shasta River confluence with reaches delineated. Reach 1 begins at the first river access below IGD. Little to no spawning occurs between the dam and the access point.

Carcass Data

Each observed carcass was retrieved and the following data were recorded: reach, depth, location (lateral position in the channel), species, sex, fork length, 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.

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 on where in the side channel the carcass was encountered.

Carcass condition (decay extent) was categorized as fresh (F_1), partly decayed (D_2), or rotten (N):

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

D_2 = no F_1 characteristics, body has some firmness and little fungus or algae;

N = rotten (decayed beyond D2).

F_1-condition carcasses were believed to have expired within one week prior to capture, D_2-condition carcasses were believed to have expired one to two weeks prior to capture, and N-condition carcasses were believed to have expired more than two weeks prior to capture. Fork lengths from all measured (F_1- and D_2-condition) carcasses were used to generate annual length-frequency distributions. Fork lengths were not recorded from N-condition carcasses.

Scale samples were collected to aid in calculating the age-structured estimates developed each year by the KRTAT. Scales samples were collected from all F_1- and D_2-condition carcasses. In 2005, scales were taken from F_1-condition carcasses only. A minimum of five scales were collected with large forceps from the preferred area of 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 with the following information: date, location, species, fork length, sex, and spawning condition. Scale samples were provided to the YTFP who coordinate the Klamath River portion of the

KRTAT age composition analysis. Scales were prepared and read for age following the standards and guidelines of Mosher (1968). Reference scales from the Iron Gate Hatchery were mixed within the scale cards to confirm aging accuracy. The KRTAT employed statistical methods (Cook and Lord 1978; Cook 1983; Kimura and Chikuni 1987) "to correct the reader-assigned age composition estimates for potential bias based on the known-age vs. read-age validation matrices" (KRTAT 2003a, 2003b, 2004, 2005, 2006, 2007, 2008, 2009; KRTT 2010, 2011).

Sex was distinguished using morphological differences. Adult males are typically larger than adult females of the same age class, develop a more-pronounced kype, and may display red or reddish-purple color along their sides. Spawned females display ventrally eroded anal and caudal fins and an emptied abdomen. F_1- and D_2-condition carcasses were cut open and sex was visually verified by gonad type or presence of eggs. Carcasses deteriorated to such a condition that sex could not be determined were classified as unknown. 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 for each week and each spawning season. F_1-condition carcasses were used to calculate weekly pre-spawn mortality. Female carcasses with spawning condition '1' and '2' were considered successful spawners. Carcasses with spawning condition '3' were considered pre-spawn mortalities.

Throughout this report the term "jack" refers to age-2 (precocious) spawners, males (true jacks) and females (jills) inclusive. The size cut-off between adults and jacks was decided each year, post sampling season, according to scale age proportions and length-frequency distributions compiled and analyzed by the KRTAT (2003a, 2003b, 2004, 2005, 2006, 2007, 2008, 2009; KRTT 2010, 2011). The KRTAT reviews data provided by various collaborators and jointly decides which method best represents the actual jack to adult proportions that should be carried forward into the stock projection estimate.

Iron Gate Hatchery (IGH), located just below IGD and operated by the California Department of Fish and Game (CDFG), produces fall Chinook salmon, coho salmon, and steelhead. The snouts of Chinook salmon carcasses with clipped adipose fins [ad clip; denoting a coded-wire-tagged (CWT) hatchery-origin fish] were removed and frozen in individual bags labeled with the following information: location recovered, sex, fork length, and spawning condition. These same data were also recorded on the survey form.

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

CWTs were later removed from recovered snouts and read by USFWS personnel. CWT numbers are linked to the hatchery of origin, race, release type, and brood year of the individual fish.

Scars on the carcasses were recorded using the following codes:

C = clubbed gills, gill rot (*Flexibacter columnaris*), or columnaris disease (*Flavobacterium columnare*);

H = hook scar (indicated by hooks in the mouth or damage from fishing line to the maxillary);

L = lamprey bite;

N = net scar (indicated by line-like damage around the head, operculum, or in front of the dorsal fin);

S = seal damage (indicated by tooth scars);

R = roe-stripped females (females that had roe removed and the carcass returned to the river);

O = other.

Tag Recovery

In 2001, all F_1- and D_2-condition carcasses were marked with colored flagging tightly wrapped around a hog ring clamped around the lower jaw, with differing survey weeks distinguished by different colored flagging. In 2002 to 2010, all 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 cut in half to indicate that they had been sampled. Recaptured (previously tagged) carcasses were examined and the following data were recorded: reach, tag number, sex, location, condition, and depth. Recaptured carcasses were then cut in half to negate the possibility of a second recapture.

Escapement Estimates

Tag-recovery data were analyzed using an unstratified (data summed from all survey weeks of each year) Petersen population estimator (Seber 1982). The assumptions under which the Petersen method operates are (1) the population is closed, (2) all carcasses have equal capture probability in the first capture event, (3) marking individuals does not affect catch probability, (4) marks are not lost between capture events, and (5) all recovered individuals are correctly identified and recorded (Krebs 1999). Although the study area is not a true closed system, the underlying purpose behind the closed system condition was not violated; we assume zero or negligible immigration or emigration occurred during each survey.

Escapement (N) was estimated without temporal or spatial stratification (unstratified) using the Petersen formula adjusted for bias (Krebs 1999):

$$\hat{N} = \frac{(M+1)(C+1)}{(R+1)} - 1,$$

where M = total number of carcasses tagged, C = total number of carcasses captured, and R = total recaptures of tagged carcasses.

For these data, 95% confidence limits were calculated by applying the normal distribution formula for standard error:

$$\hat{N} \pm 1.96 \sqrt{\frac{(M+1)(C+1)(M-R)(C-R)}{(R+1)^2(R+2)}}.$$

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

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

Individual age class estimates were calculated likewise:

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

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

Hatchery Contribution

IGH marks a proportion, varying with release group, of the juvenile Chinook salmon produced with both a CWT and an ad clip. CWT recoveries from ad-clipped Chinook salmon spawners in the Klamath River are typically expanded by the production multiplier of each CWT's specific release group to estimate hatchery-produced equivalence. Due to poor CWT recovery data most years, we resorted to basing the hatchery contribution in the main-stem reaches on the number of ad-clipped carcasses captured. Therefore we assumed the ratio of ad-clipped to hatchery-origin fish in the main stem was the same as that observed at IGH. We presume partial recoveries of CWTs were a result of insufficient snout samples, shed tags, or lost or missing data rather than carcasses misidentified as hatchery fish.

First, the proportion of hatchery-produced Chinook salmon with an ad clip at IGH [$P(AD|H)_{IGH}$] was calculated:

$$\hat{P}(AD|H)_{IGH} = \frac{R(AD)_{IGH}}{\hat{R}(H)_{IGH}},$$

where $R(AD)_{IGH}$ = the number of ad-clipped fish that returned to IGH and $R(H)_{IGH}$ = the number of hatchery-origin fish that returned to IGH. $R(H)_{IGH}$ was estimated by applying CWT-specific production multipliers to ad-clipped fish observed at IGH (CDFG 2003; Richey 2004, 2006; Hampton 2005; Chesney 2007, 2008, 2009; Chesney and Knechtle 2010, 2011; Morgan Knechtle, CDFG, personal communication).

The number of hatchery-produced Chinook salmon carcasses captured during surveys [$C(H)_{mainstem}$] was then calculated:

$$\hat{C}(H)_{mainstem} = \frac{\hat{C}(AD)_{mainstem}}{\hat{P}(AD|H)_{IGH}},$$

where $C(AD)_{mainstem}$ = the number of captured carcasses with an ad clip.

Prior to 2008, there was an uneven distribution of ad-clipped carcasses found between the two banks sampled by different crews. We are uncertain whether hatchery fish were actually unevenly distributed between the left and right banks but speculate that they were not and that the differences reflect uneven detection of ad clips between survey crews. In years where this was a large discrepancy, total ad-clip capture was predicted by expanding actual ad-clip capture from the bank with the higher number proportionately by the capture of all carcasses on each bank.

Finally, an estimate of total hatchery-produced Chinook salmon spawning in the main stem [$N(H)_{mainstem}$] was calculated:

$$\hat{N}(H)_{mainstem} = \hat{N}_{mainstem} \cdot \frac{\hat{C}(H)_{mainstem}}{C_{mainstem}},$$

where $N_{mainstem}$ = main-stem escapement (see *Escapement Estimates* above) and $C_{mainstem}$ = main-stem carcasses captured.

Escapement Estimate to Redd Count Comparison

Redd surveys were also conducted in the study area in 2001 through 2004 and 2006 (Grove and Magneson 2006a, 2006b, 2006c; Grove et al. 2006; Magneson et al. 2008). Concurrent redd and carcass surveys were conducted to determine bias between redd counts and carcass tag-recovery-based escapement estimates in heavily used spawning areas. Annual escapement estimates were reduced by the observed proportion of females and again by the percentage of successful spawning by females to obtain the ratio of successfully spawned females to redds.

Egg Deposition

Estimates of adult females, attained by multiplying unstratified Petersen estimates by the proportion of adults from scale analyses and the proportion of females from adult female–male ratios, were multiplied by predicted egg deposition per female 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. Allen and Hassler (1986) determined an average production (n_e) of 3,634 eggs by adult female Chinook salmon in the Klamath River. Escapement estimates of fully spawned females (F_{fs}) multiplied by 3,634 (n_e) were added to escapement estimates of partially spawned females (F_{ps}) multiplied by 1,817 (one-half of n_e) to yield total egg deposition in the study area:

$$\hat{N}_e = n_e \cdot \hat{F}_{fs} + \frac{1}{2} \cdot n_e \cdot \hat{F}_{ps} .$$

Results

Temporal and Spatial Distribution of Carcasses

Season totals of newly observed carcasses captured ranged from 1,091 (2005) to 8,095 (2002), adults and jacks included (Table 3; Appendix A). New carcass observations peaked in calendar weeks 44 (2005 and 2006), 45 (2002, 2003, 2004, and 2008), and 46 (2001, 2007, 2009, and 2010). Surveys were not conducted during the sixth survey week (calendar week 47) in 2001 or in what should have been the first survey week in 2004 (calendar week 41). As a result, captures in the weeks following these missing surveys may have been inflated since carcasses accumulated for more than one week.

Carcass density was generally highest in the upper reaches of the survey area (Figure 3). Peak density occurred in Reach 1 (2007), Reach 2 (2004), Reach 3 (2001 and 2002), or

Table 3. Number of Chinook salmon carcasses captured by calendar week, Klamath River surveys 2001 to 2010. Annual peak counts are in bold font. Dashes indicate no survey conducted.

Calendar week	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
41	-	-	-	-	3	40	10	-	-	-
42	50	52	39	-	59	71	37	62	22	19
43	355	363	142	458	151	252	57	164	86	31
44	600	2,505	1,072	613	**440**	**538**	204	535	399	102
45	692	**2,638**	**2,022**	**670**	311	502	411	**895**	728	281
46	**868**	1,803	1,067	512	99	220	**907**	651	**776**	**496**
47	-	627	779	202	28	72	512	247	330	265
48	285	107	140	50	-	-	519	96	158	82
49	-	-	-	-	-	-	194	-	73	35
50	-	-	-	-	-	-	140	-	-	-
Total	2,850	8,095	5,261	2,505	1,091	1,695	2,991	2,650	2,572	1,311

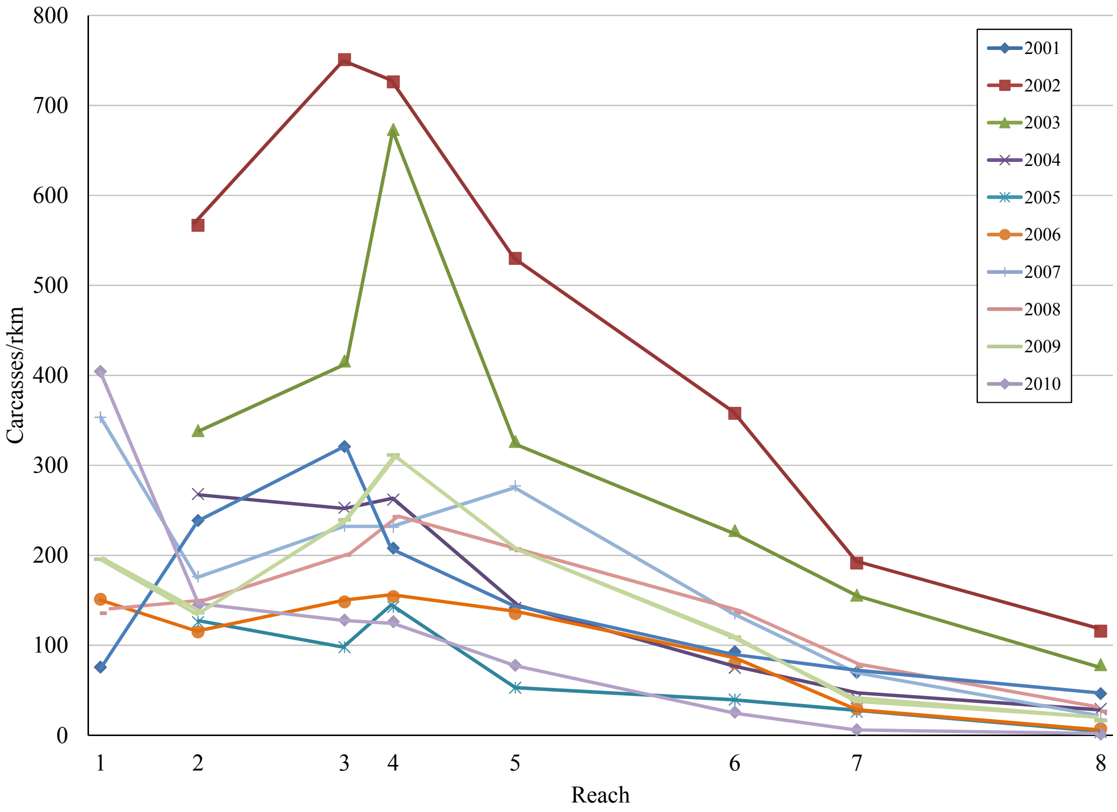

Figure 3. Chinook salmon carcass density (carcasses/rkm) by reach, Klamath River surveys 2001 to 2010. Reach 1 was not surveyed in 2002 to 2005.

Reach 4 (2003, 2005, 2006, 2008, and 2009). Carcass density typically declined steadily downstream of the peak reach. Spawner densities were generally higher in reaches located further downstream (Reaches 3 and 4) when large numbers of Chinook salmon were present.

During the 2001 sampling season, we suspected that carcasses of fish that spawned in Bogus Creek may have drifted into the main-stem river; therefore, Reach 1 was not surveyed for carcasses in 2002 to 2005 to eliminate the possibility of counting carcasses found in the main stem but did not spawn in the main stem. Reach 1 was again included in 2006 after we analyzed data for between-reach movement and determined that carcasses from Bogus Creek were not entering the main-stem river.

Length Distribution

Jack–adult size cut-offs were determined after each sampling season by the KRTAT (2003a, 2003b, 2004, 2005, 2006, 2007, 2008, 2009; KRTT 2010, 2011). The fork length cut-offs for jacks ranged from 51 cm in 2007 to 63 cm in 2001 and 2002 (Table 4).

Mean fork lengths of adult females, adult males, and jacks ranged from 66.6 cm to 78.9 cm, 77.2 cm to 87.3 cm, and 46.5 cm to 56.0 cm, respectively (Table 4). In 2007,

Table 4. Mean fork lengths by year of main-stem Klamath River Chinook salmon carcasses 2001 to 2010. Few N-condition carcasses, most of which were unknown sex, were measured prior to 2005.

	Jack–adult FL (cm) cut-off (jacks ≤)	Adult females			Adult males			Unknown sex			Jacks		
			FL (cm)			FL (cm)			FL (cm)			FL (cm)	
Year		n	mean	s.d.	n	mean	s.d.	n	mean	s.d.	n	mean	s.d.
2001	63	571	76.3	6.3	486	85.4	9.6	2	77.5	6.4	75	53.8	6.3
2002	63	1,133	75.8	6.9	1,063	82.7	9.2	7	81.9	9.0	166	56.0	6.6
2003	55	985	76.9	7.8	667	87.0	10.2	28	72.4	10.8	24	48.0	5.4
2004	57	446	78.9	7.3	400	87.3	9.7	1	58.0	-	52	50.7	5.4
2005	52	247	73.7	7.6	219	83.3	9.7	266	72.1	7.9	5	47.0	4.3
2006	60	438	74.5	6.9	432	84.0	9.8	482	75.0	7.8	242	52.6	5.7
2007	51	918	66.6	5.3	402	77.2	10.0	786	68.6	6.8	26	46.5	3.5
2008	59	595	76.8	6.4	433	84.0	12.0	816	75.0	9.2	272	53.4	4.9
2009	58	729	73.2	5.7	381	83.0	8.4	14	72.9	6.7	74	51.6	4.1
2010	61	255	78.9	6.3	186	85.4	9.2	357	77.3	8.8	61	55.8	4.5

adult Chinook salmon averaged much smaller (males: 5.5 to 10.1 cm smaller; females: 6.6 to 12.3 cm smaller) than in any of the other years of sampling. Length-frequency graphs by year are presented in Appendix B.

Adult Female–Male Ratios

Among adult carcasses, the percentage that was female ranged from 51.8% (2002) to 72.9% (2007; Figure 4). We have no explanation for the high female–male ratios in 2007 (2.7:1) and 2009 (1.9:1). In years with larger sample sizes (2005 to 2008 and 2010), mean fork lengths of carcasses of unknown sex were much closer to the mean female fork lengths than the average male fork lengths (Table 4). If most of the unidentified sex carcasses were females, then the female–male ratios may actually be biased to favor males.

