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FRESHWATER CREEK ADULT SALMONID ESCAPEMENT, 2005

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ABSTRACT

We use four different techniques to estimate the abundance of Adult steelhead (*Oncorhynchus mykiss*) and coho salmon (*O. kisutch*) returning to Freshwater Creek a small coastal tributary in Humboldt County California. Adult steelhead and coho salmon returning to Freshwater Creek were intercepted at a permanent weir facility during their upstream migration. Captured fish were marked with a PIT (Passive Integrated Transponder) tag. Post spawn downstream migrating kelt steelhead were checked for tags as they immigrated back to the ocean. Coho salmon carcasses were checked for tags during surveys of the spawning grounds. Adult escapement into Freshwater Creek was estimated by this intercept method using a temporally stratified mark-recapture experiment. We compare the intercept mark recapture estimate of coho salmon to estimates generated using; 1) carcass tagging and carcass recapture in an open population Jolly-Seber mark recapture model. 2) Redd enumeration assuming one redd per female using either the male to female ratio from weir captures (weir M/F) or live fish observations (live M/F) on the spawning grounds 3) Redd areas assuming females make between one and four redds based upon the redd area using both weir captured and live fish observed sex ratios. The intercept mark recapture escapement of adult steelhead into Freshwater Creek is estimated at 254± 33 (95% C.I). The intercept mark recapture estimate of coho salmon is estimated at 974 ± 72 (95% C.I.). The carcass mark recapture experiment yields an estimate of 818 ±53 (95% C.I) coho salmon. The one fish per redd model estimates 1003 (weir M/F) and 1226 (live M/F) coho salmon. The redd area method estimates 463 (weir M/F) and 566 (live M/F) coho salmon. Fourteen adult Chinook salmon (*O. tshawytscha*) were captured at the weir facility, but an estimate of total escapement could not be made.

ACKNOWLEDGEMENTS

The Freshwater Creek Salmonid Monitoring Project would like to thank the Humboldt Fish Action Council, the landowners of Freshwater Creek who allowed us access to trapping sites, Pacific Lumber Company for their support, the Institute for River Ecosystems for their technical and administrative assistance, and the AmeriCorps Watershed Stewards Project for their help in monitoring traps. This work was made possible by a grant from California Adaptive Watershed Improvement.

INTRODUCTION

The California Department of Fish and Game and the National Oceanic and Atmospheric Administration ~ Fisheries recognize four key parameters for assessing the long term viability of salmonid populations. These VSP (viable salmonid population) parameters are population size, population growth rate (productivity), population spatial structure, and life history diversity (McElhany et al. 2000). The Freshwater Creek Salmonid Monitoring Project is designed to be a full life cycle monitoring station with two principal goals. The first goal is to obtain necessary data needed to evaluate the VSP parameters in Freshwater Creek, a small coastal basin. A secondary goal is to evaluate various sampling methods to estimate abundance wich can be then be used, when appropriate, over a larger geographic area.

The first goal of estimating the four viability parameters require different data collection and analysis. The first two viability parameters (population size, productivity) are approached by estimating the yearly escapement of adult anadromous salmonids, as well as the production of smolts emigrating from the system. Population spatial structure is only considered within the context of Freshwater Creek, and can be evaluated by spatially explicit serial correlations in abundance through time, or more directly by investigating stray rates and reproductive behavior. Life history characterizes the variability in survival strategies and incorporates metrics such as timing of life history events, and population age structure among others.

The second goal is to define the relationships and sampling protocols necessary to appropriately gather and interpret abundance data at different spatial and temporal scales. This report focuses on different approaches to estimating spawning escapement.

The difficulty of operating a counting fence to completely intercept and census all adult salmon and steelhead has led to the development of various approaches for estimating escapement. These methods can be organized into four basic categories. 1) Mark-recapture experiments where marking is done by intercepting fish as they immigrate into a watershed, followed by a recapture sample taken from carcasses on the spawning grounds (e.g. Labelle 1994), or recapture of posts-pawn kelt steelhead emigrating from the spawning areas (e.g. Ward and Slaney 1993). 2) Carcass mark-recapture experiments, where both marking and recapture samples are taken once fish have died (Sykes and Bodford 1986, Law1994). 3) Live fish observations counted throughout the spawning season, where double counts of fish through time is corrected by estimating the area under the curve (AUC) then dividing by the number of days fish are in the study area, and again by probability of observing the fish (English et. al. 1992). 4) Redd observations where the estimates of fish depend upon redd area (Gallagher and Gallagher 2005), or an expansion based upon a fixed number of fish per redd.

Objectives This report is intended as a summary of adult salmonid work conducted by the Department of Fish and Game in 2004-2005 to i) monitor adult steelhead

(Oncorhynchus mykiss), coho salmon (O. kisutch), and Chinook salmon (O. tshawytscha) escapement into Freshwater Creek, ii) determine adult spawning distribution, iii) collect information on age structure, life history and genetics of adult salmon and steelhead, and iv) evaluate redd counts, redd areas, live fish counts, and carcass mark recapture data collected during spawning surveys as techniques to estimate spawning escapement.

Study Area Description The Freshwater Creek basin is located in Humboldt County between Eureka to the south and Arcata to the north (Figure 1). Freshwater Creek, which drains into Humboldt Bay via the Eureka Slough, is a fourth-order stream with a drainage area of approximately 9227 hectares (31 sq. mi.). Elevations in the watershed range from 823 meters at the headwaters to sea level at the mouth. The main stem of Freshwater Creek is approximately 23 km long, of which 14.5 km is anadromous fish habitat. Five main tributaries, Little Freshwater, Graham Gulch, Cloney Gulch, McCready Gulch, and South Fork Freshwater, each provide 2 to 4 km of anadromous fish habitat.

Annual rainfall is approximately 150 cm in the headwaters and 100 cm near the mouth. Levees confine the channel in the lower 6 km and the surrounding land is primarily used for cattle grazing. This section is characterized by low gradient and limited riparian development. Upstream, the riparian community is more developed and is composed of willow (*Salix spp*.), red alder (*Alnus rubra*), black cottonwood (*Populus trichocarpa*), blackberry (*Rubus ursinus*), salmonberry (*Rubus spectasbilis*), and other herbaceous plants. Bordering the riparian areas are forests of redwood (*Sequoia sempervirens*), Douglas-fir (*Psuedotsuga menziesii*), white fir (*Abies concolor*) and Sitka spruce (*Picea sitchensis*).

The fishery resources of the basin include three species of salmon: Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), and steelhead trout (*O. mykiss*). Occasionally, chum salmon (*O. keta*) are observed. Other fish present in the basin include Pacific lamprey (*Entosphenus tridentatus*), Pacific brook lamprey (*Lampetra pacifica*), cutthroat trout (*O. clarki*), and prickly and coast range sculpin (*Cottus asper, Cottus aleuticus*).

Amphibians and reptiles present include pacific giant salamanders (*Dicamptodon ensatus*), red legged frogs (*Rana boylii*), tailed frogs (*Ascaphus truei*) and western pond turtles (*Clemmys marmorata*).