Pre-spawn Mortality

Annual pre-spawn mortality rates ranged from 1.0% in 2009 to 22.1% in 2005 (Figure 5). Fully spawned individuals made up 64.4% (2005) to 97.5% (2009) of F_1- and D_2-condition female adult carcasses. Partially spawned individuals made up 1.2% (2010) to 13.5% (2005) of F_1- and D_2-condition female adult carcasses. We noted both an unusually low spawning success and high numbers of partially spawned females in 2005. Pre-spawn mortality was highest in the first survey week and decreased to near zero as the season advanced in all years except 2004 and 2005 (Figure 6; Appendix C). In 2004 we found the highest pre-spawn mortality in the fifth survey week. In 2005 we found the lowest pre-spawn mortality in the second survey week. The spike in 2004 Survey Week 5 may be due to small sample size (n = 3) as opposed to the sufficient sample size (n = 41) forming a similar spike in the same survey week in 2005.

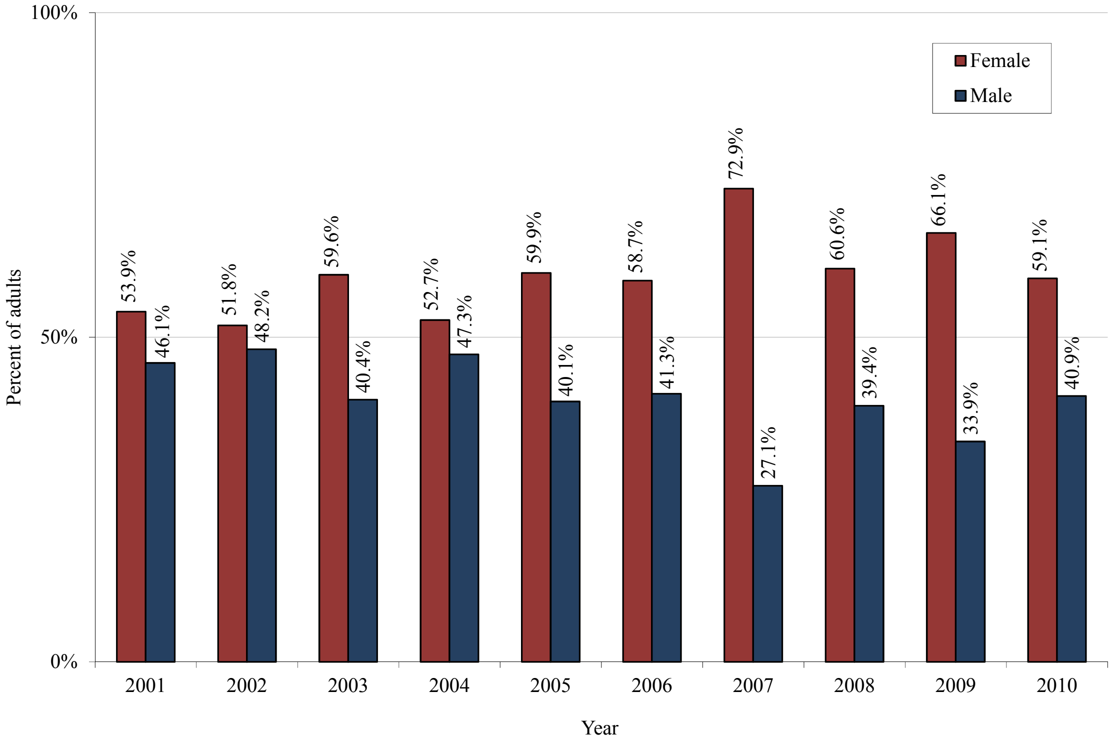

Figure 4. Female and male proportions of adult Chinook salmon carcasses in the mainstem Klamath River 2001 to 2010.

Escapement Estimates

Unstratified Petersen escapement estimates ranged from 2,782 (2010) to 14,394 (2002; Table 5). Reach 1 estimates ranged from 2.13% to 12.87% of the total escapement in the study area for years in which Reach 1 was surveyed. No correlations could be made between Reach 1 estimates and escapement in the study area, returns to IGH, or Bogus Creek run size; therefore, we resorted to adding the mean Reach 1 estimate ($\overline{N}_{Reach1}$ = 229) to the Petersen estimate for years in which only Reaches 2 through 8 were surveyed (2002 to 2005).

In 2004, we missed what should have been the first week of carcass sampling (calendar week 42; Table 3). We assume this had nominal influence on the escapement estimate because the first survey week simply had more carcass accumulation. Additionally, no corrections were made for the missing survey (Survey Week 6) in 2001 and we assumed that recoveries in the following week were sufficient to account for the missed survey.

Tagging rates of captured carcasses ranged from 28.8% (2002) to 44.1% (2009) over all ten survey seasons. The recapture rates of tagged carcasses ranged from 24.9% (2005) to 58.1% (2009). After evaluating annual recovery rates (r) versus discharge below IGD, visibility (Secchi disk depth), and carcass numbers, only flow (Q; discharge) demonstrated any correlation to explain recapture variation. The linear model:

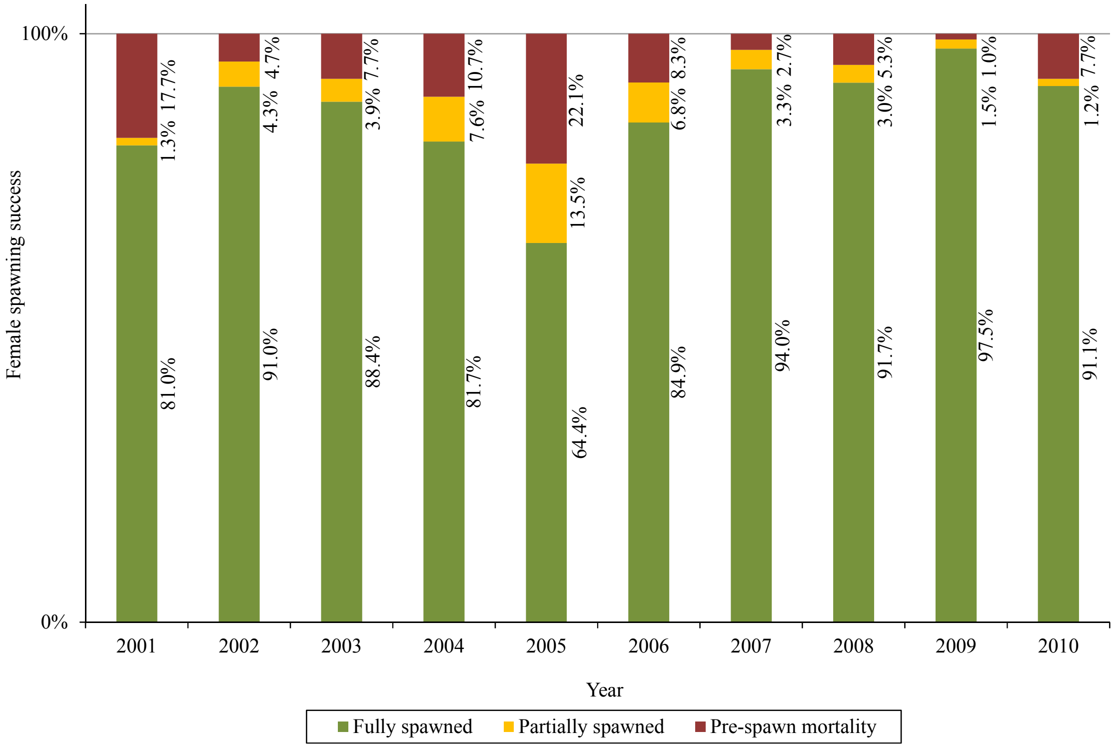

Figure 5. Spawning success of female Chinook salmon based on F_1- and D_2-condition carcasses, Klamath River surveys 2001 to 2010.

$$r_i = \beta_0 + \beta_1 Q_i + \varepsilon_i = 0.848 - 0.000298 Q_i + \varepsilon_i\,,\ \varepsilon \sim N\left(0, \sigma^2\right),$$

demonstrated a slight negative linear relationship between recovery rate and discharge ($p = 0.15$; $R^2 = 0.24$; Figure 7). We found less than 8% of tagged carcasses drifted from one study reach to another but crews conducting concurrent redd surveys did not find any tagged carcasses below the Shasta River confluence, partially supporting the assumption of no losses of marked fish.

Age-Structured Escapement Estimates

Between 214 and 1,178 scale samples were collected from carcasses and analyzed each year to estimate the age composition of the main-stem spawning escapement. On average, spawning escapement has been dominated by age-3 (46.2%) and age-4 (44.7%) fish, although there is high inter-annual variability due to the varying production of each brood year that contributes to spawning escapement in each year (Figure 8). The proportion of the youngest adult age class, age 3, was particularly high in 2007 (91.1%). The proportion of age-5 spawners was less than 1% except in 2005 (17.8%), 2006 (3.3%), and 2009 (2.4%). The proportion of age-2 spawners ranged from 0.1% to 17.1%. The proportions of jack carcasses present during the 2006 (15.8%) and 2008 (17.1%) sampling seasons were exceptionally high compared to other years. Annual differences

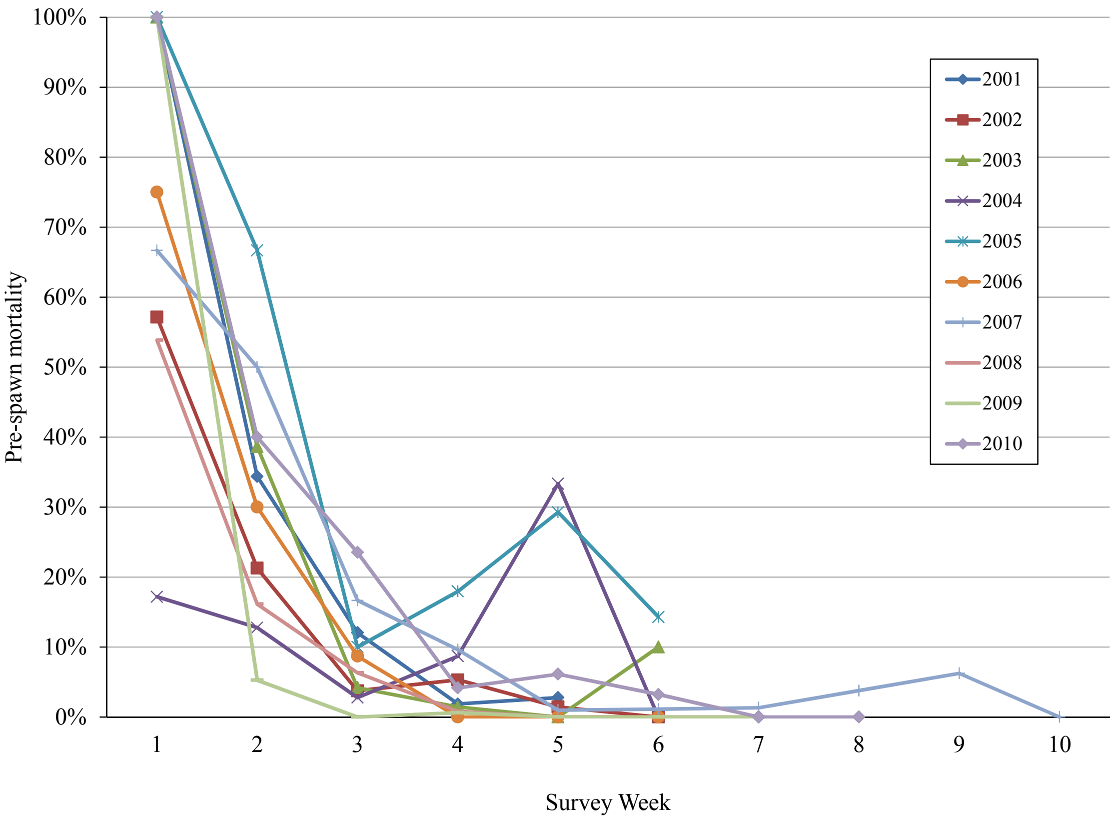

Figure 6. Weekly pre-spawn mortality from F_1-condition female Chinook salmon carcasses, Klamath River surveys 2001 to 2010. Only F_1-condition carcasses were included since we can assume only those fish expired the week they were found.

Table 5. Unstratified Petersen fall Chinook salmon escapement estimates and tag-recovery data, Klamath River surveys 2001 to 2010.

	Carcasses					Escapement	95% confidence limits	
Year	Captured	Tagged	Recovered	Tagging rate	Recovery rate	estimate	Lower	Upper
2001	2,850	1,070	389	37.5%	36.4%	7,828	7,253	8,403
2002[a]	8,095	2,335	1,334	28.8%	57.1%	14,394	13,934	14,855
2003[a]	5,261	1,661	686	31.6%	41.3%	12,958	12,274	13,642
2004[a]	2,505	896	500	35.8%	55.8%	4,715	4,469	4,960
2005[a]	1,091	378	94	34.6%	24.9%	4,585	3,860	5,309
2006	1,695	547	258	32.3%	47.2%	3,587	3,296	3,879
2007	2,991	1,225	663	41.0%	54.1%	5,523	5,273	5,774
2008	2,650	1,022	553	38.6%	54.1%	4,894	4,649	5,140
2009	2,572	1,133	658	44.1%	58.1%	4,427	4,238	4,615
2010	1,311	452	230	34.5%	50.9%	2,572	2,362	2,782

[a] Reach 1 not surveyed. Mean Reach 1 escapement estimate (229) from 2001 and 2006–2010 added to Petersen calculation.

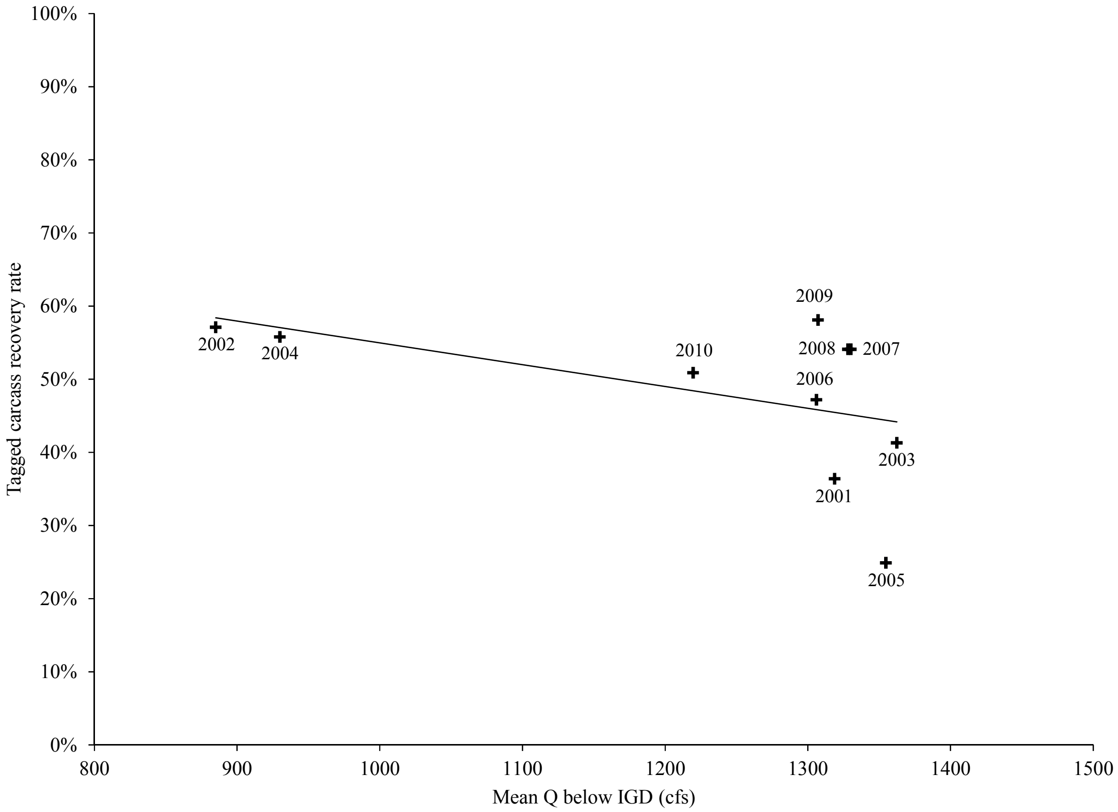

Figure 7. Relationship between mean discharge below IGD and recovery rates of tagged Chinook salmon carcasses in the main-stem Klamath River, 2001 to 2010.

between proportions of fish designated as jacks by fork length cut-offs and those estimated to be 2-year olds by scale aging were less than 1.5%.

Jack (age-2) escapement estimates ranged from 4 (2005) to 836 (2008), age-3 estimates ranged from 950 (2008) to 7,189 (2002), age-4 estimates ranged from 397 (2007) to 6,743 (2002), and age-5 estimates ranged from 0 (2001) to 816 (2005; Table 6). Extremely low jack numbers in 2005 and low jack numbers in 2007 boded poor returns of age-3 adults in 2006 and 2008 and of age-4 adults in 2007 and 2009. Jack estimates were highest in 2001, 2002, 2006, and 2008, portending good returns of 3-year old spawners in each subsequent year and of 4-year old spawners two years after the season having abundant jack estimates. The run size of 4-year olds in 2010 was not particularly large but was the dominant age class that year.