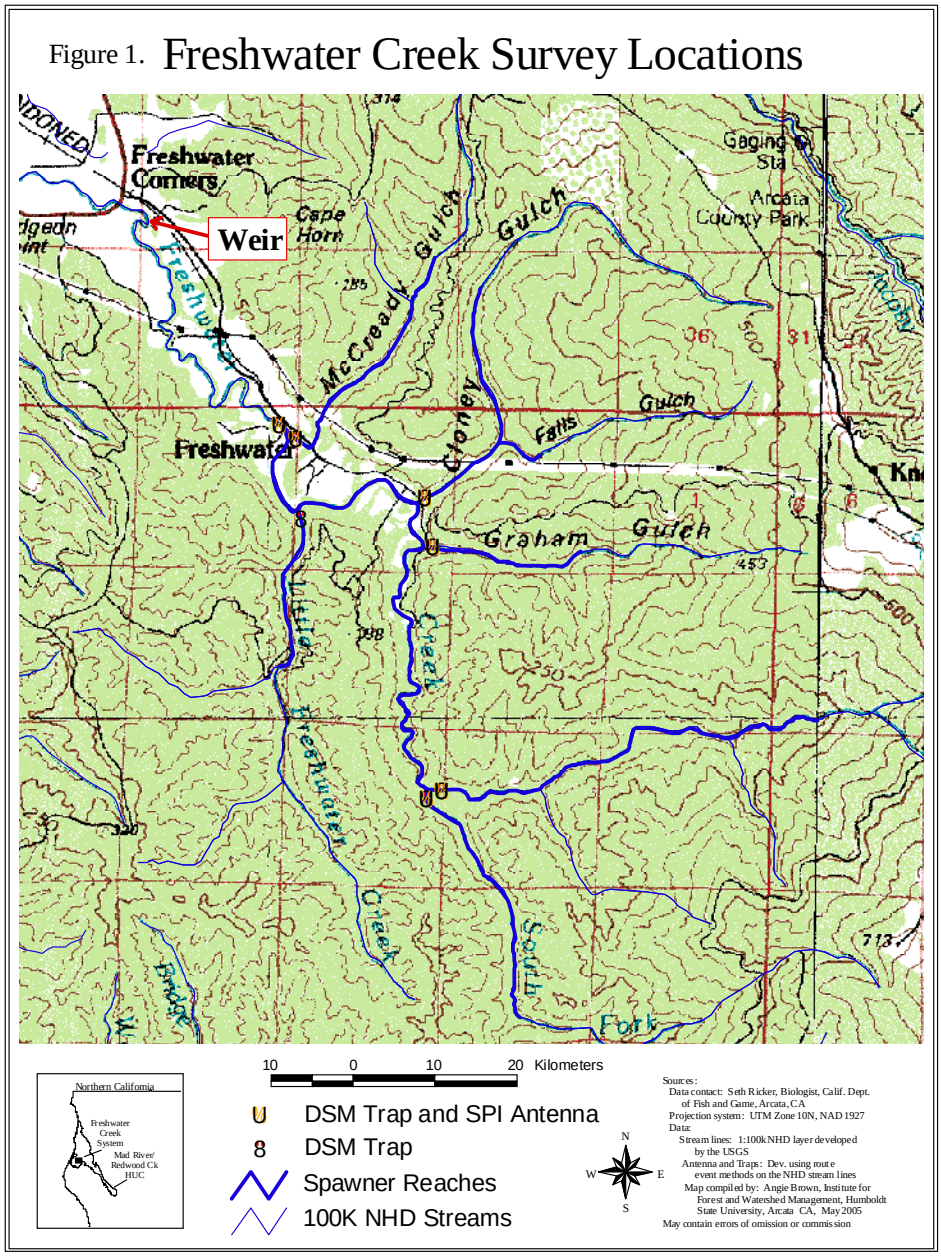

Figure 1. This figure depicts the location of the Freshwater Creek basin in Humboldt County, and the location of sampling sites and survey reaches.

METHODS

Escapement Estimation

Intercept Mark-Recapture

Trapping & Marking Adult fish were intercepted entering Freshwater Creek at a permanent weir facility located near "Freshwater Corners", which is approximately 5 river kilometers (rk) upstream from the mouth of Freshwater Creek where it enters Humboldt Bay. The weir is constructed of a series of metal panels that are attached to a concrete base on the creek bed and concrete abutments on either bank. Each panel can be raised and lowered independently for cleaning purposes or when flows preclude trapping. The trap portion of the weir is located on the northern side of the structure and consists of two concrete walls on each side and metal panels on the upstream and downstream ends. Fish migrating upstream voluntarily entered the trap through two metal fyke panels attached on the downstream side. The trap was operated continuously from the first fall rains in late October or early November, 2004 until early June, 2005.

At the weir, captured fish were netted and placed in a tagging cradle for biological sampling. Each fish was identified to species, measured for fork length, examined for fin-clips, punches, tags, predator marks and other wounds, and sexed. Scale samples were collected from an area located posterior to the dorsal fin between the lateral line and the dorsal. Captured steelhead and coho salmon were checked for individual identifying 32mm PIT (passive integrated transponder) tags that may have been given in prior years and any untagged fish were given a PIT tag. The tag was injected anteriorly, just beneath the skin, in the same area where the scale sample was taken. The broken skin was then sealed closed with veterinary skin adhesive. Salmon were also given a hole-punch to the operculum as a secondary mark to check for PIT tag loss. All fish were then released immediately upstream of the trapping facility. These biological procedures were accomplished quickly while the fish was submerged in a sampling cradle without the use of anesthetic.

Steelhead Recovery Sample The recovery sample of steelhead was obtained in either of two ways. Post-spawn downstream migrating kelts were captured a) at the weir using a pipe trap or b) at several locations where juvenile downstream migrant traps were set up (see project 2a6). Numbers of marked and unmarked steelhead were recorded at the downstream traps. Unmarked kelts captured at the juvenile trap locations received a PIT tag to identify them as "counted" in the event that they were captured again at any of the other traps. All kelts were then released to return to the ocean.

Coho Salmon Recovery Sample Recovery samples for salmon were obtained by inspecting carcasses for PIT tags. Recoveries occurred primarily during surveys of the spawning grounds, but any carcasses washed back to the weir were also checked for PIT tags and used in the recovery sample. During each survey, carcasses were inspected for PIT tags and operculum punches, then given a uniquely numbered jaw tag. Jaw tagged carcasses that were recovered in subsequent surveys were not used in the recovery sample.

Data Analysis A temporally stratified closed population mark-recapture estimator was used to calculate escapement. The mark-recapture data was analyzed using Darroch Analysis with Ranked Regression (DARR) to produce bounded estimates of abundance (Darroch 1961, Bjorkstedt pers. comm.). Briefly, this method is a stratified mark-recapture experiment that estimates capture probability for each period, accounting for the effects of spawn timing (e.g. death) on the pool of marked fish susceptible to capture during each period. Strata that contain problematic structure for Darroch (1961) analysis (e.g. no recaptures from a given marking strata) are combined to neighboring strata thereby reducing the rank of the data to the least possible extent to produce a dataset amenable to analysis (Bjorkstedt pers. comm.).

Carcass Only Mark-Recapture

Spawning Ground Surveys The area of potential spawning habitat within Freshwater Creek was divided into eight distinct reaches (Table 1). Spawning surveys were conducted in each reach on a weekly basis from November 7, 2004 to March 5, 2005 as flows allowed (Table 2). The spatial and temporal extent of both coho and Chinook salmon spawning was covered by these surveys. Spawning surveys were discontinued prior to the end of steelhead spawning.

Table 1. Spatial extent of spawner survey reaches in Freshwater Creek.