Hatchery Fish Contribution

The number of observed ad-clipped carcasses and estimated proportions of hatchery-origin spawners are summarized in Table 7. A significant shift in hatchery fish proportions midway through the decade occurred as hatchery contributions were less than 6% in 2001 to 2004, 13.0% in 2005, 20.2% in 2006, and ranged from 25.3% to 35.3% in

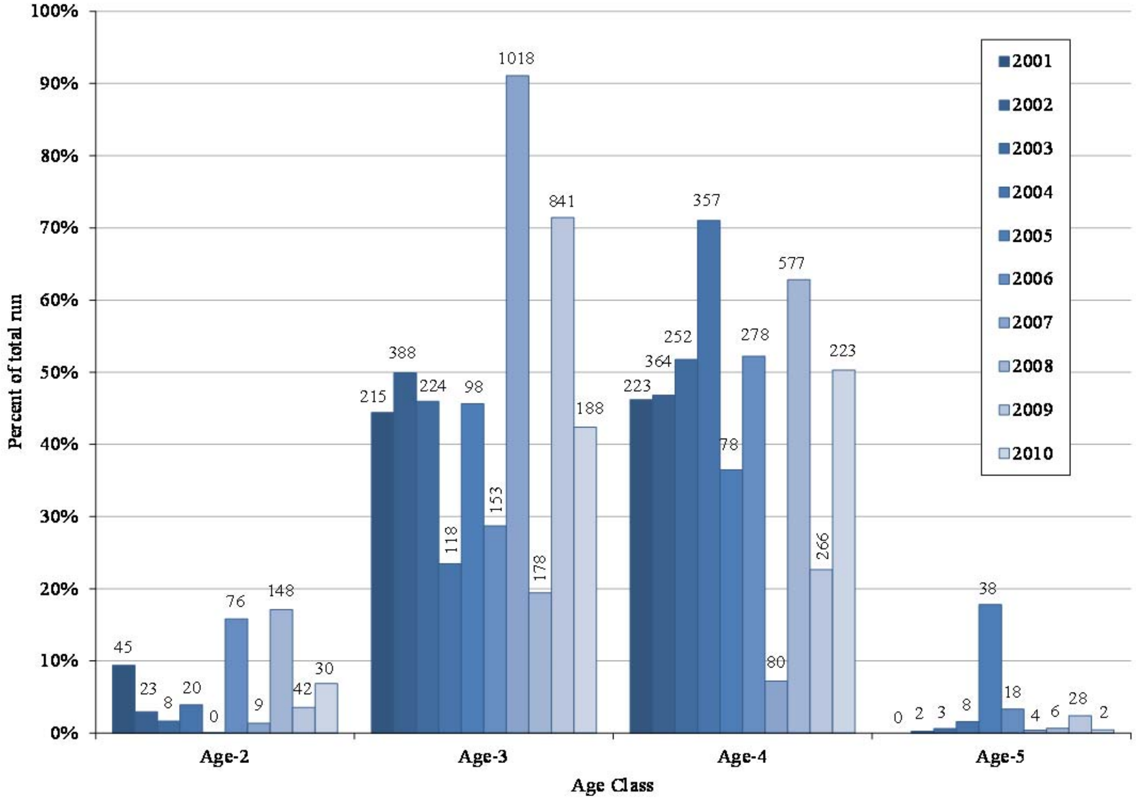

Figure 8. Fall Chinook salmon age composition percentages based on scale readings, Klamath River 2001 to 2010. Sample sizes by age are presented at the top of each bar.

Table 6. Fall Chinook salmon spawning escapement estimates (and percent of total run) for each age class, Klamath River surveys 2001 to 2010 (age compositions from Figure 8).

	Age				
Year	2[a]	3	4	5	Adults[b]
2001	734 (9.4%)	3,479 (44.4%)	3,616 (46.2%)	0 (0.0%)	7,095
2002	424 (2.9%)	7,189 (49.9%)	6,743 (46.8%)	37 (0.3%)	13,970
2003	215 (1.7%)	5,957 (46.0%)	6,706 (51.8%)	80 (0.6%)	12,743
2004	184 (3.9%)	1,107 (23.5%)	3,349 (71.0%)	75 (1.6%)	4,531
2005	4 (0.1%)	2,092 (45.6%)	1,673 (36.5%)	816 (17.8%)	4,581
2006	567 (15.8%)	1,030 (28.7%)	1,873 (52.2%)	118 (3.3%)	3,021
2007	73 (1.3%)	5,032 (91.1%)	397 (7.2%)	21 (0.4%)	5,450
2008	836 (17.1%)	950 (19.4%)	3,075 (62.8%)	33 (0.7%)	4,058
2009	157 (3.6%)	3,162 (71.4%)	1,001 (22.6%)	107 (2.4%)	4,270
2010	176 (6.8%)	1,091 (42.4%)	1,294 (50.3%)	12 (0.5%)	2,398

[a] age 2 same as jacks

[b] adults equals sum of ages 3 through 5

Table 7. Hatchery composition of fall-run Chinook salmon in the main-stem Klamath River, IGD to the Shasta River confluence, based on carcass surveys, 2001 to 2010.

Year	Total carcass capture	Adipose fin-clipped carcass capture [a]	CWT's recovered	Proportion of hatchery-produced fish with ad-clip at IGH	Estimated capture of hatchery carcasses	Estimated hatchery proportion [c]	Petersen escapement estimate	
							Total	Hatchery only
	$C_{mainstem}$	$C(AD)_{mainstem}$		$P(AD\|H)_{IGH}$	$\hat{C}(H)_{mainstem}$	$\hat{P}(H)_{mainstem}$	$\hat{N}_{mainstem}$	$\hat{N}(H)_{mainstem}$
2001	2850	5	0	3.76%	133	4.7%	7828	365
2002	8095	18	0 [b]	3.98%	440	5.4%	14394	783
2003	5261	6	3	5.73%	113	2.1%	12958	278
2004	2505	1	0	9.01%	11	0.4%	4715	21
2005	1091	11	4	7.78%	141	13.0%	4585	594
2006	1695	21	0	6.27%	343	20.2%	3587	726
2007	2991	49	23	4.66%	1057	35.3%	5523	1952
2008	2650	42	30	6.20%	677	25.6%	4894	1251
2009	2572	45	27	6.90%	652	25.3%	4427	1122
2010	1311	33	4	8.80%	375	28.6%	2572	735

[a] In 2002, 2003, 2006, and 2007 there were high discrepencies between banks in ad-clip detections. For these years $C(AD)_{mainstem}$ 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] No coded wire tags were read in 2002 after the freezers used to store samples malfunctioned and all collected snouts were ruined

[c] $\hat{P}(H)_{mainstem} = \hat{C}(H)_{mainstem}/\hat{C}_{mainstem}$

2007 to 2010. Coincidentally, the proportion of hatchery-produced fish that entered IGH [$P(H)_{IGH}$] were lower in 2001 to 2006 (range = 55.6% to 79.6%) than in 2007 to 2010 (range = 88.3% to 100%; CDFG 2003; Richey 2004, 2006; Hampton 2005; Chesney 2007, 2008, 2009; Chesney and Knechtle 2010, 2011; Morgan Knechtle, personal communication). Regression analysis revealed that the polynomial model:

$$\begin{aligned}\hat{P}(H)_{mainstem,i} &= \beta_0 + \beta_1 \hat{P}(H)_{IGH,i} + \beta_2 \hat{P}(H)_{IGH,i}{}^2 + \varepsilon_i \\ &= 30.3 - 1.23\hat{P}(H)_{IGH,i} + 0.0127\hat{P}(H)_{IGH,i}{}^2 + \varepsilon_i,\ \varepsilon \sim N(0,\sigma^2),\end{aligned}$$

best showed the positive correlation between these proportions ($p = 0.018$; $R^2 = 0.68$; Figure 9).

Escapement Estimate and Redd Count Comparison

Redd counts were substantially less than carcass tag-recovery adult female escapement estimates. The ratio of the successfully (partially or fully) spawned female escapement estimate ($\hat{F}_S$) to observed redds (R_{obs}) ranged from 3.3:1 (2002) to 4.8:1 (2003) over the entire study area (Appendix D). This ratio varied little as demonstrated by the strong positive linear relationship between these paired values using the regression model:

$$R_{obs,i} = \beta_0 + \beta_1 \hat{F}_{s,i} + \varepsilon_i = 15.2 + 0.254\hat{F}_{s,i} + \varepsilon_i,\ \varepsilon \sim N(0,\sigma^2),$$

over the range of run sizes ($p = 0.016$; $R^2 = 0.89$; Figure 10). Within the study area mean ratios by reach of successfully spawned female escapement estimates to observed redds ($r_{F:R}$) ranged from 8.4:1 (Reach 2) to 2.1:1 (Reach 8). Annual reach-wise successfully spawned females per redd data were used to fit an exponential model:

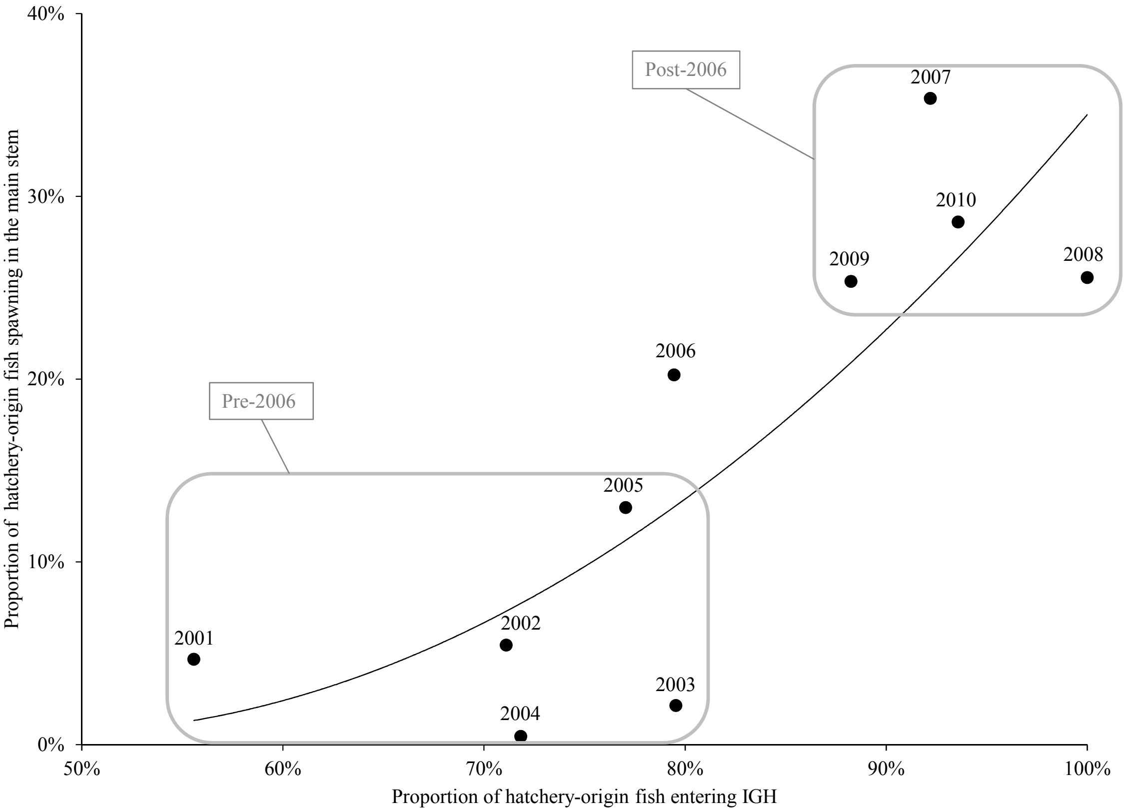

Figure 9. Relationship of hatchery-origin Chinook salmon proportions between fish entering IGH and spawning in the main-stem Klamath River spawners, 2001 to 2010.

$$\hat{r}_{F:R,i} = \alpha \cdot e^{\beta \cdot d_{n,i}} + \varepsilon_i = 6.70e^{-0.0626 d_{n,i}} + \varepsilon_i \,,\ \varepsilon \sim N\left(0, \sigma^2\right),$$

where d_n = distance downstream from the start of Reach 1 to the middle of Reach n (n = 1 to 8). This model estimated negative exponential decay of the successfully spawned female–redd ratio moving downstream ($p_\beta = 0.0041$; Figure 11).

Egg Deposition

Annual egg deposition in the study area was estimated to range from a low of 4.7 million from 1,308 females (2010) to a high of 25.0 million from 7,014 females (2003; Table 8). 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, flow, etc. (McNeil 1964; Nelson et al. 2012).

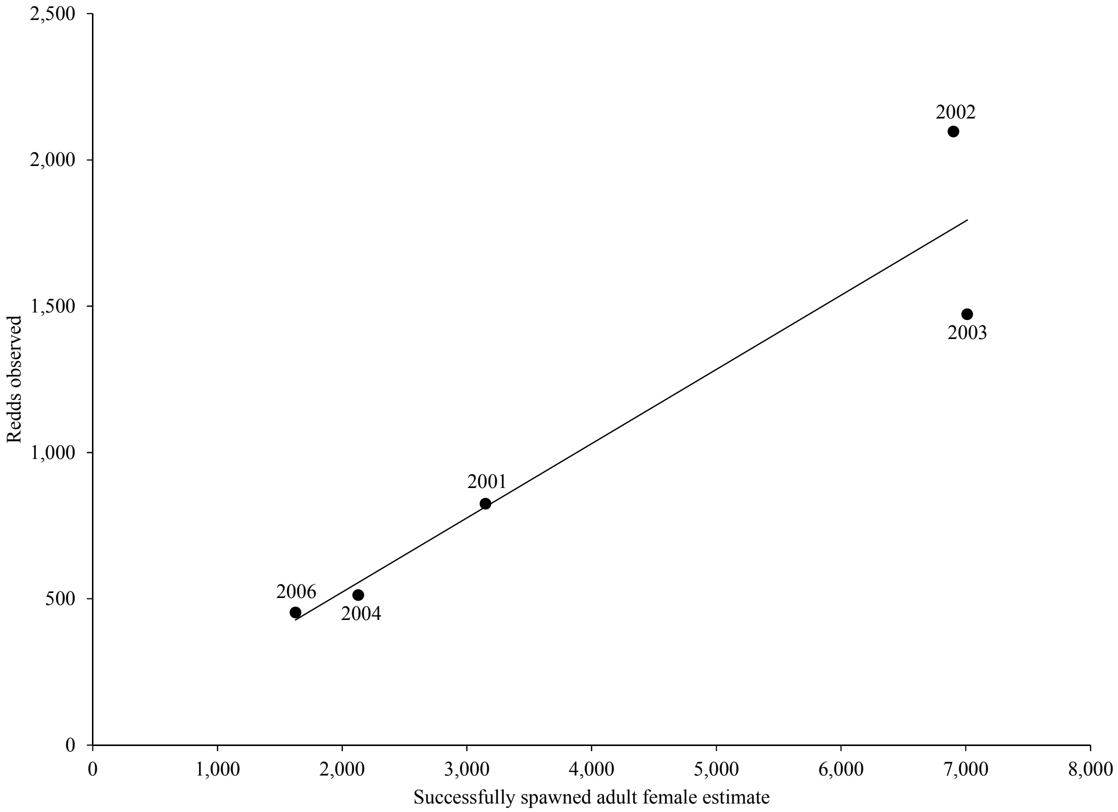

Figure 10. Relationship between carcass tag-recovery escapement estimates of successfully spawned adult female Chinook salmon and redd counts in the main-stem Klamath River from IGD to the Shasta River confluence, 2001 to 2004 and 2006.

Discussion

Our escapement estimates are validated by high sample sizes, marking rates, and recapture rates. High overall recapture rates and large sample sizes are indicators of high accuracy and precision of population estimates (Williams et al. 2001). The minimum sample size (numbers tagged and examined for tags), as recommended by Robson and Regier (1964), for each year's respective population size was met every year except 2005 when more carcasses should have been tagged. We tagged a minimum of 378 carcasses each year and over 1,000 for most years with tagging rates ranging between 28.8% and 44.1% of the total capture (Table 5). We had sufficiently high recovery rates of tagged carcasses, ranging from 24.9% to 58.1% (mean = 48.0%). A weak correlation with mean discharge below IGD ($R^2 = 0.24$) partially explains the variation in recovery rates. There were no mentionable correlations between recovery rate and underwater visibility or carcass numbers, though the year with the highest carcass count (2002) is associated with the second highest recovery rate and the year with the lowest carcass count (2005) is associated with the lowest recovery rate. Consistency of recovery rates over most years,

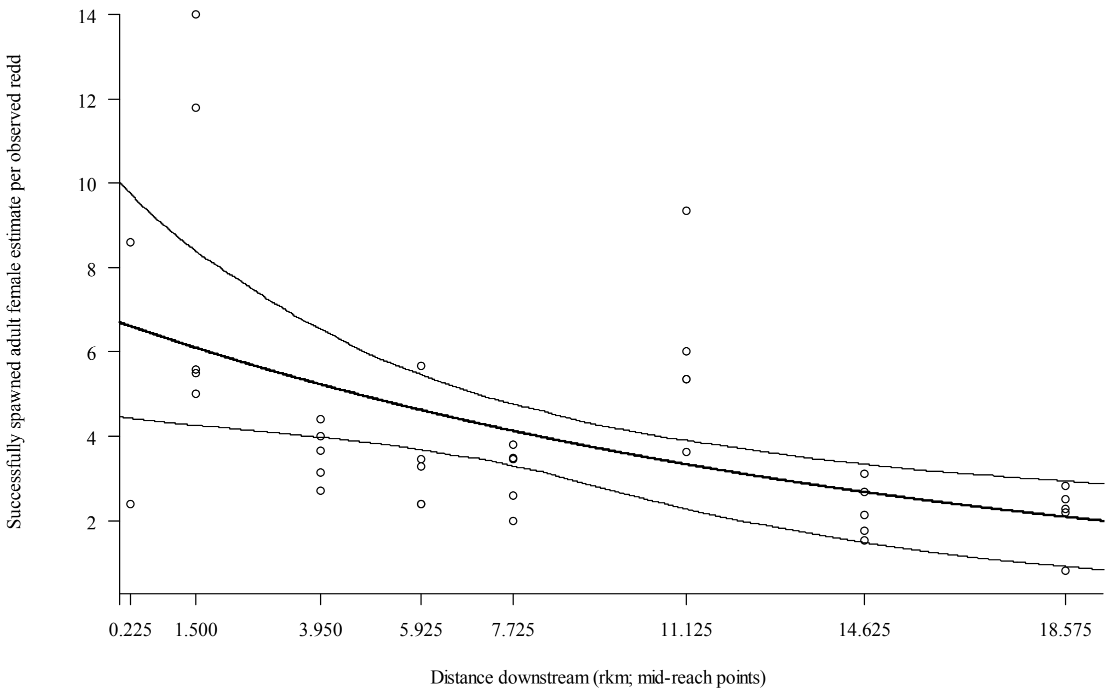

Figure 11. Relationship between successfully spawned female estimate–redd count ratios (with 95% confidence limits) and distance downstream in the main-stem Klamath River from IGD to the Shasta River confluence, 2001 to 2004 and 2006. Reach-wise female estimates are based on carcass capture proportions.

Table 8. Egg deposition (N_e) of Chinook salmon based on unstratified Petersen estimates from Klamath River carcass surveys 2001 to 2010. Note that F_{fs} and F_{ps} are escapements of fully and partially spawned females.

Year	$\hat{F}_{fs}$	$\hat{F}_{ps}$	$\hat{N}_e$
2001	3,100	49	11,400,000
2002	6,589	310	24,500,000
2003	6,718	296	25,000,000
2004	1,948	181	7,400,000
2005	1,767	371	7,100,000
2006	1,506	120	5,700,000
2007	3,732	131	13,800,000
2008	2,255	74	8,300,000
2009	2,743	42	10,000,000
2010	1,291	17	4,700,000

particularly in the later five years (2006 to 2010), indicates similar survey effort and observation efficiency.

From 2002 through 2005, Reach 1 was excluded from the survey due to concerns of counting fish that spawned in Bogus Creek whose carcasses were later transported in the drift into the main-stem Klamath River. However flows were typically low in Bogus Creek for most years surveyed, which reduces the likelihood that carcasses were transported from Bogus Creek over the delta at the mouth of Bogus Creek and into the Klamath River. CDFG personnel have conducted annual carcass surveys on Bogus Creek since 1978 and have operated a fish-marking weir since 1981. The fish marking weir was converted to a video fish counting station in 2003. Prior to the operation of the video weir, all adult fish that passed through the fish marking weir were marked with an operculum punch. No operculum-punched fish were encountered during the main-stem river carcass surveys in 2001, reinforcing the assumption that there was little or no influence from Bogus Creek on the main-stem Klamath River escapement estimates. In addition, CDFG staff surveyed Bogus Creek twice per week during the entire spawning run and all carcasses encountered during the surveys were cut in half to eliminate duplicate sampling. Using the mean Reach 1 estimate was a reasonable surrogate to add to the estimates generated for Reaches 2 through 8 in 2002 to 2005 since there appears to be a limit to spawning activity in this short reach (i.e., in years with large run sizes spawning activity tends to extend downstream rather than become more concentrated in the uppermost reach).

Two other mark recapture methods commonly used for estimating salmon escapement were considered: the Schaefer (1951) population estimator and a stratified Petersen method in which an estimate is generated for each survey recovery week (Darroch 1961). The Schaefer estimator can be used as an alternative to Petersen estimators in the event that underlying assumptions (i.e., equal mixing of tagged and untagged carcasses, homogeneous capture probability, and homogeneous recapture probability) of the Petersen methods are shown to be violated (Schwarz et al. 2002). We decided not to use these weekly-based estimators because of small sample sizes and low recapture rates in the early and late sampling weeks can lead to violations of these assumptions. Estimates from the Schaefer and stratified Petersen methods for these weeks are likely inflated by low recapture rates, biasing the overall estimate upward. Although stratified Petersen and Schaefer estimates were not used in our analyses, calculations from these methods are provided in Appendices E and F. Agreements between Petersen and Schaefer estimates in past studies have ranged from “often very similar” (Eames et al. 1983) to “infrequent” (Ricker 1975).

Chinook salmon adult spawners in the main-stem Klamath River between IGD and the Shasta River confluence substantially contribute to the natural spawning escapement of the Klamath Basin, and presumably to natural production. They accounted for 53.7% to 89.5% of natural adult spawners in the main-stem Klamath River above Indian Creek, 15.4% to 40.2% of natural adult spawners in the Klamath River Basin above the Trinity River, and 6.4% to 22.2% of natural adult spawners in the entire Klamath River Basin (Appendix G). In the entire Klamath River Basin, Chinook salmon adult spawners in the main-stem Klamath River between IGD and the Shasta River confluence accounted for

4.3% to 15.5% of total adult escapement (hatchery and natural spawners) and 2.6% to 8.9% of the total adult in-river run (hatchery and natural spawners and inriver harvest). Our estimate of upper Klamath main-stem spawning escapement was highest in 2002, a year in which a large kill of adult salmon in the lower Klamath River occurred (Guillen 2003). CDFG estimated that Trinity River spring- and fall-run Chinook salmon took the brunt of that fish kill based on an analysis of CWTs from those fish (CDFG 2004). This claim is supported by the proportion of main-stem Klamath spawners in the Klamath River Basin escapement being highest in 2002.

Low recoveries of ad-clipped carcasses prior to 2006 may indicate low incidences of "straying" by hatchery-reared fish (i.e., spawning in the river instead of within the hatchery). We are uncertain whether the notable increase in ad-clipped captures after 2006 was a result of (1) more hatchery returns, possibly as a result of increased survival when the hatchery began practicing volitional releases of YOY fish in 2002, (2) an increase in straying of hatchery-produced fish, or (3) an increase in ad-clip detection by the surveyors. Concurrent increases in the proportion of hatchery-origin fish returning to IGH (Figure 9) and in the number of hatchery-origin fish spawning in the main stem (Table 7) support the first assertion.

Carcass survey estimates of spawned females showed that redd counts greatly underestimated escapement in this study area, regardless of the number of spawners (Figure 10; Appendix D). We are unable to explain this phenomenon, but the same result has been observed in the Sacramento River (Bill Snider, CDFG, personal communication). Undercounting redds likely resulted from poor observer efficiency or redd superimposition. Over a wide range of run sizes the overall successfully spawned female estimate–redd count ratios were relatively constant (Figure 10). However when broken down into the carcass survey reaches, spawned female estimate–redd count ratios were typically higher in the upstream reaches where spawning activity was more concentrated and redd superimposition more prevalent (Figure 11). Beyond the spatial scope of these data, this ratio trends towards one-to-one in the more sparsely used spawning grounds below the Shasta River confluence (Reach 8). These results help confirm our recommendation that a carcass survey be used in high density (and numbers) spawning areas. The implementation of statistical carcass surveys also provides the additional benefit of spawning success/pre-spawn mortality, male–female ratio, length-frequency, age composition, and hatchery stray data.

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Appendix A. Summary of Chinook salmon carcasses observed, Klamath River surveys 2001 to 2010. Jacks enumerated on the basis of postseason KRTAT length criteria.

			New carcass captures								Recoveries from Survey Week[b]:																	
	Survey	Survey	Tagged				Not tagged				1		2		3		4		5		6		7		8		9	
Year	Week	Dates	M	F	U	J	M	F	U	J	A	J	A	J	A	J	A	J	A	J	A	J	A	J	A	J	A	J
2001	1	Oct 16-19	21	23	0	1	1	3	1	0																		
	2	Oct 22-26	50	68	1	3	56	71	103	3	7																	
	3	Oct 29-Nov 2	125	157	0	30	106	130	45	7	2		43															
	4	Nov 5-9	155	163	0	19	166	146	26	17	0		6		136													
	5	Nov 12-16	118	117	0	20	304	235	50	24	0		3		19		131											
	7[a]	Nov 26-30					95	91	87	12	0		0		0		1		41									
	Total		469	528	1	73	728	676	312	63	9		52		155		132		41									
2002	1	Oct 15-16	16	21	0		6	4	5	0																		
	2	Oct 21-23	145	95	1	6	23	38	52	3	9	0																
	3	Oct 28-Nov 1	422	531	4	64	531	396	516	41	3	0	122	1														
	4	Nov 4-7	303	293	1	50	636	571	715	69	0	0	18	0	512	23												
	5	Nov 11-14	151	161	0	34	438	433	527	59	0	0	1	0	70	4	279	14										
	6	Nov 18-20	14	21	0	2	163	196	212	19	0	0	1	0	27	2	46	3	129	13								
	7	Nov 25-26					18	28	60	1	0	0	0	0	2	0	5	2	16	1	10	1						
	Total		1,051	1,122	6	156	1,815	1,666	2,087	192	12	0	142	1	611	29	330	19	145	14	10	1						
2003	1	Oct 15-16	7	15	0	1	2	11	2	1																		
	2	Oct 20-22	28	62	2	1	12	24	12	1	2	0																
	3	Oct 26-30	265	312	4	7	206	146	129	3	0	0	21	0														
	4	Nov 3-6	297	429	6	7	493	423	415	10	0	0	6	0	208	1												
	5	Nov 10-15	57	113	1	2	163	230	465	7	0	0	2	0	31	0	155	1										
	6	Nov 17-22	8	35	1	1	194	261	249	1	0	0	0	0	17	0	133	1	72	0								
	7	Nov 24-25					38	63	38	1	0	0	0	0	2	0	14	0	7	0	8	0						
	Total		662	966	14	19	1,108	1,158	1,310	24	2	0	29	0	258	1	302	2	79	0	8	0						
2004	1	Oct 19-21	109	121	0	3	52	108	59	6																		
	2	Oct 25-28	138	144	0	12	84	71	154	10	94	0																
	3	Nov 1-4	115	120	1	25	112	91	195	11	29	0	130	3														
	4	Nov 8-10	32	52	0	6	148	127	113	34	6	0	32	2	112	12												
	5	Nov 16-17	6	12	0	0	70	63	44	7	0	0	5	0	24	1	38	1										
	6	Nov 22-23					19	11	19	1	0	0	0	0	3	0	2	0	5	0								
	Total		400	449	1	46	485	471	584	69	129	0	167	5	139	13	40	1	5	0								
2005	1	Oct 4	1	1	0	0	1	0	0	0																		
	2	Oct 11-12	10	17	1	2	15	12	2	0	0	0																
	3	Oct 17-19	40	47	0	0	34	22	8	0	0	0	6	0														
	4	Oct 24-26	80	96	3	2	102	52	104	1	0	0	1	0	9	0												
	5	Oct 31-Nov 2	15	54	0	0	50	38	154	0	0	0	2	1	2	0	38	0										
	6	Nov 8-9	1	8	0	0	18	28	44	0	0	0	0	0	0	0	11	0	13	0								
	7	Nov 15					5	7	16	0	0	0	0	0	0	0	2	0	4	0	0	0						
	Total		147	223	4	4	225	159	328	1	0	0	9	1	11	0	51	0	17	0	0	0						
2006	1	Oct 11-12	5	8	0	1	8	5	12	1																		
	2	Oct 17-18	12	18	1	4	8	7	18	3	2	0																
	3	Oct 24-25	76	78	0	15	34	15	31	3	1	0	5	0														
	4	Oct 30-Nov 1	65	87	0	49	93	67	134	43	1	0	2	0	58	3												
	5	Nov 8-9	27	48	0	19	83	54	201	70	0	0	1	0	21	4	57	12										
	6	Nov 14-15	4	28	0	2	31	36	90	29	0	0	0	0	5	0	16	5	28	4								
	7	Nov 20-21					6	13	43	10	0	0	1	0	0	0	5	0	5	1	11	0						
	Total		189	267	1	90	263	197	529	159	4	0	9	0	84	7	78	17	33	5	11	0						
2007	1	Oct 10-11	3	4	0	0	0	0	3	0																		
	2	Oct 16-17	7	20	0	0	2	4	4	0	1	0																
	3	Oct 23-24	12	28	0	1	1	2	12	1	1	0	9	0														
	4	Oct 29-31	64	79	1	2	9	4	45	0	0	0	2	0	19	0												
	5	Nov 5-7	82	156	1	2	17	4	149	0	0	0	0	0	3	0	58	1										
	6	Nov 13-16	103	279	0	2	26	12	477	8	0	0	0	0	1	0	21	0	107	0								
	7	Nov 19-21	42	171	0	2	10	11	272	4	0	0	0	0	0	0	3	0	6	0	157	1						
	8	Nov 26-28	15	124	0	0	17	4	357	2	0	0	0	0	0	0	3	0	16	0	46	0	93	0				
	9	Dec 4-5	3	22	0	0	3	6	160	0	0	0	0	0	0	0	0	0	2	0	15	0	17	0	40	0		
	10	Dec 11-13					0	11	127	2	0	0	0	0	0	0	0	0	0	0	8	0	10	0	10	0	6	0
	Total		331	883	2	9	85	58	1,606	17	2	0	11	0	23	0	85	1	131	0	226	1	120	0	50	0	6	0
2008	1	Oct 14-15	10	23	0	7	4	7	6	5																		
	2	Oct 21-22	44	49	0	8	15	12	33	3	10	1																
	3	Oct 27-30	133	147	1	54	47	31	100	22	2	0	38	2														
	4	Nov 4-7	109	173	5	55	22	12	464	55	1	0	7	0	88	12												
	5	Nov 10-13	41	108	1	21	28	18	399	35	0	0	5	1	50	4	131	16										
	6	Nov 17-19	6	27	0	0	2	5	202	5	0	0	0	0	13	2	29	6	77	6								
	7	Nov 24-25					1	5	88	2	0	0	0	0	4	0	20	1	8	1	10	0						
	Total		343	527	7	145	119	90	1,292	127	13	1	50	3	155	18	180	23	85	7	10	0						

A = Adults
M = Male adults
F = Female adults
U = Unknown sex adults
J = Jacks

[a] no survey in Week 6, 2001
[b] recaptures in 2001 not distinguished by sex, size, or age

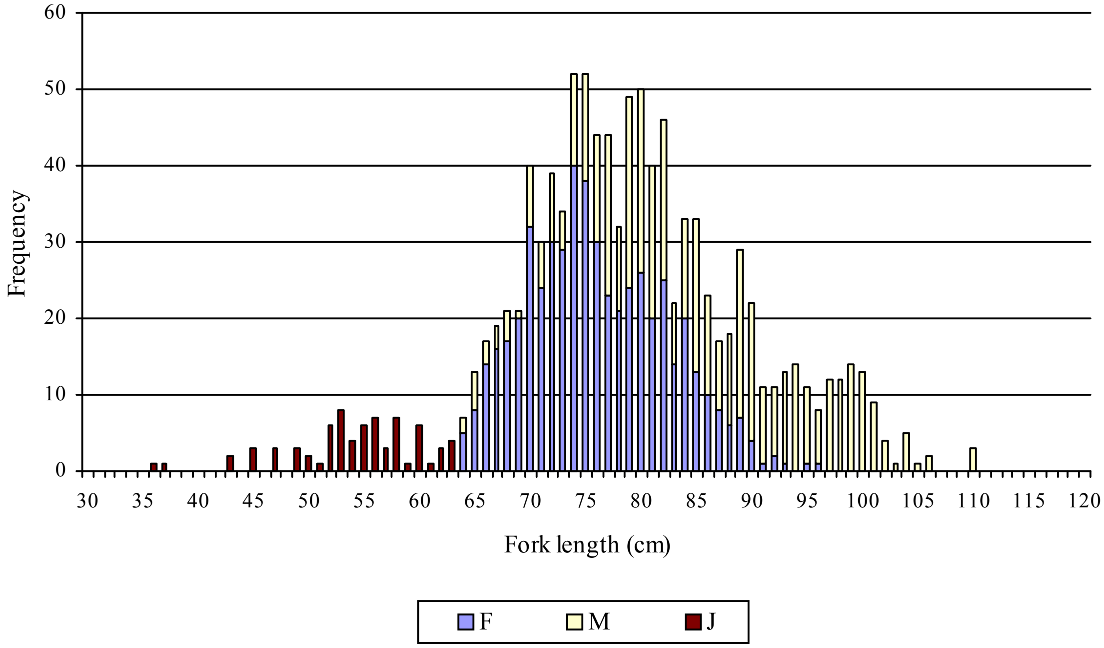
Appendix A (continued). Summary of Chinook salmon carcasses observed, Klamath River surveys 2001 to 2010. Jacks enumerated on the basis of postseason KRTAT length criteria.

			New carcass captures								Recoveries from Survey Week[b]:																	
	Survey	Survey	Tagged				Not tagged				1		2		3		4		5		6		7		8		9	
Year	Week	Dates	M	F	U	J	M	F	U	J	A	J	A	J	A	J	A	J	A	J	A	J	A	J	A	J	A	J
2009	1	Oct 14-15	1	11	0	2	1	0	7	0																		
	2	Oct 20-21	31	30	0	3	0	0	22	0	5	0																
	3	Oct 27-29	120	135	1	8	13	8	114	0	0	0	27	0														
	4	Nov 2-6	135	229	0	19	6	3	323	13	0	0	6	1	140	4												
	5	Nov 9-12	63	198	4	11	10	6	471	13	0	0	3	0	24	2	175	7										
	6	Nov 16-19	8	80	0	1	6	2	229	4	0	0	0	0	7	0	26	1	109	5								
	7	Nov 23-25	6	37	0	0	3	5	107	0	0	0	0	0	0	0	6	0	23	1	21	0						
	8	Nov 30-Dec 1					1	1	71	0	0	0	0	0	2	0	9	0	14	0	10	0	15	0				
		Total	364	720	5	44	40	25	1,344	30	5	0	36	1	173	6	216	8	146	6	31	0	15	0				
2010	1	Oct 13-14	3	5	0	0	2	0	8	1																		
	2	Oct 19-20	6	8	0	0	2	0	15	0	4	0																
	3	Oct 26-27	24	24	0	1	1	2	47	3	0	0	7	0														
	4	Nov 2-3	75	63	0	8	4	2	124	5	0	0	0	0	15	1												
	5	Nov 9-11	47	89	1	14	4	2	327	12	0	0	0	0	7	0	69	0										
	6	Nov 16-17	17	45	0	7	1	0	180	15	0	0	0	0	2	0	17	1	54	4								
	7	Nov 22-23	0	15	0	0	0	0	65	2	0	0	0	0	0	0	5	0	6	0	18	1						
	8	Nov 30-Dec 1					0	1	34	0	0	0	0	0	0	0	3	0	7	0	7	0	2	0				
		Total	172	249	1	30	14	7	800	38	4	0	7	0	24	1	94	1	67	4	25	1	2	0				

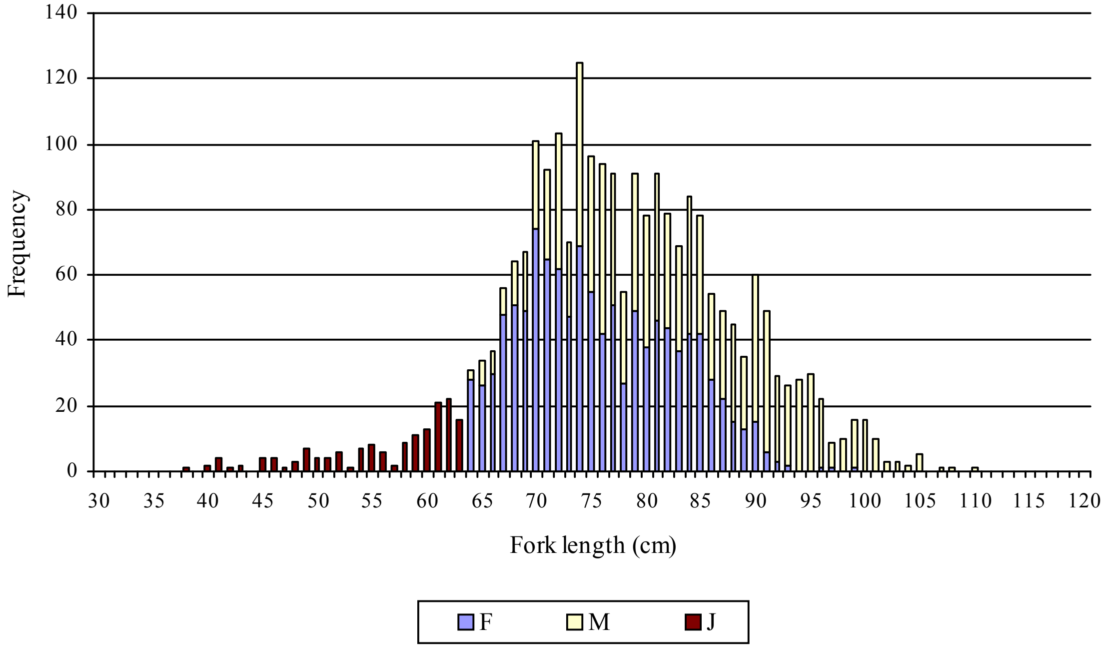
A = Adults
M = Male adults
F = Female adults
U = Unknown sex adults
J = Jacks

Appendix B. Length-frequency graphs of Chinook salmon spawners from main-stem Klamath River carcass surveys 2001 to 2010 (*F* = female; *M* = male; *J* = jack).