Reach Name	Reach Abbreviation	Start	End
McCready Gulch	MCR	300m	2500m
Cloney Gulch	CLO	Confluence with main stem	2900m
Falls Gulch	FAL	Confluence with Cloney Gulch	560m
Graham Gulch	GRA	Confluence with mainstem	1950m
Lower Main Stem	LMS	Howard Heights Bridge (D/S of Mcready Gulch)	Confluence with Cloney Gulch 2633m
Middle Main Stem	MMS	Confluence with Cloney Gulch	Confluence with South Fork 4700m
Upper Main Stem	UMS (A) and (B) (Continuous)	Confluence with South Fork	4500m
South Fork	SFO	Confluence with main stem	3200m
Little Freshwater	LFR	Confluence with main stem	2510m

Table 2. Temporal distribution of spawner surveys conducted by reach in Freshwater Creek.

Basin	MCR	CLO	FAL	GRA	UMS (A)	UMS (B)	SFO	LMS	MMS	LFR
Week						x				
11/7-11/13	x	x	x				x			
11/14-11/20										
11/21-11/27				x				x	x	x
11/28-12/4										
12/5-12/11										
12/12-12/18	x	x	x	x	x	x	x	x	x	x
12/19-12/25		x			x	x	x	x		x
12/26-1/1										
1/2-1/8	x	x	x	x	x	x	x	x	x	x
1/9-1/15	x	x	x	x	x	x	x	x	x	x
1/16-1/22	x	x	x	x	x	x	x	x	x	x
1/23-1/29	x	x	x	x			x		x	x
1/30-2/5	x	x	x	x	x	x	x	x	x	x
2/6-2/12	x	x	x	x	x	x	x	x	x	x
2/13-2/9	x	x	x	x	x	x	x	x	x	x
2/20-2/26										
2/27-3/5	x	x	x	x	x	x	x	x	x	x

Carcass Tagging and Recapture During each survey of the spawning grounds, all coho salmon carcasses were given an individually numbered jaw tag. On subsequent surveys, carcasses were inspected for jaw tags, and the unique number recorded on all recaptures. Marking and recapturing carcasses continued each survey through the entire spawning season. All carcasses were replaced in the exact location they were found.

Data Analysis The reach level carcass tagging and recapture data were combined for each time period to estimate total basin escapement (Table 2). The carcass marking and recapture data was analyzed as a standard Jolly-Seber model for open populations (Jolly 1965, Seber 1965, Sykes and Botsford 1986, Law 1994), using program Jolly (Pollock et al. 1990). This model assumes a fully open population; estimating population size, as well as recruitment of new carcasses to the spawning grounds, and survival of carcasses from one period to the next.

Live Fish Observation Efficiency

Assignment of Live Fish to Species During each spawning ground survey, all observed live fish were recorded by species or as unknown. Unknown fish were assigned a either steelhead or coho salmon according to the date of observation.

We utilized the trapezoidal approximation to calculate the area under the curve as fish days using equation 1 (Hilborn et al 1999).

$$AUC = \sum (t_i - t_{i-1}) * (x_i + x_{i-1}) * 0.5 \qquad \text{Equation [1]}$$

Where t_i is the number of days from time zero that fish were observed and x_i is the number of fish observed on the *i*th day.

Time zero We operated six radio frequency identification (RFID) antenna systems in Freshwater Creek basin to track the movement of adult coho salmon during their spawning run. Fish were captured at the permanent weir were tagged with 32 mm passive integrated transponder (PIT) tags. After tagging, fish were released upstream of the weir to continue their migration. RFID antenna arrays were installed near the mouths of four of the five major sub basins as well as in the lower and upper main stem (Fig 1). The arrays consisted of two stream-width antennas arranged to allow the determination of up and down stream movement. Briefly, the antennas emit an electromagnetic pulse that excites PIT tags located within the antenna's field causing them to transmit the 16 digit tag identification code as a low frequency radio signal which is received by the antenna. The codes are unique to each fish and when transmitted, are read by the antenna and logged into a computer file along with the date and time of logging. We operated the antennas continually throughout the adult coho migration except during short intervals when high flows prevented operation. Time zero for each reach used in the trapezoidal approximation was set as the date the first fish was recorded at the RFID antenna array moving into the reach. There was no RFID antenna operated on Little Freshwater Creek or the upper most main stem reach (UMSB). Time zero for these reaches was set December 12, the median date of first fish entry to tributary basins that had antennas.

Residence Time Residence time is defined as the number of days fish are alive and in the survey area. Tagging adult immigrants at the weir with PIT tags, and 'recapturing' their unique tag code as they moved through the series of RFID antenna arrays located throughout the basin, gave us the opportunity to define the residence time of individual fish between tagging and entry into the spawning ground survey area.

The estimation of total escapement ($\hat{E}$) is obtained by summing the area under the curve for all reaches, dividing by residence time and again by observation efficiency:

$$\hat{E} = \left(\left(\sum_{i=1}^{n} AUC_i \right) * rt^{-1} \right) * v^{-1} \qquad \text{Equation [2]}$$

where *i* is the reach, *rt* is the number of days fish are alive in the survey area (residence time), and *v* is the probability of observing all fish (observer efficiency).

We could not directly measure values for observer efficiency (*v*). To estimate observer efficiency likely encountered in Freshwater Creek, however, we substituted our estimate of escapement from the intercept mark-recapture experiment as ($\hat{E}$) rearranging equation 2, to solve for season average observation efficiency using equation 3.

$$V = \left(\left(\sum_{i=1}^{n} AUC_i \right) * rt^{-1} \right) * \hat{E}^{-1} \qquad \text{Equation [3]}$$

Redd Methods

Data collection
Each redd encountered on spawning ground surveys was given an individual record number, including date and location of the redd within the channel. This information was recorded on datasheets and on flagging tape tied to the nearest vegetation above high water. If the fish was identifiable and still actively guarding the area, then the species of fish that made the redd was recorded. If no fish were present, and the redd area was visibly definable in space (i.e. the redd was still visible and the pot and tail spill had reasonable definition in the streambed), the depth, width and length of the pot, and the length and two widths of the tail spill were measured. The dominant substrate in the pot and tail spill was recorded categorically as: 1 = gravel < 1.0", 2 = small cobble 1.0"- 2.5", 3 = medium cobble 2.5"- 4", and 4 = large cobble >4.0".

Assignment of Redds to Species Redds were assigned to species if identified live fish were observed building or guarding them. Redds that had either unknown species of fish actively building or guarding, or had no fish associated with them were assigned to species based upon date. Any redds recorded as unknown species before February 19, 2005 (the last date an identified coho redd was observed) were assigned coho, and after February 19, 2005 assigned steelhead. We did not assign any unknown redds to Chinook salmon because there were few Chinook salmon captured at the weir, and few redds recorded as having identified Chinook guarding or making them.

One Redd per Female Escapement estimates assuming one redd per female were made by multiplying the number of redds by 1) the proportion of females observed on spawner surveys and 2) the proportion of females observed at the weir.

Redd Area Pot area was calculated as either a circle or oval depending on agreement of length and width measurements. Tail spill area was calculated as either a rectangle or triangle depending on length and width measurements (See Gallagher 2002). Total redd area is the sum of pot and tail areas. The redd area method is based on the assumption that the number of redds a female makes is related to the size of the redd. For comparison of methodologies we assume coho make between 1 and 4 redds and redd areas larger than 5.2m^2 represent one female, redds between 5.1m^2 and 2.1m^2 represent half a female and redds smaller than 2.1m^2 represent a quarter of a female (Gallagher and Gallagher 2005). We used the average redd size of measured redds (2.6m^2) to represent all redds that could not be measured. We then multiplied the number of females based on the redd area by the male to female ratio of live fish observed on spawner surveys.