2001 [n = 1,063 (n_F = 530; n_M = 461; n_J = 72)]

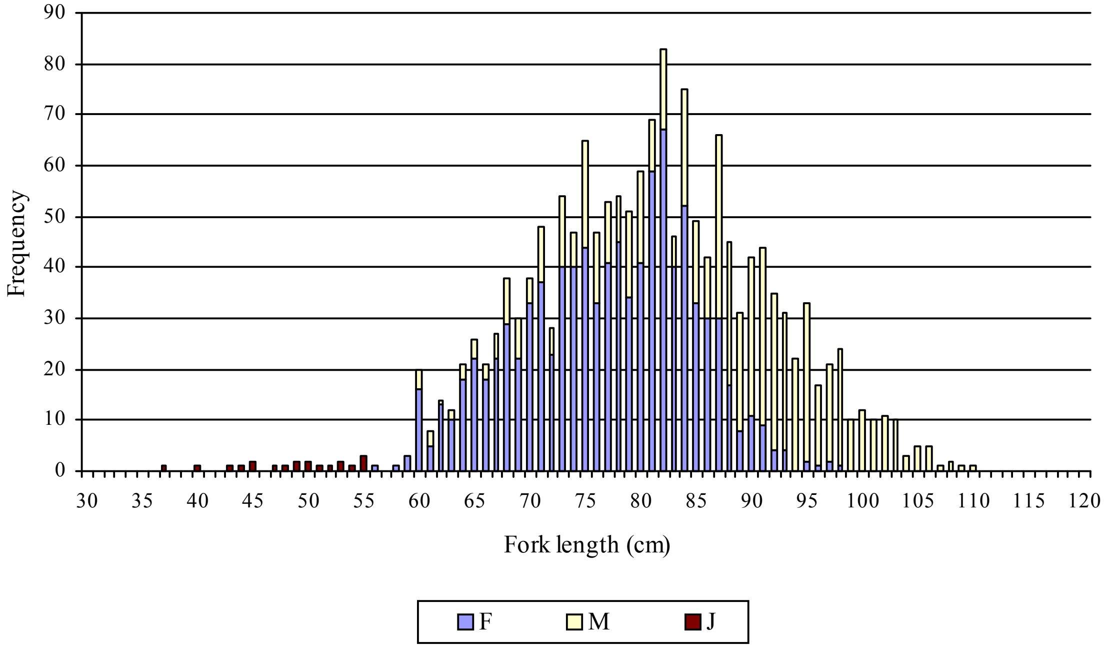


2002 [n = 2,349 (n_F = 1,129; n_M = 1,061; n_J = 159)]

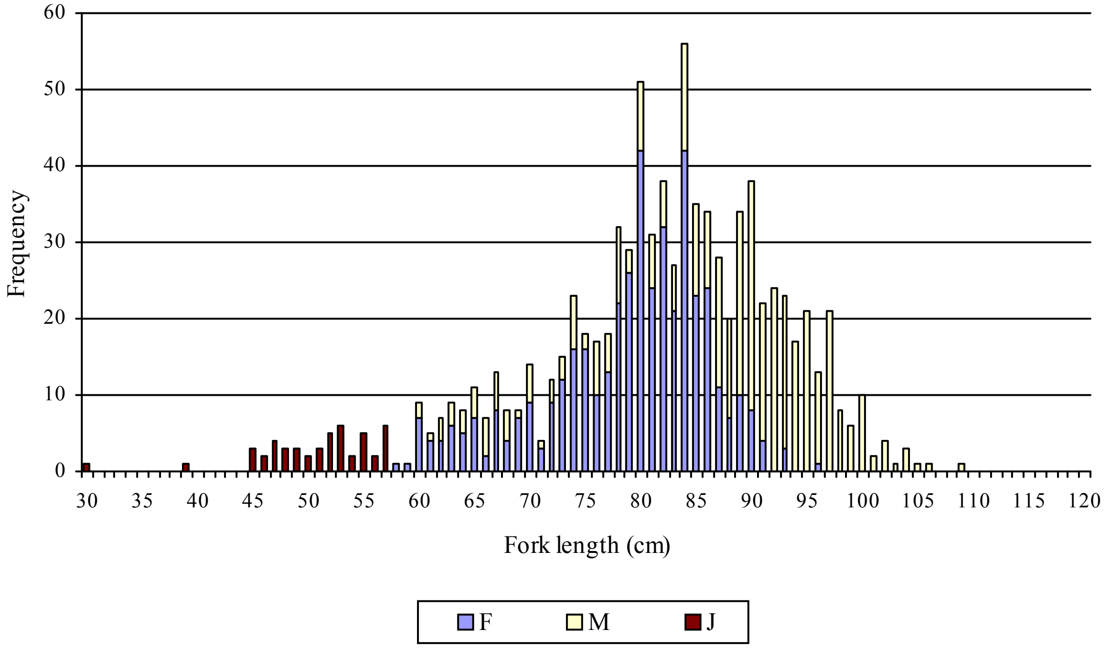


Appendix B (continued). Length-frequency graphs of Chinook salmon spawners from main-stem Klamath River carcass surveys 2001 to 2010 (*F* = female; *M* = male; *J* = jack).

2003 [n = 1,632 (n_F = 961; n_M = 651; n_J = 20)]

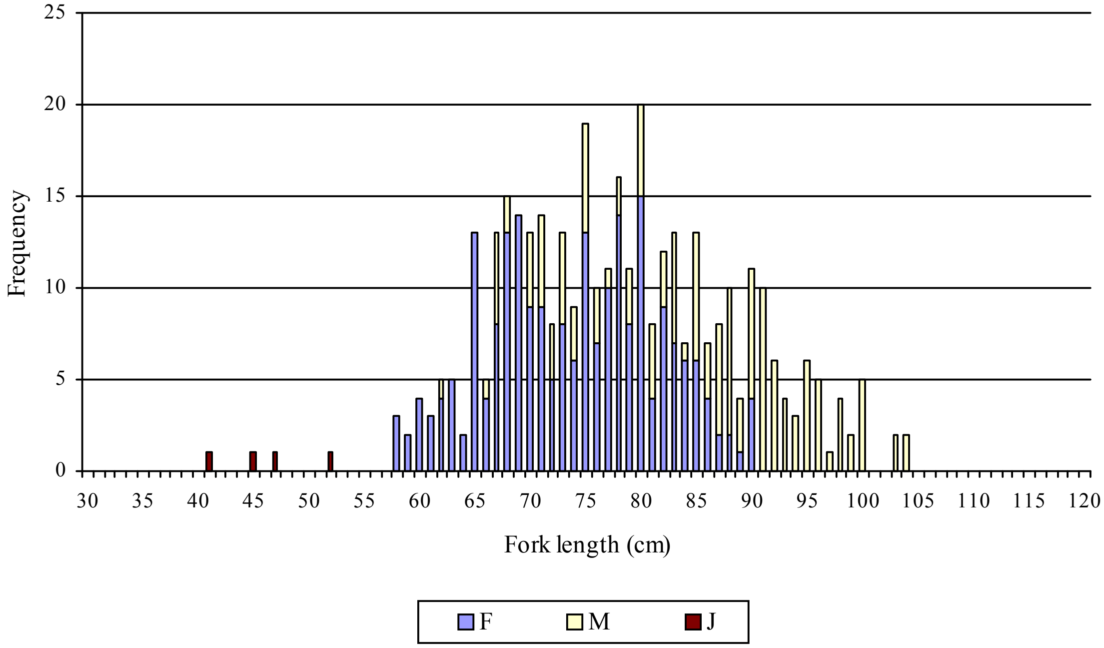


2004 [n = 887 (n_F = 444; n_M = 395; n_J = 48)]

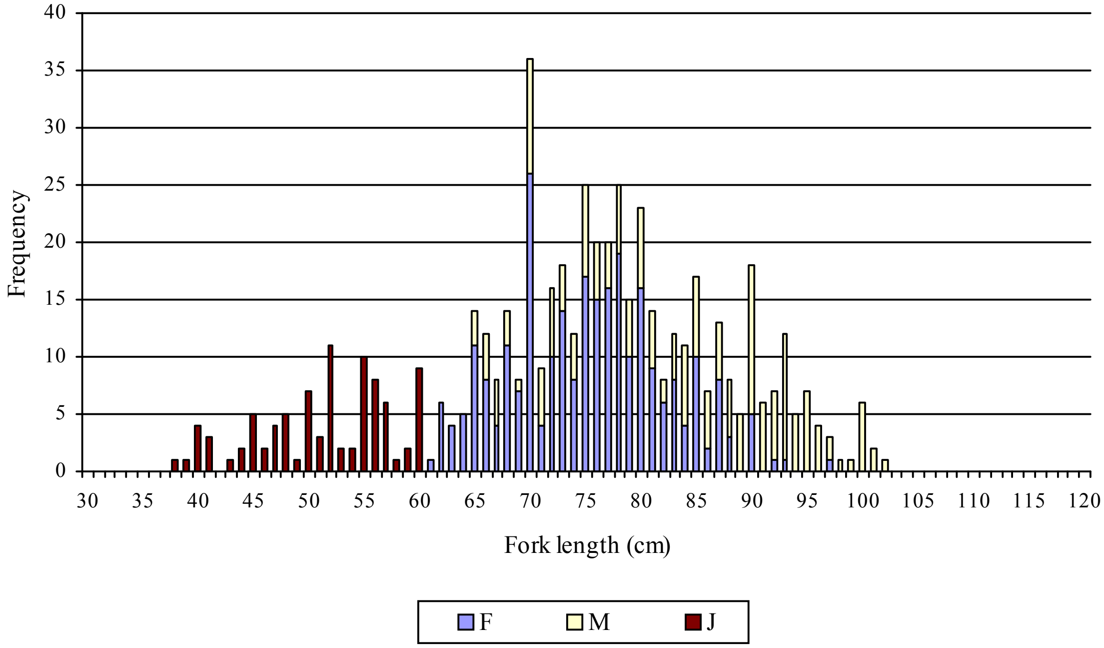


Appendix B (continued). Length-frequency graphs of Chinook salmon spawners from main-stem Klamath River carcass surveys 2001 to 2010 (*F* = female; *M* = male; *J* = jack).

2005 [$n = 375$ ($n_F = 224$; $n_M = 147$; $n_J = 4$)]

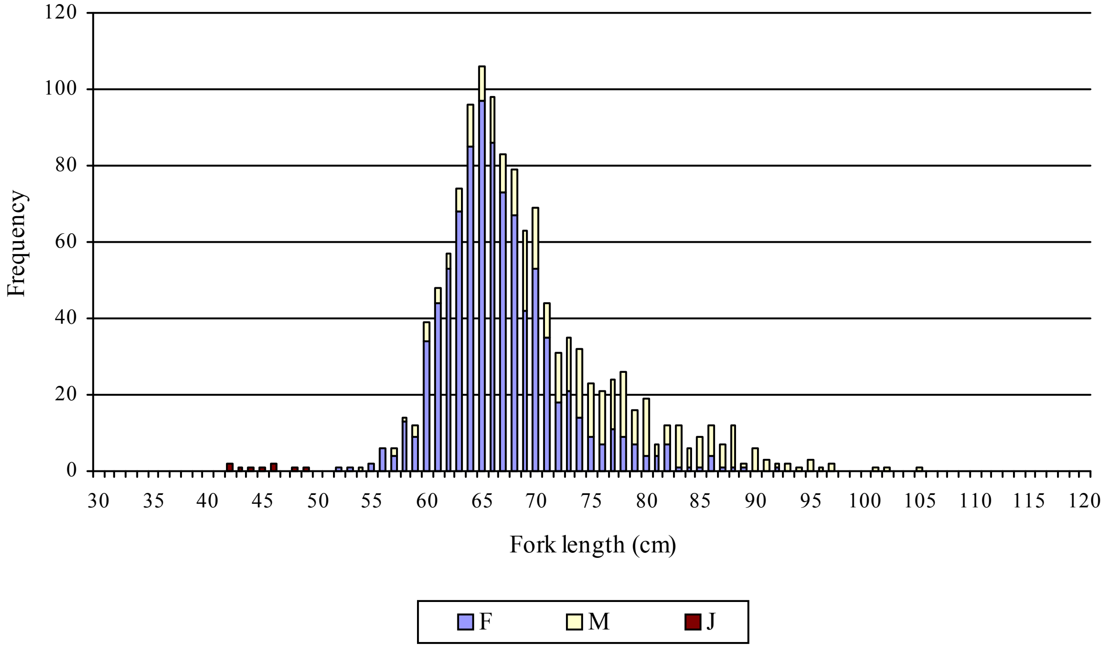


2006 [$n = 549$ ($n_F = 270$; $n_M = 189$; $n_J = 90$)]

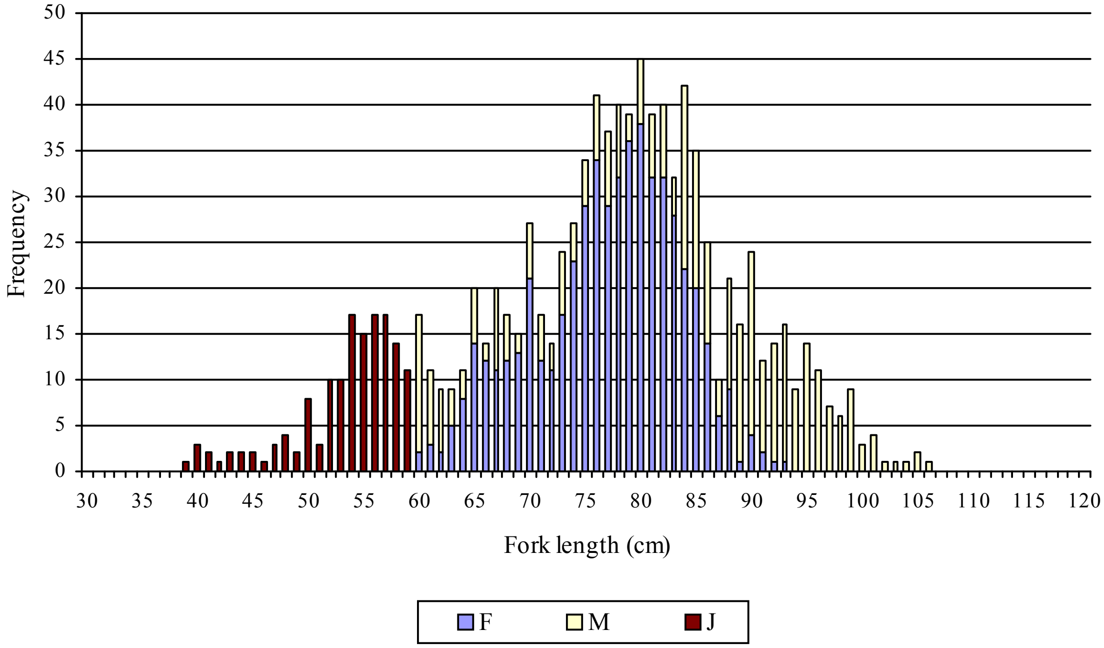


Appendix B (continued). Length-frequency graphs of Chinook salmon spawners from main-stem Klamath River carcass surveys 2001 to 2010 (*F* = female; *M* = male; *J* = jack).