Redd Distribution Each reach was measured by hip chain, and meter markers were posted at approximately 10m intervals. The location of observed redds and fish were referenced to the posted markers. These data were then collapsed into 100m bins for presentation. On all spawning surveys redd age was recorded as: 1 = fish on redd, 2 = new since last survey, 3 = older, tail spill flat or pot with fines, 4 = old and hard to

discern, and 5 = no redd, only a flag. Redd longevity was calculated in days from the first observation of the redd until the first date the redd was no longer visible

RESULTS

Life History

Coho Salmon

Size, Age and Sex Ratio Fork lengths of adult coho salmon ranged from 235 mm to 790mm and averaged 647 mm. By dividing the histogram at the nadir of 565 mm, it is estimated that 13.6 % of the adult coho run are age two and 86.4% are age three. Eighty percent of the two year old fish are male and 20% are female. The three year old fish are comprised of 70 % female and 30% male (Figure 2). Expanding the coho salmon intercept mark-recapture escapement point estimate by these age specific sex ratios yields an estimate of 358 male and 616 female coho.

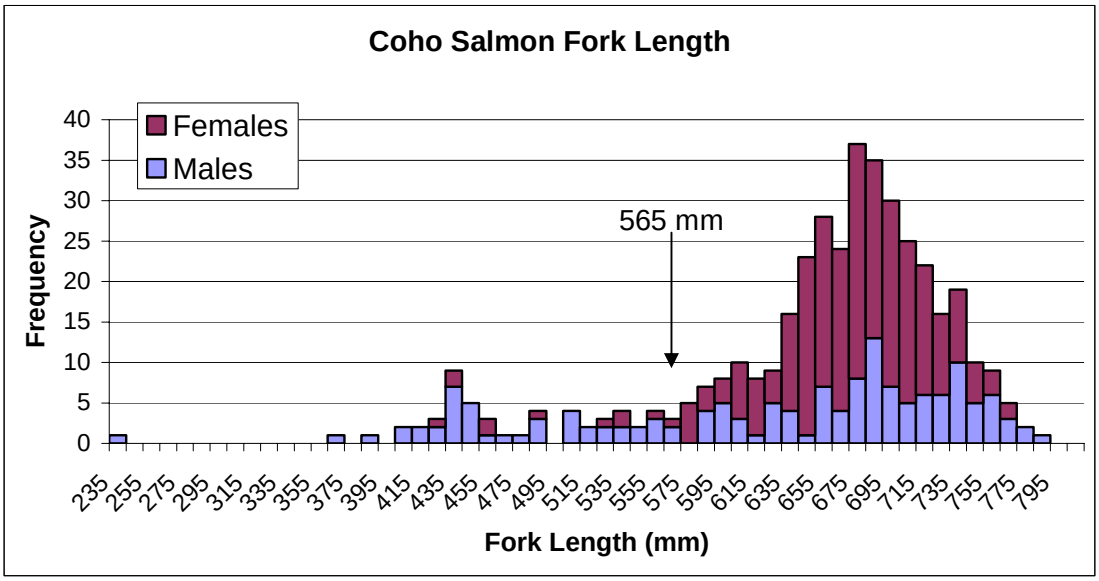

Figure 2. Length frequency histogram of adult coho salmon captured at the weir, Freshwater Creek, 2004-2005.

Run Timing: The first coho salmon was captured at the weir on October 26, 2004. Weir captures peaked on December 7, 2004, and the last coho was captured on February 20, 2005 (Figure 3). The first identified coho redd was seen on November 16, 2004. Redd observations peaked on January 6, 2005, and the last new redd was observed February 19 2005. The first coho carcass was found and identified on December 21, 2005. Carcass numbers peaked the week of February 2, 2005 and the last carcass was seen on February 19, 2005 (Figure 3). The time between peak weir capture to peak redd observation was 30 days. The time between peak redd observations and peak carcass counts was seven 27 days (Figure 6).

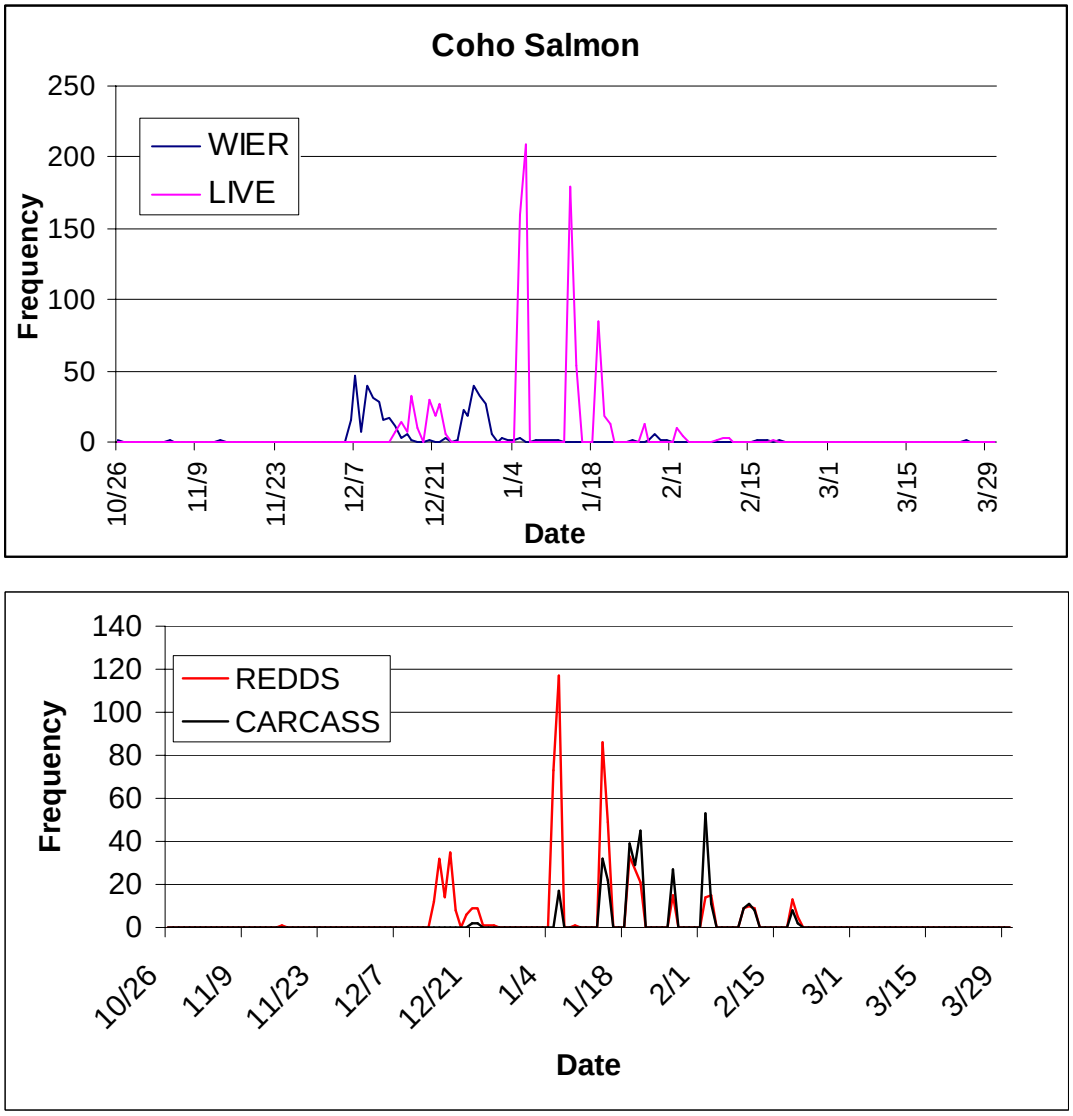

Figure 3. Date of coho salmon weir captures, live fish observations redd observations, and carcass counts in Freshwater Creek, 2004-2005.

Chinook Salmon

Size and Age Fork lengths of adult Chinook salmon ranged from 400 mm to 1005mm and averaged 716 mm. Eight of the 14 (57%) chinook salmon captured were male.

Run Timing The first Chinook salmon was captured at the weir on October 26, 2004. Weir captures peaked on December 10, 2004, and the last Chinook salmon was captured on January 2, 2005. Two Chinook salmon carcasses were observed on January 14, 2005 and a third was found on January 19, 2005.

Steelhead

Size and Age Sex Ratio Fork lengths of adult steelhead ranged from 465 mm to 870mm and averaged 671 mm. Sixty-six percent of the steelhead captured at the weir were female and 34 percent male. Expanding the steelhead intercept mark-recapture escapement point estimate by these sex ratios yields an estimate of 86 male and 168 female steelhead (Figure 4).

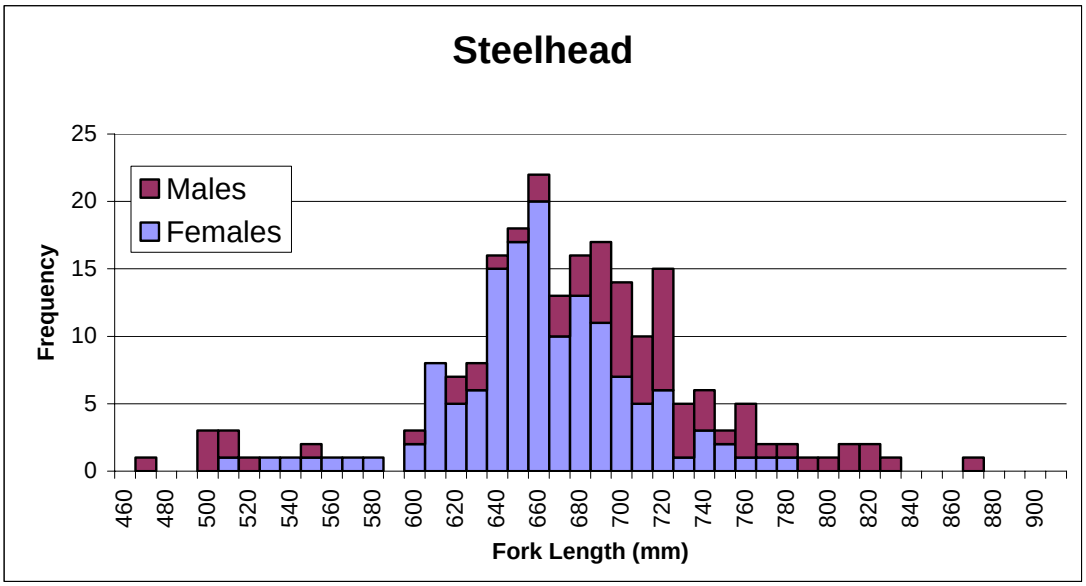

Figure 4. Length-frequency histogram of all adult steelhead captured at the weir on Freshwater Creek, 2004-2005.

Run Timing The first steelhead was captured migrating into Freshwater Creek at the weir on December 9, 2004. Upstream weir captures peaked on January 29, 2005 and the last upstream migrating steelhead was captured on March 20, 2005. Downstream migration of steelhead kelts captured at the weir began on January 18, 2005, peaked with 45 captures on March 22, 2005, and the last downstream kelt was captured on May 10, 2005. Residence time of steelhead calculated from peak upstream captures to peak kelt downstream captures was 52 days (Figure 5).

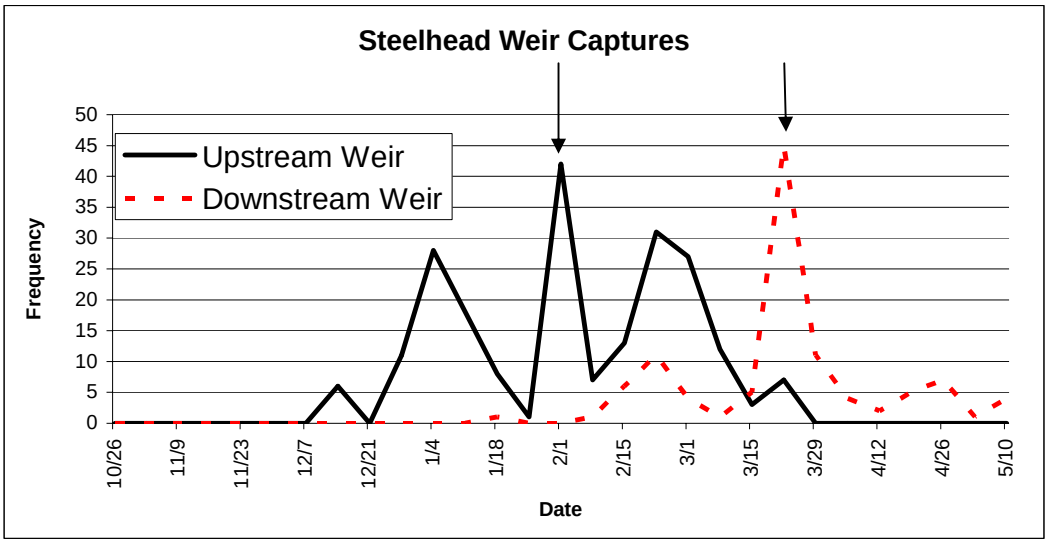

Figure 5. Timing of steelhead captured migrating upstream and downstream at the weir. Arrows indicate the peak of migration events.

Escapement Estimation

Intercept Mark-Recapture

Steelhead During the study period, 210 upstream migrating steelhead were captured and PIT tagged. Thirty seven of the 45 post spawn kelts recaptured at the weir or downstream juvenile migrant traps were identified as having been tagged. The adult steelhead escapement to Freshwater Creek was estimated to be 254 ± 33 (95% C.I.).

Coho Salmon During the study period, 407 captured adult coho salmon were marked with PIT tags. One hundred and twenty seven of the 177 carcasses were identified as having received a mark at the weir. All weeks were pooled by the algorithms used by program DARRv2 (Bjorkstedt pers. com.). The adult coho salmon escapement into Freshwater Creek was estimated to be 974 ± 72 (95% C.I.).

Chinook Salmon Only 14 Chinook salmon were captured and marked at the weir. One of the seven carcasses found on the spawning grounds was identified as having been marked. An estimate of escapement could not be produced, but at least 20 Chinook salmon entered Freshwater Creek.

Carcass Only Mark-Recapture

Coho Salmon We estimated 818 ± 62 (95% C.I.). carcasses on the spawning grounds by summing the weekly estimates of carcasses for all survey periods (Table 3). The overall model of goodness of fit test suggests the data appropriately fits the model structure (X^2=6.49, P=0.69, df=9). We could not estimate the standard error for periods 1, 2 and 8 due to low recaptures of carcasses marked during periods 1 and 2, and no recaptures after period 8. The confidence bound surrounding the total estimate of carcasses (95% Conf. = 756-880) therefore does not reflect the errors of estimation

for these periods. The estimates of survival of carcasses from one spawning survey to the next ranged from 0.28 to 0.94 and averaged 0.55.

Table 3. Abundance estimates and associated errors of the carcass Jolly-Seber mark recapture experiment by period and total for the 2004-2005 season.