2007 [n = 1,237 (n_F = 895; n_M = 333; n_J = 9)]

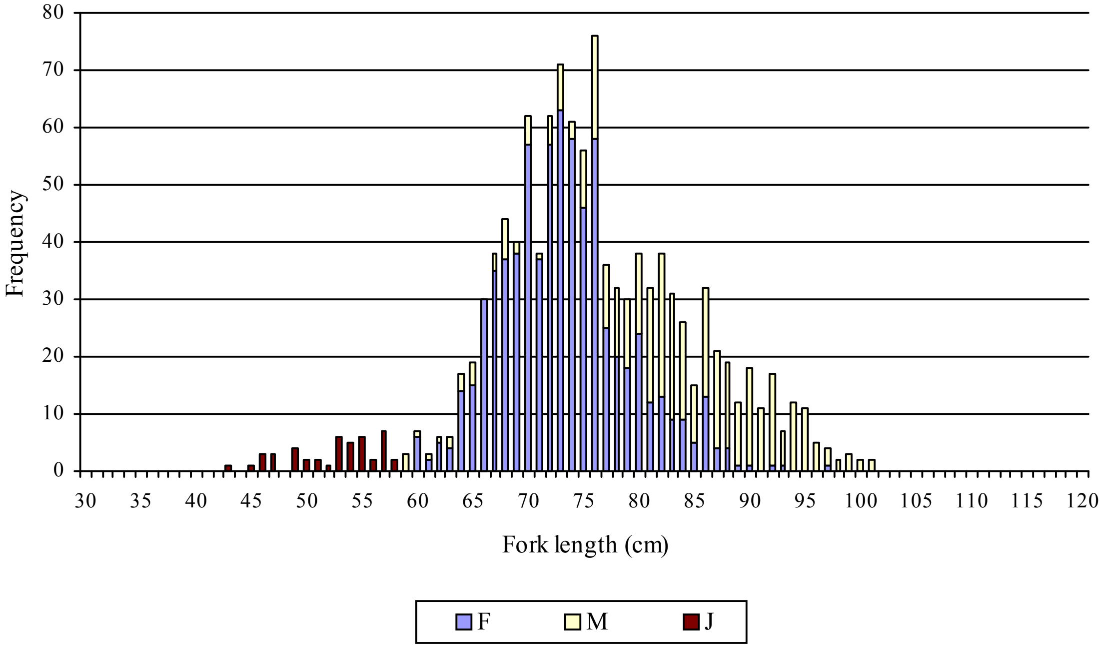


2008 [n = 1,028 (n_F = 536; n_M = 347; n_J = 145)]

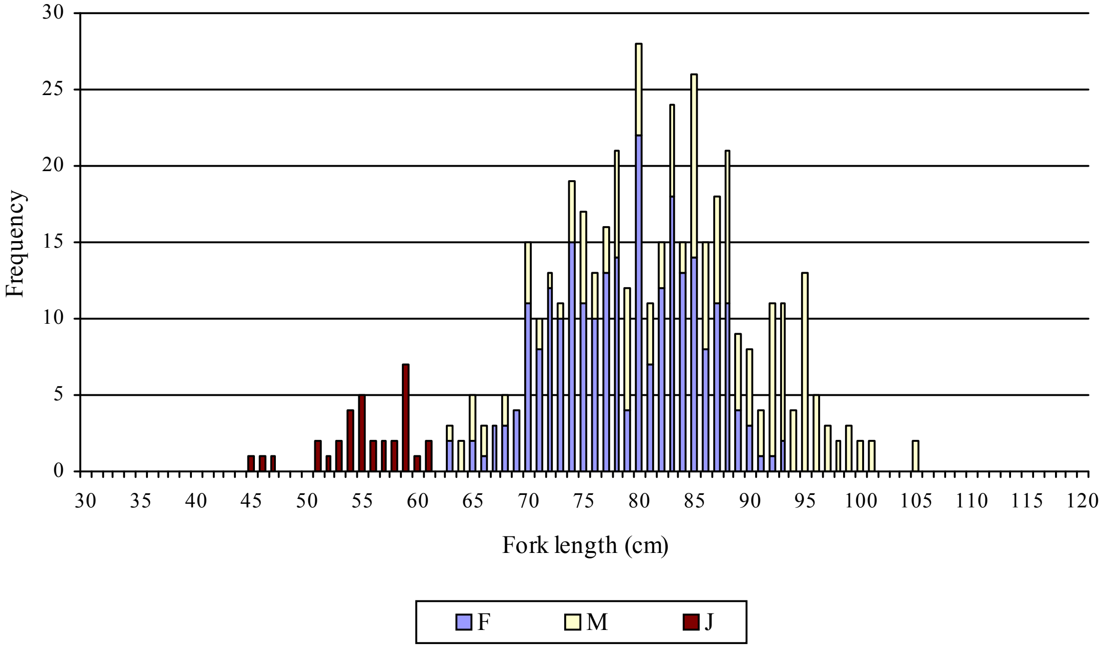


Appendix B (continued). Length-frequency graphs of Chinook salmon spawners from main-stem Klamath River carcass surveys 2001 to 2010 (*F* = female; *M* = male; *J* = jack).

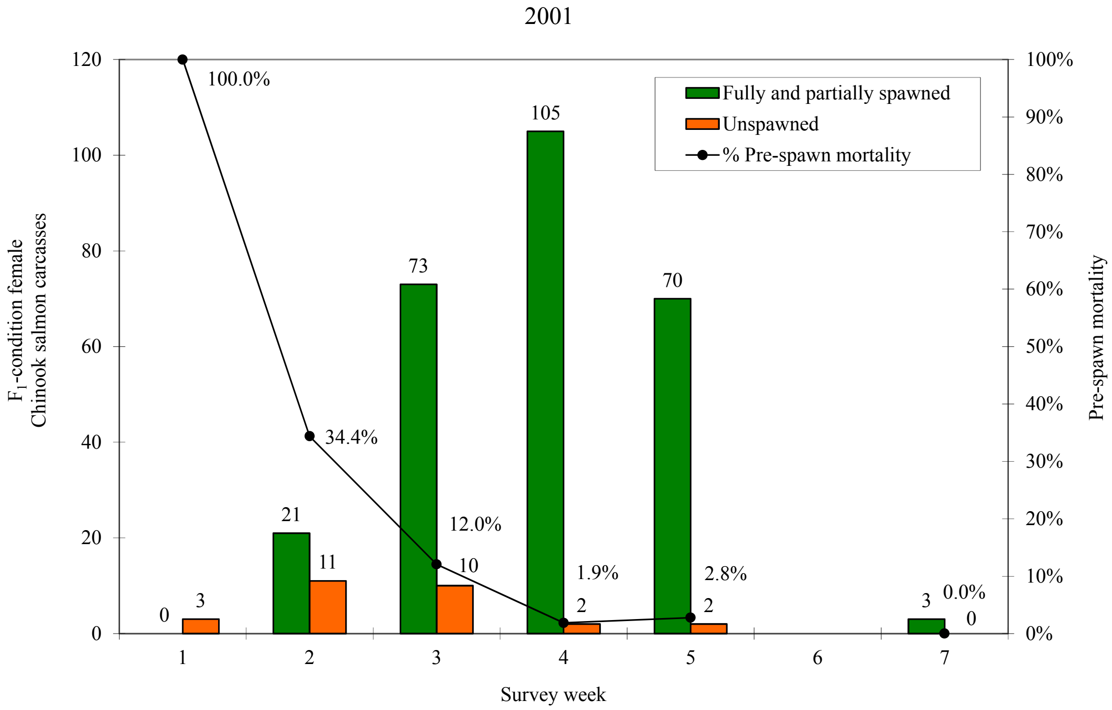
2009 [n = 1,140 (n_F = 723; n_M = 372; n_J = 45)]

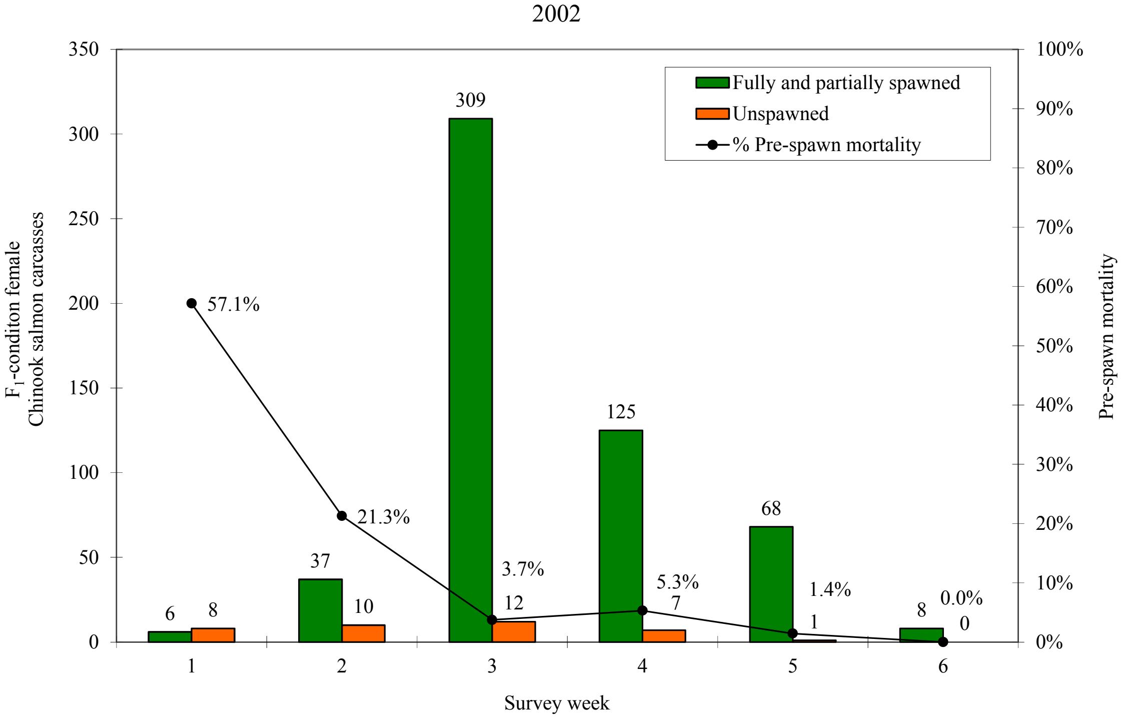


2010 [n = 457 (n_F = 250; n_M = 174; n_J = 33)]

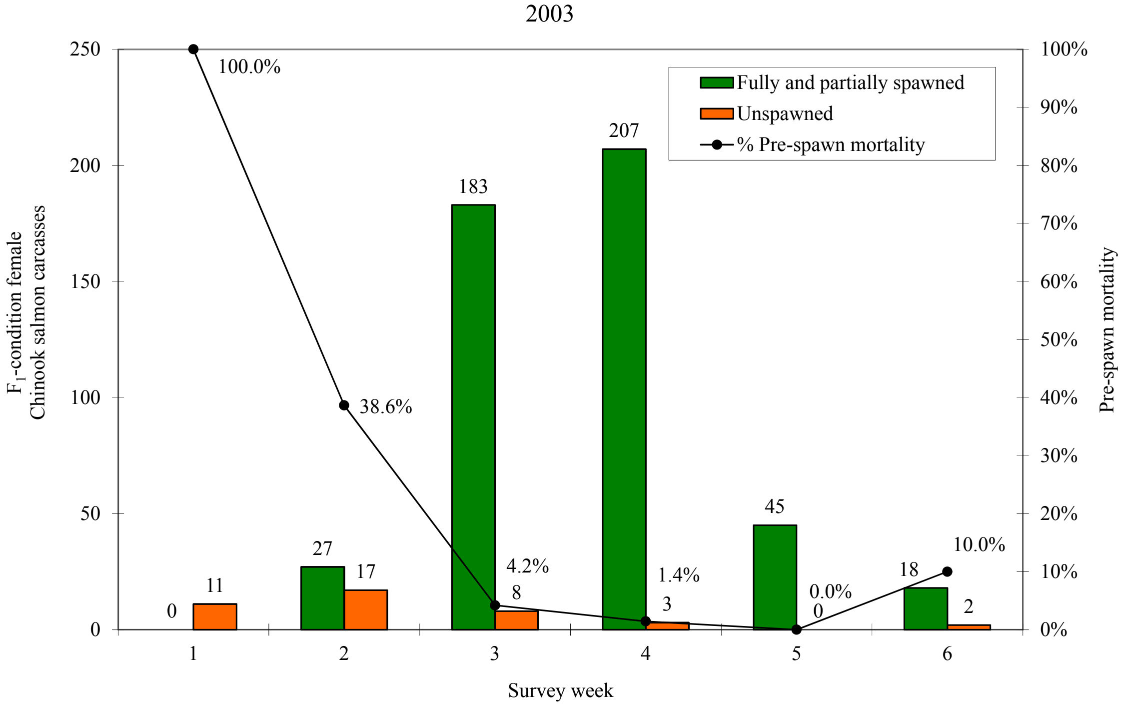


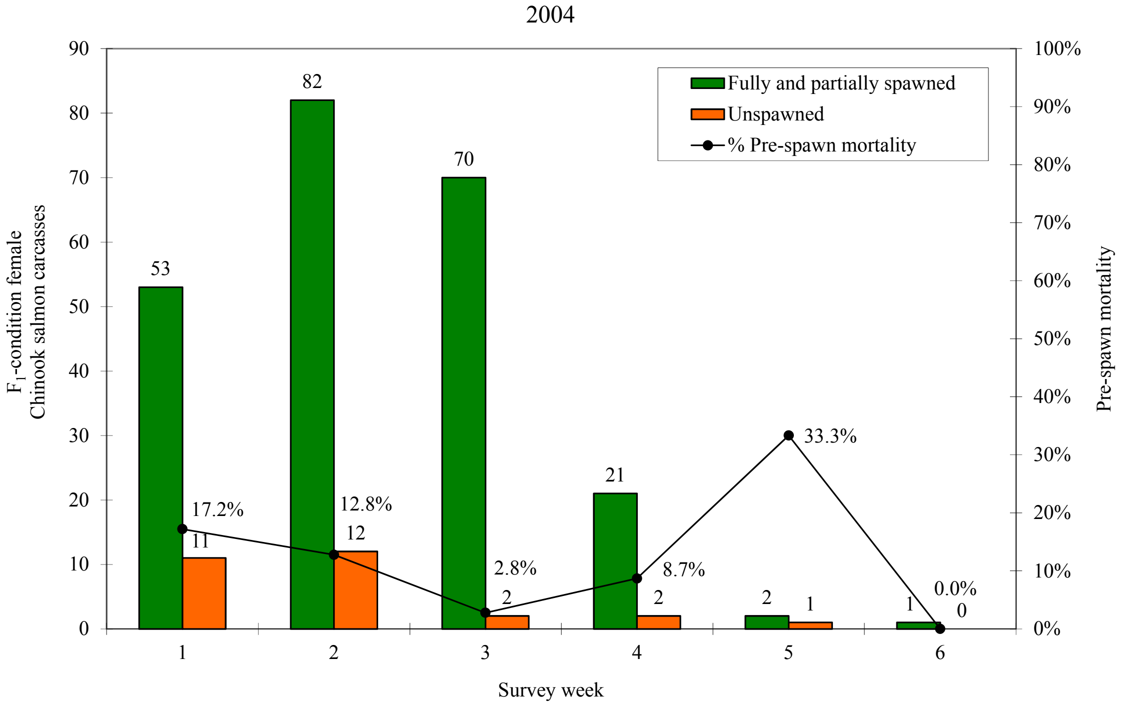
Appendix C. Weekly pre-spawn mortality from F_1-condition female carcasses by year, Klamath River surveys 2001 to 2010.



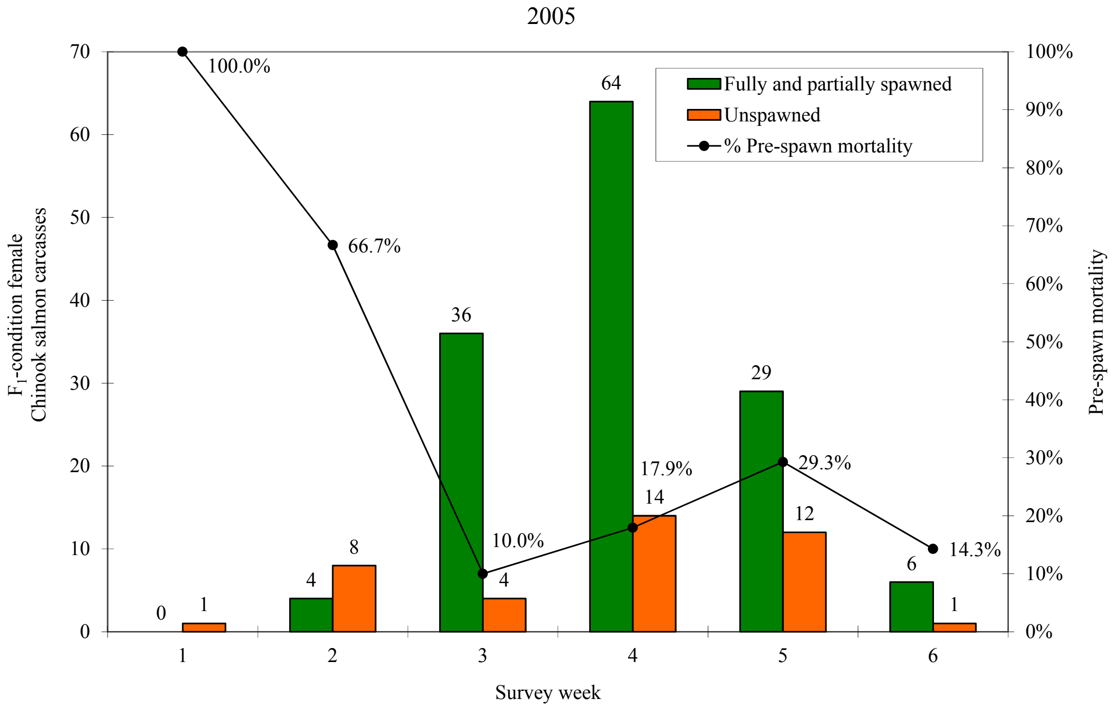


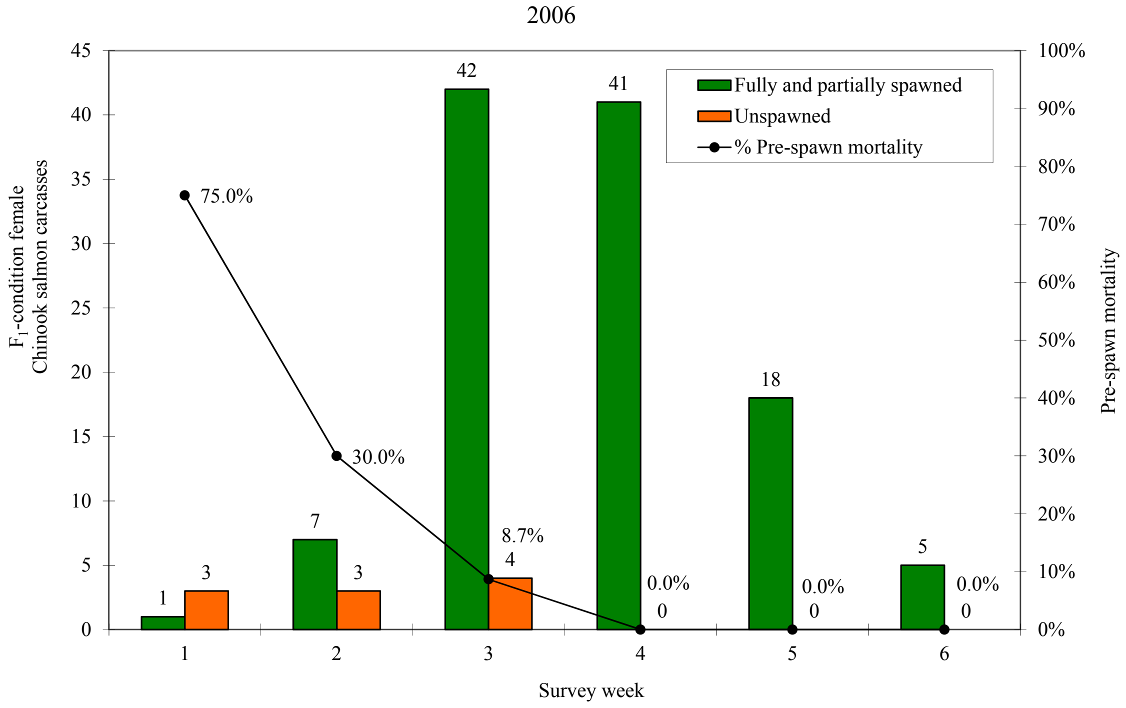
Appendix C (continued). Weekly pre-spawn mortality from F_1-condition female carcasses by year, Klamath River surveys 2001 to 2010.