Period	Est.(N)	SE(N)	Var(N)	95% Conf.	
2	18	Div/0	Div/0	Div/0	Div/0
3	59	Div/0	Div/0	Div/0	Div/0
4	161.14	9.21	84.824	141.55	180.73
5	193.62	18.77	352.31	155.7	231.55
6	203.78	21.39	457.53	159.42	248.14
7	128.47	10.96	120.12	101.59	155.35
8	54	Div/0	Div/0	Div/0	Div/0
Total	**818.0**	**31.9**	**1014.8**	**755.6**	**880.4**

N= Estimated number of carcasses
Bold=Estimated error for periods 3-7

Live Fish Observation Efficiency

Assignment of Live Fish to Species All unidentified fish prior to February 19 were assumed to be coho salmon for this analysis (Figure 6). We did not assign any unknown fish species to Chinook salmon because there were few Chinook salmon captured at the weir, and few live fish were observed during spawner surveys.

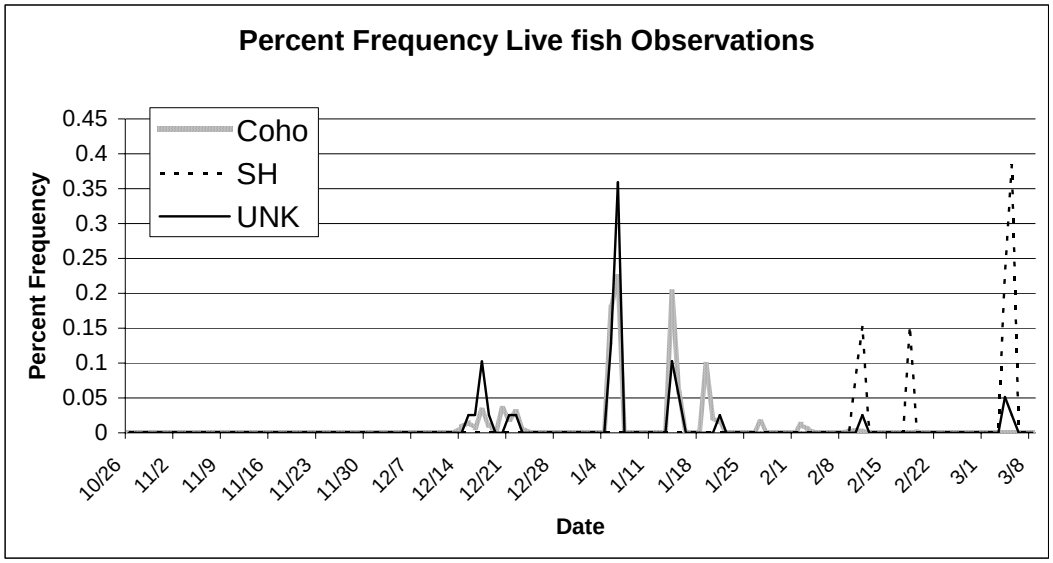

Figure 6. Percent frequency of live fish observation by date in Freshwater Creek, 2004-2005.

Residence Time We estimated the timing of coho salmon migration from the weir to the antenna bounding the lower end of the spawning survey area (HHL), HHL to

carcass, and weir to carcass. Male and female coho salmon residence time within the survey area differed averaging 33.6 days and 29.5 days respectively. Coho salmon of different sizes (used as a surrogate for age; see Figure 2) differed in their residence time. Coho salmon <560 mm spent an average of 41 days (n=3), while coho salmon >550mm averaged 30.4 days (n=78). Coho salmon entering Freshwater Creek early in the season spent more time in the lower river than those fish entering near the peak of the run. Similarly, those fish entering Freshwater Creek earlier in the season survived fewer days until first being found as carcasses (Table 4). We used the average residence time (30.8 days) of all coho salmon from entrance to the spawning ground survey area (HHL) to carcass in equation [3] to determine live coho salmon observation efficiency.

Table 4. Average residence time of coho salmon from capture at the weir to the lower boundary of the spawning survey area (Weir→HHL), the lower boundary of the spawning survey area to carcass (HHL→Carcass), and total residence time from weir tagging to Carcass (Weir→Carcass) within Freshwater Creek, 2004-2005. Sample size is indicated in parentheses.

Week of Weir Capture	Weir→HHL		HHL→Carcass		Weir→Carcass	
12/4-12/10	15.8	(7)	28.1	(7)	45.2	(31)
12/11-12/17	8.6	(42)	32.4	(42)	40.8	(43)
12/18-12/24						
12/25-12/31	1.1	(30)	30.0	(30)	30.1	(52)
1/1-1/7	0.0	(2)	19	(2)	21	(3)
1/8-1/14						
1/15-1/21						
1/22-1/28						
1/28-2/4					12	(3)
All	6.2	(81)	30.8	(132)	36.5	(132)
Males	3.9	(26)	33.6	(26)	39.5	(48)
Females	7.2	(55)	29.5	(55)	34.8	(84)
FL<56			41.0	(3)	46.8	(10)
FL>55			30.4	(78)	35.7	(122)

Area Under the Curve(AUC) The total number of fish days calculated as AUC by the trapezoidal approximation is 7900 (Table 5)

Table 5. Area Under the Curve (AUC) calculated with the trapezoidal approximation, for live fish observations in each reach within Freshwater Creek, 2004-2005.

Basin	Time Zero	AUC
McCready Gulch	12/09/2004	309.5
Graham Gulch	12/28/2004	144
Cloney Gulch	12/13/2004	1377.5
Upper Main-stem (reach A)	12/12/2004	1308
Upper Main-stem (reach B)	12/12/2004	1620
South Fork	12/11/2004	1685
Little Freshwater Creek	12/12/2004	1035
Falls Gulch	12/12/2004	179.5
Lower Main-stem	12/09/2004	242
Total		**7900.5**

Observation Efficiency By substituting the point estimate from our intercept mark-recapture experiment of 974 in equation [3] we determined the observation efficiency of live coho salmon in the survey area within Freshwater Creek to be 26%.

$$\mathbf{0.26 = 7900.5 \ x \ 30.8^{-1} \ x \ 974^{-1}} \qquad \text{Equation [3]}$$

Redd Methods

One Redd per Female Six hundred and thirty redds were assigned as being produced by coho salmon. The proportion of females observed live during spawner surveys is 51.4% (738/1434). The proportion of female coho salmon captured at the weir is 62.8 % (253/403). The escapement estimate based on observed live fish sex ratios is 1226 fish. The escapement estimate based on weir captured sex ratio is 1003 fish.

Redd Area The escapement estimate for coho salmon based on redd areas and the observed live fish sex ratio, and weir captured sex ratio is 566 and 463 fish respectively. Total areas of all redds with observed coho salmon guarding them (CO) ranged from 0.4m^2 to 11.8 m^2 and averaged 3.9 m^2 (SE=0.24, n=129). Redd areas assigned to be coho salmon redds based on date (CO_{date}) ranged from 0.1m^2 to 11.5 m^2 and averaged 2.4m^2 (SE=0.12, n=262) (Figure 7, Table 6).

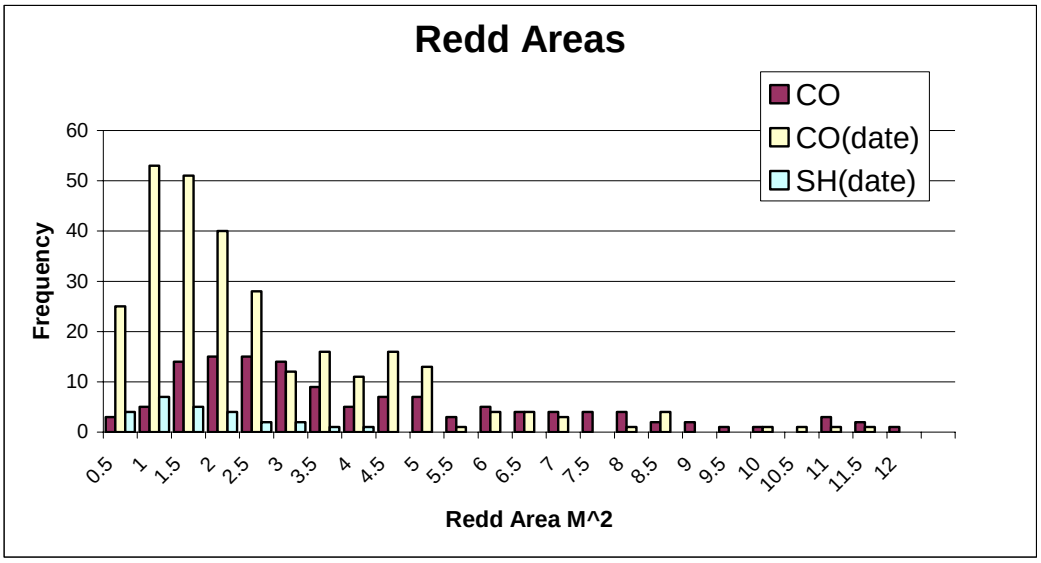

Figure 7. Redd Areas calculated as the sum of pot and tail spill areas for coho salmon redds (CO), redds assigned to coho salmon by date ($CO_{(date)}$), and steelhead redds assigned by date ($SH_{(date)}$), in Freshwater Creek, 2004-2005.

Table 6. Average and SE of coho salmon redds observed, coho salmon redds assigned by date, and steelhead redds assigned by date in Freshwater Creek 2004-2005.

	Coho						Steelhead		
	Coho observed (CO)			Coho Assigned By Date (CO_{date})			Steelhead Assigned By Date (SH_{date})		
	Average	SE	N	Average	SE	N	Average	SE	N
Pot Depth	0.37	0.016	263	0.37	0.11	263	0.26	0.03	24
Pot Area	2.8	0.2	129	1.6	0.1	262	1.9	0.1	24
Tail spill Area	1.1	0.07	129	0.8	0.04	262	0.6	0.1	24
Redd Area	3.9	0.24	129	2.38	0.12	262	1.4	0.2	24

Redd Spatial Distribution Redds were spatially concentrated in specific areas within Freshwater Creek. A large number of redds were located on the upper main-stem reach between 3000-3200m above the confluence of the South Fork. A second aggregation of redds was located on the South Fork between 200-300m above the confluence with the main-stem. A third but smaller aggregation of redds was seen

near the confluence on both Cloney Gulch and Falls Gulch (Figure 8).

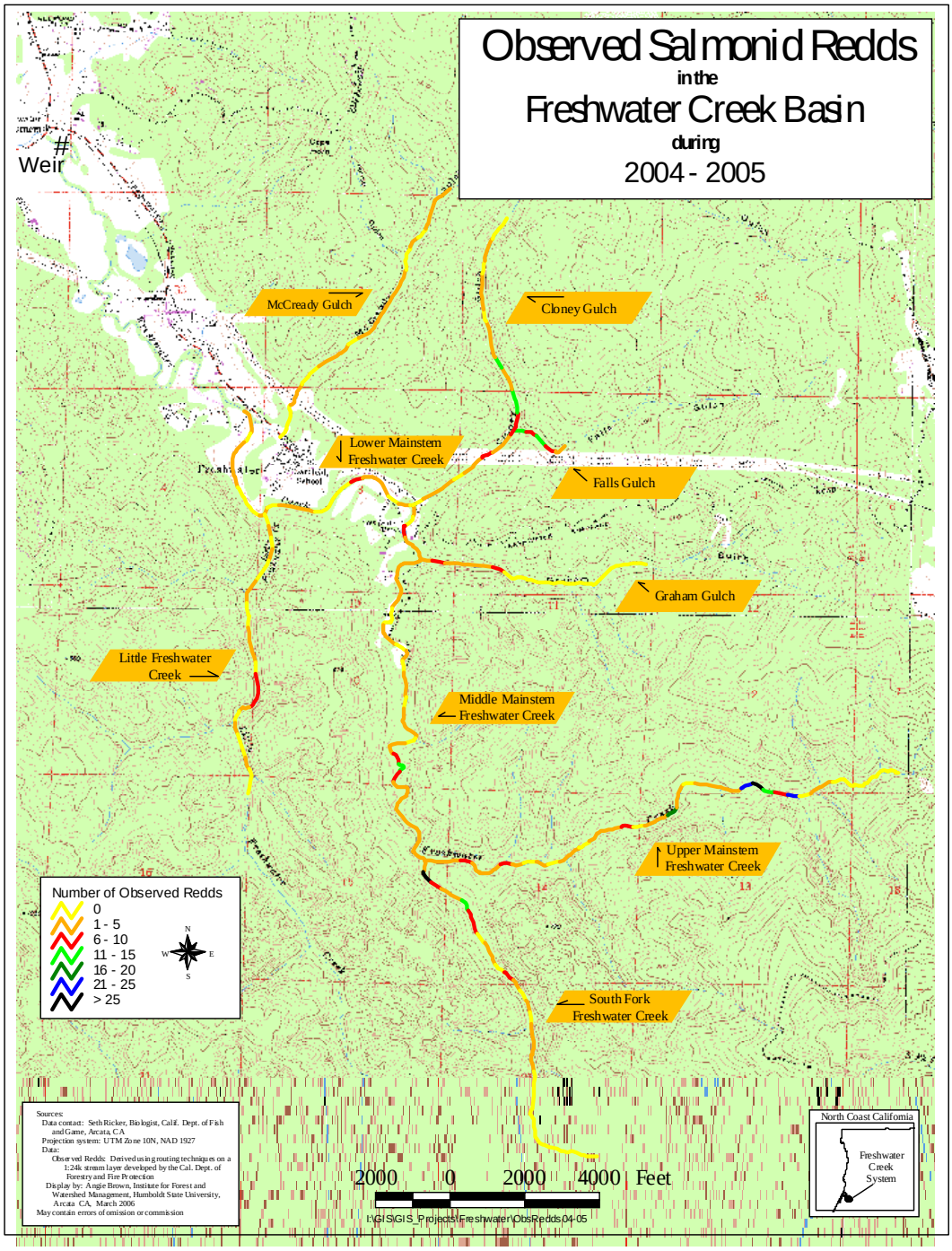

Figure 8. Map of Freshwater Creek basin depicting the density of observed redds during 2004-2005 spawning ground surveys.