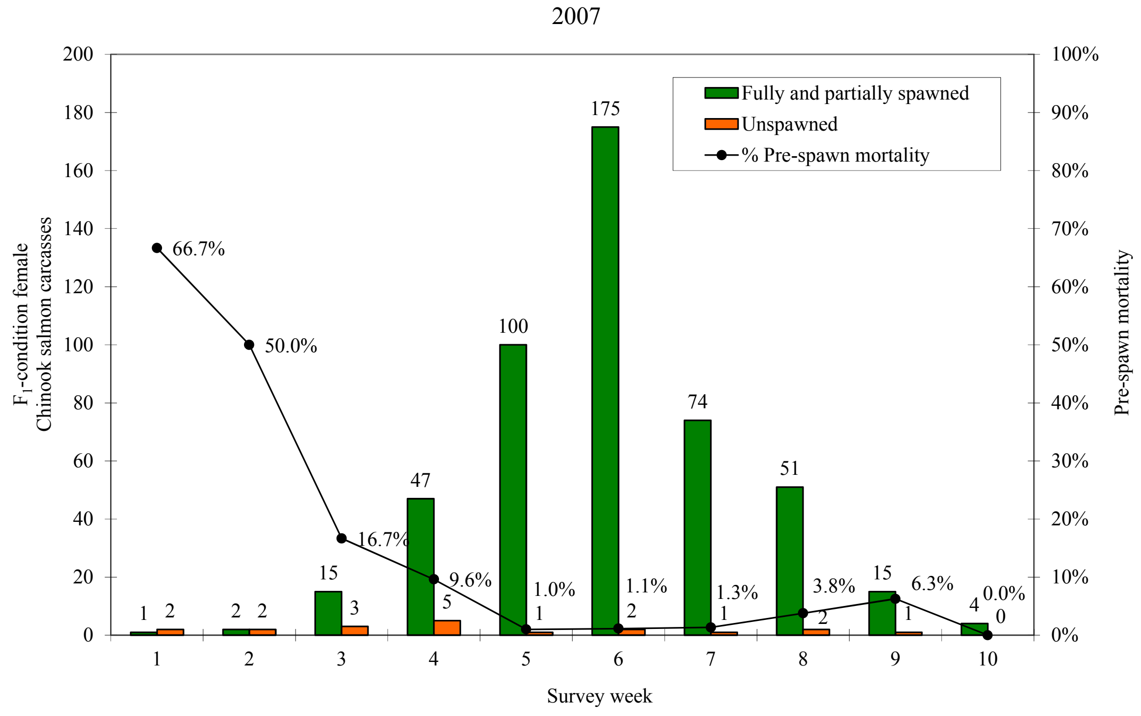


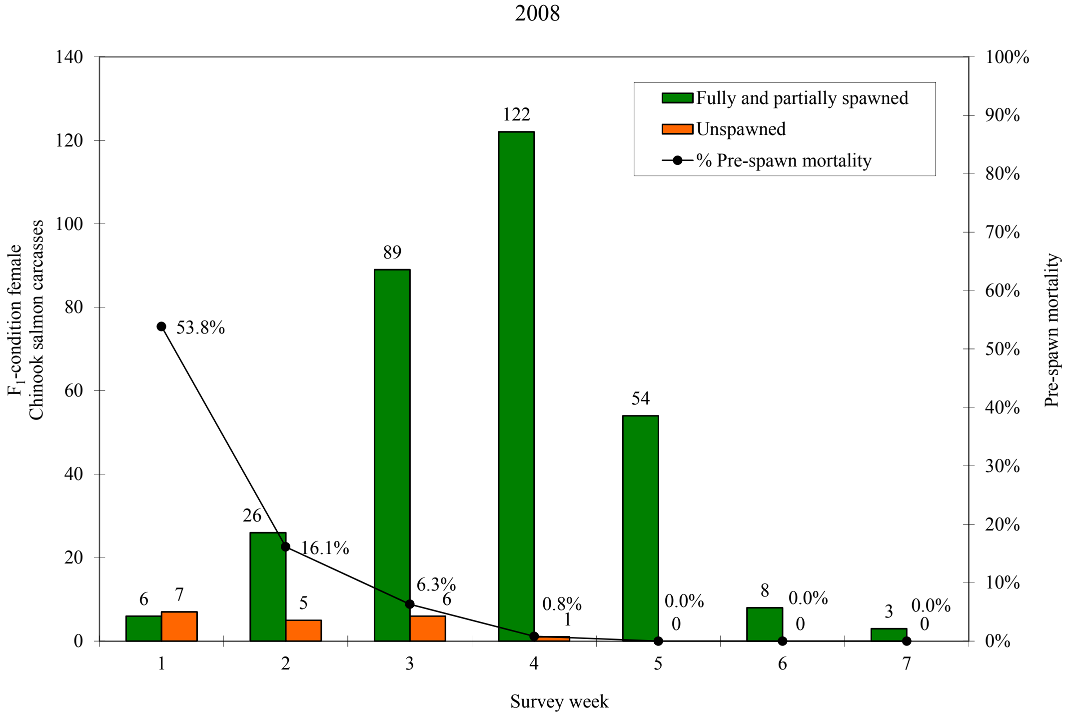
Appendix C (continued). Weekly pre-spawn mortality from F_1-condition female carcasses by year, Klamath River surveys 2001 to 2010.



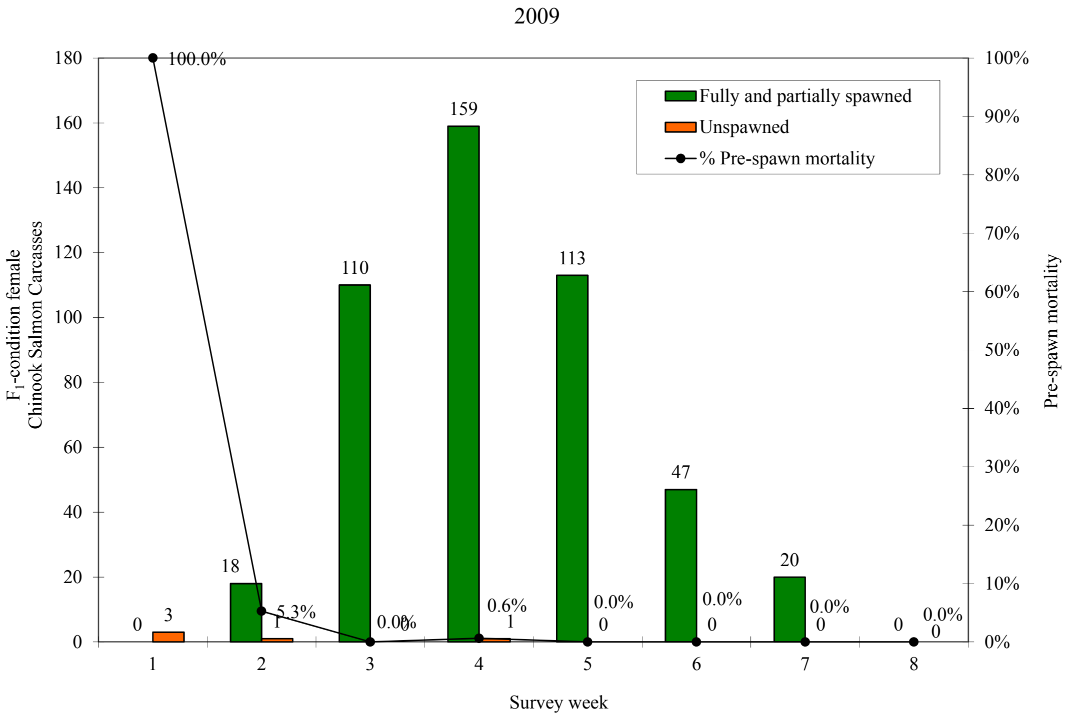


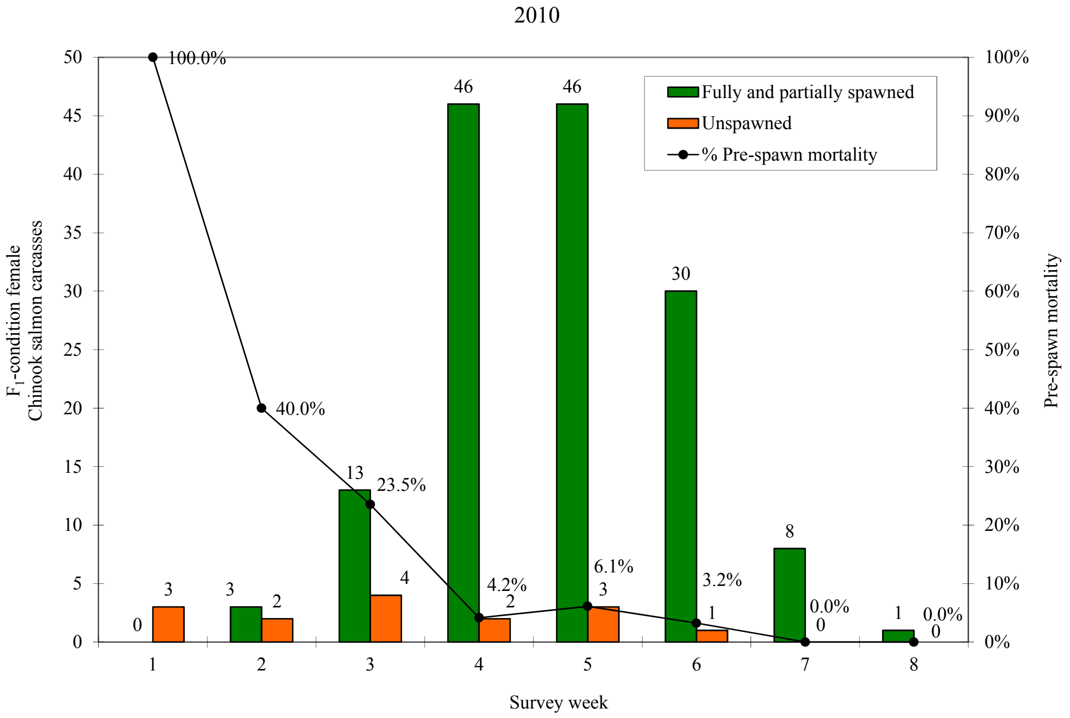
Appendix C (continued). Weekly pre-spawn mortality from F_1-condition female carcasses by year, Klamath River surveys 2001 to 2010.





Appendix C (continued). Weekly pre-spawn mortality from F_1-condition female carcasses by year, Klamath River surveys 2001 to 2010.





Appendix D. Unstratified Petersen tag-recovery-based estimates of successfully (fully and partially) spawned adult females per observed redd, Klamath River surveys 2001 to 2004 and 2006.

Year	Redds observed	Successfully spawned adult female estimate	Estimated successfully spawned adult females per observed redd
2001	825	3,150	3.8
2002	2,097	6,901	3.3
2003	1,472	7,013	4.8
2004	512	2,130	4.2
2006	453	1,626	3.6

Appendix E. Stratified Petersen method escapement estimates, Klamath River surveys 2001 to 2010.

Escapement was alternatively estimated using a weekly-stratified Petersen formula:

$$\hat{N}_i = \frac{(M_{i-1}+1)(C_i+1)}{(R_i+1)} - 1 \quad ;$$

N_i = escapement of the *i*th survey period (week);

$M_{i\text{-}1}$ = total number of carcasses tagged the survey week prior to the *i*th survey week;

C_i = total number of carcasses captured in the *i*th survey week;

R_i = total carcass recaptures in the *i*th survey week that were tagged during the previous survey week, *i*-1.

An escapement estimate for the season was then calculated by summing the weekly estimates:

$$\hat{N} = \sum \hat{N}_i \quad .$$

95% confidence limits were calculated each week by applying the normal distribution formula for standard error:

$$N_i \pm 1.96\sqrt{\frac{(M_{i-1}+1)(C_i+1)(M_{i-1}-R_i)(C_i-R_i)}{(R_i+1)^2(R_i+2)}} \quad .$$

Tag number recording errors or hog rings with removed tags were associated with 20 recoveries in 2002, 5 in 2003, 1 in 2004, 5 in 2005, 10 in 2006, 7 in 2007, 5 in 2008, 15 in 2009, and 0 in 2010. The survey weeks from which these carcasses were tagged cannot be determined. There were no such errors from lost flagging in 2001. Since stratified Petersen and Schaefer estimates require both tag week and recapture week information, fish with missing tag week were not included with the recaptures for these two methods.

The stratified Petersen method yielded estimates ranging from 3,285 (2010) to 19,091 (2003). Recapture rates of carcasses tagged one week prior ranged from 17.5% (2005) to 47.7% (2002). We found linear relationships between weekly recovery rates and the number of carcasses tagged, which we assumed to indicate that the underlying assumptions of the Petersen estimator were not violated (Krebs 1999). No corrections were made for the missing Reach 1 surveys in 2002 to 2005.

Appendix E (continued). Stratified Petersen method escapement estimates, Klamath River surveys 2001 to 2010.

Stratified Petersen estimates were consistently higher than both the unstratified Petersen (by 4.4% to 60.1%; Table 5) and Schaefer estimates (by 8.4% to 44.1%; Appendix F). Our data exhibit small sample sizes and low recapture rates in the early and late sampling weeks. Estimates from the stratified Petersen method for these weeks were likely inflated by low recapture rates, biasing the overall estimate upward.

Recapture rates in the stratified Petersen method are lower than the other two because estimates were calculated on a week-by-week basis and each stratum allows just one week of recapture opportunity. The higher recapture rates and sample sizes used in the unstratified Petersen and Schaefer methods indicate that these methods may yield a more robust estimate of true population than the stratified Petersen method. We reduced our reliance on the stratified Petersen estimator on this basis.

Year	Survey Week	Carcasses			Tagging rate	Recovery rate	Escapement estimate	95% confidence limits	
		Captured	Tagged	Recovered				Lower	Upper
2001	1	50	45		90.0%				
	2	354	121	7	34.2%	15.6%	2,040	842	3,239
	3	601	313	43	52.1%	35.5%	1,668	1,293	2,044
	4	693	337	136	48.6%	43.5%	1,590	1,411	1,768
	5	867	254	131	29.3%	38.9%	2,222	1,950	2,493
	7[a]	285		41		16.1%	1,735	1,297	2,174
	Total	2,850	1,070	358	37.5%	33.5%	9,255	6,793	11,717
2002 [b]	1	52	37		71.2%				
	2	363	247	9	68.0%	24.3%	1,382	690	2,074
	3	2,505	1,021	123	40.8%	49.8%	5,011	4,405	5,617
	4	2,638	647	535	24.5%	52.4%	5,031	4,769	5,293
	5	1,803	346	293	19.2%	45.3%	3,975	3,668	4,282
	6	627	37	142	5.9%	41.0%	1,523	1,355	1,691
	7	107		11		29.7%	341	196	486
	Total	8,095	2,335	1,113	28.8%	47.7%	17,263	15,084	19,442
2003 [b]	1	39	23		59.0%				
	2	142	93	2	65.5%	8.7%	1,143	105	2,181
	3	1,072	588	21	54.9%	22.6%	4,584	2,961	6,207
	4	2,022	722	209	35.7%	35.5%	5,673	5,092	6,254
	5	1,067	187	156	17.5%	21.6%	4,917	4,291	5,544
	6	779	48	72	6.2%	38.5%	2,008	1,667	2,349
	7	140		8		16.7%	767	351	1,183
	Total	5,261	1,661	468	31.6%	28.2%	19,091	14,466	23,717
2004 [b]	1	458	233		50.9%				
	2	613	294	94	48.0%	40.3%	1,511	1,297	1,726
	3	670	261	133	39.0%	45.2%	1,476	1,312	1,641
	4	512	90	124	17.6%	47.5%	1,074	956	1,192
	5	202	18	39	8.9%	43.3%	461	366	556
	6	50		5		27.8%	161	68	253
	Total	2,505	896	395	35.8%	44.1%	4,683	3,998	5,368
2005 [b]	1	3	2		66.7%				
	2	59	30	0	50.8%	0.0%	179	-23	381
	3	151	87	6	57.6%	20.0%	672	271	1,073
	4	440	181	9	41.1%	10.3%	3,880	1,745	6,014
	5	311	69	38	22.2%	21.0%	1,455	1,081	1,829
	6	99	9	13	9.1%	18.8%	499	289	709
	7	28		0		0.0%	289	-86	664
	Total	1,091	378	66	34.6%	17.5%	6,974	3,278	10,670
2006	1	40	14		35.0%				
	2	71	35	2	49.3%	14.3%	359	50	668
	3	252	169	5	67.1%	14.3%	1,517	503	2,531
	4	538	201	61	37.4%	36.1%	1,477	1,203	1,751
	5	502	94	69	18.7%	34.3%	1,451	1,197	1,704
	6	220	34	32	15.5%	34.0%	635	476	795
	7	72		11		32.4%	212	126	298
	Total	1,695	547	180	32.3%	32.9%	5,651	3,555	7,746

[a] no survey Week 6

[b] Reach 1 not surveyed; no correction applied

Appendix E (continued). Stratified Petersen method escapement estimates, Klamath River surveys 2001 to 2010.