Redd Temporal Distribution Redd formation appeared to be fairly well separated by date for coho salmon and steelhead. The few observations of Chinook salmon redds indicate however that these species spawn timing overlap with coho salmon significantly. Redds remained visible for and average of 22 days. The distribution of redd longevity, however, is non-normally distributed with 14% of the redds only observed during one survey and obscured before the next survey (Figure 9)

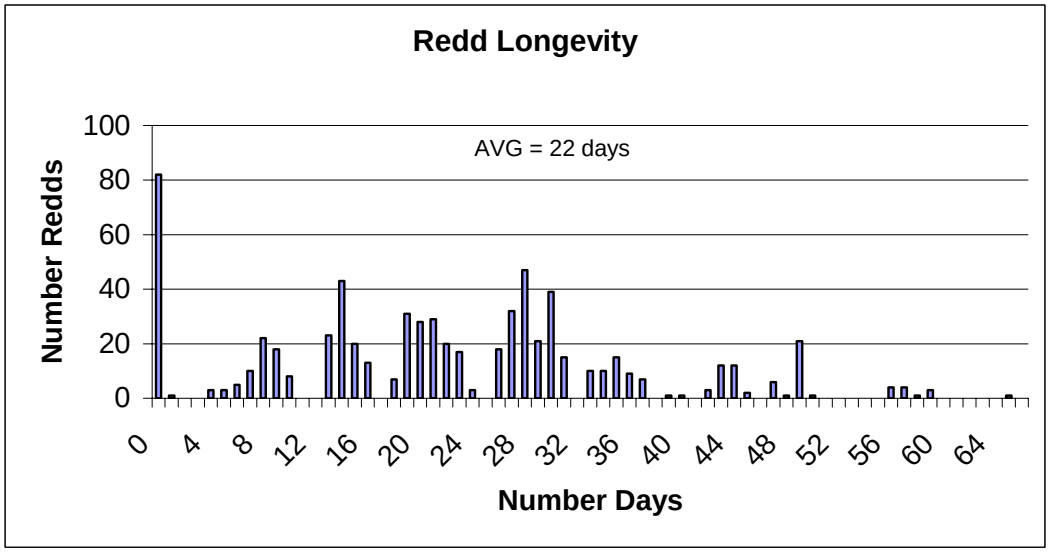

Figure 9. Distribution of the number of days redds remained visible from first observation to obscurity in Freshwater Creek, 2004-2005.

Comparison of Escapement Estimates

Coho Salmon Estimates of coho salmon ranged from a high of 1226 fish from the one fish per redd live (M/F) to a low of 463 from the redd area weir (M/F). The one fish per redd weir (M/F) estimate of 1003 fish is the most comparable to the intercept mark recapture estimate of 974 fish (Figure 10).

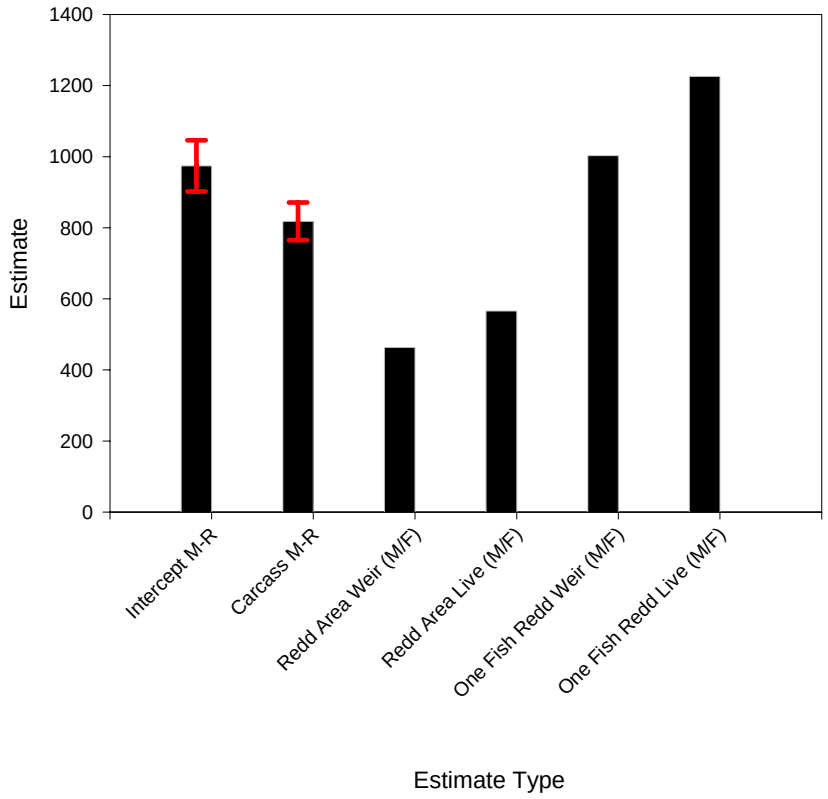

Figure 10. Coho Salmon population estimates from Freshwater creek, 2004-2005.

DISCUSSION

I consider the intercept mark recapture estimate of escapement to be the most robust method evaluated in terms of the underlying model assumptions. Comparison of this estimate to the others produced in this report does not, however, validate or invalidate those methods, but provides useful insight to potential unaccounted for errors.

It is apparent that expanding the number of redds to the number of fish is inherently sensitive to the sex ratio of the population. In this study, the sex ratios of coho salmon are different between those fish observed at the weir and those observed on the spawning grounds. Intuitively, we may consider the weir captured and examined fish to have a higher rate of correct sex identification than those observed on the spawning grounds. Small age 2 fish may not be captured as well as lager age 3 fish at the weir. This may potentially bias the sex ratio gathered from weir data because of the higher male component observed for smaller age 2 fish. Estimates of sex ratios gathered from live fish observations may also be biased by the fact that males survive an average of nearly 13% (4.1 days) longer in the study area and therefore may have higher probability of being seen during live fish counts. Redd distribution throughout the basin was not uniform. Spawning grounds in certain areas were highly utilized while others were apparently vacant. This clumping of redds in both space and time led to a significant number of redds being superimposed on other redds. This spawning behavior was problematic to individual redd discrimination. Once high density spawning sites were fully utilized, surveyors were unable to discern if new redds were constructed on top of older redds, or determine how many redds existed in a highly utilized area. Both the redd area method which assumes a female can build multiple redds but a fixed total area, as well as expansions based upon the assumption that females build one redd each, are both confounded by the inability to estimate the probability of observing redds during any given survey. Survey conditions, redd spatial and temporal distribution, as well as periodicity of survey effort can change this underlying parameter. Without robust procedures for estimating observation probability for redds, it is impossible to bound either redd estimation procedures with a level of uncertainty.

The carcass mark-recapture estimate appeared to be free from biases associated with open population mark recaptures assumptions. Carcass ‘survival’ within the spawning area was high (54% -94%) and the between-survey interval short (1 week), which allowed survey crews to locate and find a relatively large number carcasses. This high level of carcass ‘survival’ coupled with the relatively high capture probability allowed us to estimate these nuisance parameters adequately and as a consequence, produce estimates with a acceptable level of uncertainty. This method, however, may not perform as well in terms of associated uncertainty and/or outright failure of the estimator in populations that are either too small, or during seasons where ‘survival’ of carcasses is reduced due to poor survey conditions and reduced effort.

Estimates of population size produced from live fish counts using the AUC method are highly sensitive to observation efficiency of live fish, and residence time of these

fish within the survey area. We used an average residence time of all tagged coho salmon for our investigation of observation efficiency, but it is apparent that there is some heterogeneity in residence time between male and female fish, as well as small and large fish. It is clear, however, that we were not able to observe all live fish during our surveys and estimates of spawning escapement based on live fish counts and AUC procedures should be approached with caution when this parameter cannot be directly estimated.

RECOMENDATIONS

Fishery managers require estimates of abundance to assess population status, trends through time, as well as productivity either in terms of survival or recruits per spawner. In order to assess these population parameters at any spatial scale, we must provide a defensible means to address the level of certainty we have in our abundance estimates. We recommend that spawner survey data alone, and associated redd and live fish estimation procedures, should not be used to assess these viability parameters unless they are associated with a more robust procedure to estimate escapement.

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