	Survey	Carcasses			Tagging	Recovery	Escapement	95% confidence limits	
Year	Week	Captured	Tagged	Recovered	rate	rate	estimate	Lower	Upper
2007	1	10	7		70.0%				
	2	37	27	1	73.0%	14.3%	151	6	296
	3	57	41	9	71.9%	33.3%	161	91	231
	4	204	146	19	71.6%	46.3%	430	303	556
	5	411	241	59	58.6%	40.4%	1,008	828	1,189
	6	907	384	107	42.3%	44.4%	2,034	1,767	2,300
	7	512	215	158	42.0%	41.1%	1,241	1,119	1,364
	8	519	139	93	26.8%	43.3%	1,194	1,030	1,357
	9	194	25	40	12.9%	28.8%	665	514	815
	10	140		6		24.0%	523	220	825
	Total	2,991	1,225	492	41.0%	40.2%	7,407	5,879	8,934
2008	1	62	40		64.5%				
	2	164	101	11	61.6%	27.5%	563	315	811
	3	535	335	40	62.6%	39.6%	1,332	1,033	1,632
	4	895	342	100	38.2%	29.9%	2,980	2,524	3,435
	5	651	171	147	26.3%	43.0%	1,510	1,349	1,671
	6	247	33	83	13.4%	48.5%	507	444	570
	7	96		10		30.3%	299	167	430
	Total	2,650	1,022	391	38.6%	38.3%	7,191	5,832	8,549
2009	1	22	14		63.6%				
	2	86	64	5	74.4%	35.7%	217	96	337
	3	399	264	27	66.2%	42.2%	928	682	1,173
	4	728	383	144	52.6%	54.5%	1,331	1,201	1,461
	5	776	276	182	35.6%	47.5%	1,629	1,480	1,778
	6	330	89	114	27.0%	41.3%	796	707	886
	7	158	43	21	27.2%	23.6%	649	435	864
	8	73		15		34.9%	203	44	361
	Total	2,572	1,133	508	44.1%	44.8%	5,753	4,645	6,862
2010	1	19	8		42.1%				
	2	31	14	4	45.2%	50.0%	57	28	85
	3	102	49	7	48.0%	50.0%	192	109	275
	4	281	146	16	52.0%	32.7%	828	527	1,130
	5	496	151	69	30.4%	47.3%	1,043	880	1,206
	6	265	69	58	26.0%	38.4%	684	565	804
	7	82	15	19	18.3%	27.5%	290	198	381
	8	35		2		13.3%	191	-580	962
	Total	1,311	452	175	34.5%	38.7%	3,285	1,727	4,842

Appendix F. Schaefer method escapement estimates, Klamath River surveys 2001 to 2010.

Escapement estimates were alternatively calculated with the Schaefer (1951) estimator:

$$\hat{N} = \sum \hat{N}_{ij} = \sum R_{ij}\left(\frac{M_i}{R_i}\right)\left(\frac{C_j}{R_j}\right);$$

M_i = number of fish tagged in the *i*th period (week) of tagging;

C_j = number of fish caught and examined in the *j*th week of recovery;

R_{ij} = number of fish tagged in the *i*th tagging week which are recaptured in the *j*th recovery week;

R_i = total recaptures of fish tagged in the *i*th week;

R_j = total recaptures during the *j*th week.

There is no method for calculating standard error and applying confidence limits to the Schaefer estimate (Arnason et al. 1996).

Tag number recording errors or hog rings with removed tags were associated with 20 recoveries in 2002, 5 in 2003, 1 in 2004, 5 in 2005, 10 in 2006, 7 in 2007, 5 in 2008, 15 in 2009, and 0 in 2010. The survey weeks from which these carcasses were tagged cannot be determined. Since stratified Petersen and Schaefer estimates require both tag week and recapture week information, fish with missing tag week were not included with the recaptures for these two methods.

Schaefer adult escapement estimates ranged from 2,416 (2010) to 14,544 (2003). Excluding tag number recording errors mentioned above, recapture rates of all previously tagged carcasses ranged from 23.5% (2005) to 56.8% (2009) over all ten survey seasons. No corrections were made for the missing Reach 1 surveys in 2002 to 2005.

Schaefer estimates were 0.02% to 23.1% higher than the unstratified Petersen estimates (Table 5) every year except 2004 and 2010 when the unstratified Petersen estimates were 21.8% and 6.4% higher, respectively. The Schaefer method produces an unbiased estimate when “capture probabilities are equal in all initial strata or the recovery probabilities are the same in all the final strata” (Arnason et al. 1996). Our data exhibit small sample sizes and low recapture rates in the early and late sampling weeks. Estimates from the Schaefer method for these weeks were likely inflated by low recapture rates, biasing the overall estimate upward. Our results conflict with Law (1994) who found Petersen estimates to be consistently and substantially larger overestimates than those provided by the Schaefer estimator. On the other hand, Schwarz et al. (2002) found the Schaefer estimator to be “essentially equivalent to the pooled-Petersen estimator in terms of conditions for consistency, bias when assumptions are violated, and precision” and “there is no reason to prefer it over the simpler and better understood Petersen estimate.”

Appendix F (continued). Schaefer method escapement estimates, Klamath River surveys 2001 to 2010.

2001

Observations

Recovery Week	Tagging Week 1	2	3	4	5	Recovered (R_j)	Captured (C_j)	C_j/R_j
1							50	
2	7					7	354	50.6
3	2	43				45	601	13.4
4		6	136			142	693	4.9
5		3	19	131		153	867	5.7
7*				1	41	42	285	6.8
Recovered (R_i)	9	52	155	132	41	389	2,850	
Tagged (M_i)	45	121	313	337	254	1,070		
M_i/R_i	5.0	2.3	2.0	2.6	6.2			

Calculations

Recovery Week	Tagging Week 1	2	3	4	5	Total	Recovery rate ($\Sigma R_i/\Sigma M_i$)
1							36.4%
2	1,770					1,770	
3	134	1,336				1,470	
4	0	68	1,340			1,408	
5	0	40	217	1,895		2,152	
7*	0	0	0	17	1,724	1,741	
Total	1,904	1,444	1,558	1,913	1,724	8,541	

* no survey Week 6

2002

Observations

Recovery Week	Tagging Week 1	2	3	4	5	6	Recovered (R_j)	Carcasses (C_j)	C_j/R_j
1								52	
2	9						9	363	40.3
3	3	123					126	2,505	19.9
4		18	535				553	2,638	4.8
5		1	74	293			368	1,803	4.9
6		1	29	49	142		221	627	2.8
7			2	7	17	11	37	107	2.9
Recovered (R_i)	12	143	640	349	159	11	1,314	8,095	
Tagged (M_i)	37	247	1,021	647	346	37	2,335		
M_i/R_i	3.1	1.7	1.6	1.9	2.2	3.4			

Calculations

Recovery Week	Tagging Week 1	2	3	4	5	6	Total	Recovery rate ($\Sigma R_i/\Sigma M_i$)
1								56.3%
2	1,119						1,119	
3	184	4,224					4,408	
4	0	148	4,071				4,220	
5	0	8	578	2,661			3,248	
6	0	5	131	258	877		1,271	
7	0	0	9	38	107	107	261	
Total	1,303	4,385	4,790	2,957	984	107	14,526	

Appendix F (continued). Schaefer method escapement estimates, Klamath River surveys 2001 to 2010.

2003

Observations

Recovery Week	Tagging Week						Recovered (R_j)	Carcasses (C_j)	C_j/R_j
	1	2	3	4	5	6			
1								39	
2	2						2	142	71.0
3		21					21	1,072	51.0
4		6	209				215	2,022	9.4
5		2	31	156			189	1,067	5.6
6			17	134	72		223	779	3.5
7			2	14	7	8	31	140	4.5
Recovered (R_i)	2	29	259	304	79	8	681	5,261	
Tagged (M_i)	23	93	588	722	187	48	1,661		
M_i/R_i	11.5	3.2	2.3	2.4	2.4	6.0			

Calculations

Recovery Week	Tagging Week						Total		Recovery rate ($\Sigma R_i/\Sigma M_i$)
	1	2	3	4	5	6			
1									41.0%
2	1,633						1,633		
3	0	3,438					3,438		
4	0	181	4,462				4,643		
5	0	36	397	2,092			2,525		
6	0	0	135	1,112	595		1,842		
7	0	0	21	150	75	217	462		
Total	1,633	3,655	5,015	3,354	670	217	14,544		

2004

Observations

Recovery Week	Tagging Week					Recovered (R_j)	Carcasses (C_j)	C_j/R_j
	1	2	3	4	5			
1							458	
2	94					94	613	6.5
3	29	133				162	670	4.1
4	6	34	124			164	512	3.1
5		5	25	39		69	202	2.9
6			3	2	5	10	50	5.0
Recovered (R_i)	129	172	152	41	5	499	2,505	
Tagged (M_i)	233	294	261	90	18	896		
M_i/R_i	1.8	1.7	1.7	2.2	3.6			

Calculations

Recovery Week	Tagging Week					Total		Recovery rate ($\Sigma R_i/\Sigma M_i$)
	1	2	3	4	5			
1								55.7%
2	1,107					1,107		
3	217	940				1,157		
4	34	181	665			880		
5	0	25	126	251		401		
6	0	0	26	22	90	138		
Total	1,358	1,147	816	273	90	3,683		

Appendix F (continued). Schaefer method escapement estimates, Klamath River surveys 2001 to 2010.

2005

Observations

Recovered Week	Tagging Week 1	2	3	4	5	6	Recovered (R_j)	Carcasses (C_j)	C_j/R_j
1								3	
2							0	59	N/A
3		6					6	151	25.2
4		1	9				10	440	44.0
5		3	2	38			43	311	7.2
6				11	13		24	99	4.1
7				2	4	0	6	28	4.7
Recovered (R_i)	0	10	11	51	17	0	89	1,091	
Tagged (M_i)	2	30	87	181	69	9	378		
M_i/R_i	N/A	3.0	7.9	3.5	4.1	N/A			

Calculations

Recovery Week	Tagging Week 1	2	3	4	5	6	Total	Recovery rate ($\Sigma R_i/\Sigma M_i$)
1								23.5%
2	0						0	
3	0	453					453	
4	0	132	3,132				3,264	
5	0	65	114	975			1,155	
6	0	0	0	161	218		379	
7	0	0	0	33	76	0	109	
Total	0	650	3,246	1,170	293	0	5,359	

2006

Observations

Recovery Week	Tagging Week 1	2	3	4	5	6	Recovered (R_j)	Carcasses (C_j)	C_j/R_j
1								40	
2	2						2	71	35.5
3	1	5					6	252	42.0
4	1	2	61				64	538	8.4
5		1	25	69			95	502	5.3
6			5	21	32		58	220	3.8
7		1		5	6	11	23	72	3.1
Recovered (R_i)	4	9	91	95	38	11	248	1,695	
Tagged (M_i)	14	35	169	201	94	34	547		
M_i/R_i	3.5	3.9	1.9	2.1	2.5	3.1			

Calculations

Recovery Week	Tagging Week 1	2	3	4	5	6	Total	Recovery rate ($\Sigma R_i/\Sigma M_i$)
1								45.3%
2	249						249	
3	147	817					964	
4	29	65	952				1,047	
5	0	21	245	771			1,037	
6	0	0	35	169	300		504	
7	0	12	0	33	46	106	198	
Total	425	915	1,233	973	347	106	3,999	

Appendix F (continued). Schaefer method escapement estimates, Klamath River surveys 2001 to 2010.

2007

Observations

Recovery Week	Tagging Week 1	2	3	4	5	6	7	8	9	Recovered (R_j)	Carcasses (C_j)	C_j/R_j
1											10	
2	1									1	37	37.0
3	1	9								10	57	5.7
4		2	19							21	204	9.7
5			3	59						62	411	6.6
6			1	21	107					129	907	7.0
7				3	6	158				167	512	3.1
8				3	16	46	93			158	519	3.3
9					2	15	17	40		74	194	2.6
10						8	10	10	6	34	140	4.1
Recovered (R_i)	2	11	23	86	131	227	120	50	6	656	2,991	
Tagged (M_i)	7	27	41	146	241	384	215	139	25	1,225		
M_i/R_i	3.5	2.5	1.8	1.7	1.8	1.7	1.8	2.8	4.2			

Calculations

Recovery Week	Tagging Week 1	2	3	4	5	6	7	8	9	Total	Recovery rate ($\Sigma R_i/\Sigma M_i$)
1											53.6%
2	130									130	
3	20	126								146	
4	0	48	329							377	
5	0	0	35	664						699	
6	0	0	13	251	1,384					1,647	
7	0	0	0	16	34	819				869	
8	0	0	0	17	97	256	547			916	
9	0	0	0	0	10	67	80	292		448	
10	0	0	0	0	0	56	74	114	103	347	
Total	149	174	377	947	1,524	1,197	701	406	103	5,578	

2008

Observations

Recovery Week	Tagging Week 1	2	3	4	5	6	Recovered (R_j)	Carcasses (C_j)	C_j/R_j
1								62	
2	12						12	164	13.7
3	2	41					43	535	12.4
4	1	7	100				108	895	8.3
5		6	54	147			207	651	3.1
6			15	35	83		133	247	1.9
7			4	21	9	10	44	96	2.2
Recovered (R_i)	15	54	173	203	92	10	547	2,650	
Tagged (M_i)	40	101	335	342	171	33	1,022		
M_i/R_i	2.7	1.9	1.9	1.7	1.9	3.3			

Calculations

Recovery Week	Tagging Week 1	2	3	4	5	6	Total	Recovery rate ($\Sigma R_i/\Sigma M_i$)
1								53.5%
2	437						437	
3	66	954					1,020	
4	22	108	1,605				1,735	
5	0	35	329	779			1,143	
6	0	0	54	110	287		450	
7	0	0	17	77	36	72	203	
Total	526	1,098	2,004	966	323	72	4,989	

Appendix F (continued). Schaefer method escapement estimates, Klamath River surveys 2001 to 2010.

2009

Observations

Recovery Week	Tagging Week							Recovered (R_j)	Carcasses (C_j)	C_j/R_j
	1	2	3	4	5	6	7			
1									22	
2	5							5	86	17.2
3		27						27	399	14.8
4		7	144					151	728	4.8
5		3	26	182				211	776	3.7
6			7	27	114			148	330	2.2
7				6	24	21		51	158	3.1
8			2	9	14	10	15	50	73	1.5
Recovered (R_i)	5	37	179	224	152	31	15	643	2,572	
Tagged (M_i)	14	64	264	383	276	89	43	1,133		
M_i/R_i	2.8	1.7	1.5	1.7	1.8	2.9	2.9			

Calculations

Recovery Week	Tagging Week							Total		Recovery rate ($\Sigma R_i/\Sigma M_i$)
	1	2	3	4	5	6	7			
1										56.8%
2	241							241		
3	0	690						690		
4	0	58	1,024					1,082		
5	0	19	141	1,144				1,305		
6	0	0	23	103	462			588		
7	0	0	0	32	135	187		354		
8	0	0	4	22	37	42	63	169		
Total	241	768	1,192	1,302	634	229	63	4,428		

2010

Observations

Recovery Week	Tagging Week							Recovered (R_j)	Carcasses (C_j)	C_j/R_j
	1	2	3	4	5	6	7			
1									19	
2	4							4	31	7.8
3		7						7	102	14.6
4			16					16	281	17.6
5			7	69				76	496	6.5
6			2	18	58			78	265	3.4
7				5	6	19		30	82	2.7
8				3	7	7	2	19	35	1.8
Recovered (R_i)	4	7	25	95	71	26	2	230	1,311	
Tagged (M_i)	8	14	49	146	151	69	15	452		
M_i/R_i	2.0	2.0	2.0	1.5	2.1	2.7	7.5			

Calculations

Recovery Week	Tagging Week							Total		Recovery rate ($\Sigma R_i/\Sigma M_i$)
	1	2	3	4	5	6	7			
1										50.9%
2	62							62		
3	0	204						204		
4	0	0	551					551		
5	0	0	90	692				782		
6	0	0	13	94	419			526		
7	0	0	0	21	35	138		194		
8	0	0	0	8	27	34	28	98		
Total	62	204	654	816	481	172	28	2,416		

Appendix G. Proportions of Chinook salmon adult spawners in the main-stem Klamath River from IGD to the Shasta River confluence within different scales of the Klamath River Basin 2001 to 2010. Data compiled from Magneson (2008) and KRTAT (2003a, 2003b, 2004, 2005, 2006, 2007, 2008, 2009; KRTT 2010, 2011).

Year	Main-stem 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 inriver 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%	21.3%	10.0%	6.1%	4.9%
2007	79.3%	25.6%	9.0%	5.7%	4.1%
2008	69.6%	21.3%	13.2%	9.1%	5.8%
2009	53.7%	15.4%	9.6%	6.7%	4.2%
2010	65.0%	15.8%	6.4%	4.3%	2.6%

[a] includes natural spawners, hatchery spawners, and inriver harvest