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Results of regional spawning ground surveys and estimates of total salmonid redd construction in the Humboldt Bay, Humboldt County California, 2015-2016.

Prepared by

Humboldt State University Sponsored Programs Foundation In partnership with State of California Department of Fish and Wildlife

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Abstract

Field staff conducted spawning ground surveys in 23 reaches within the Humboldt Bay watershed between November 17, 2015 and April 21, 2016. Individual stream reaches were surveyed an average of 4.1 times at an average return interval of 29 days. We observed 2 Chinook salmon, 740 coho salmon, 34 steelhead trout, and 23 unidentified live fish. A total of 2 Chinook salmon, 339 coho salmon, 2 steelhead trout, and 53 unidentified carcasses were found. We identified 454 individual redds of which 171 were assigned to a species. We estimate 617 (430-849, 95% Confidence Interval) coho redds and 97 (21-184, 95% Confidence Interval) steelhead redds in Humboldt Bay as expanded from the sampled reaches. We estimate 323 (251-394, 95% Confidence Interval) coho redds within the Freshwater Creek Life Cycling Monitoring Station as the sum of a complete census of all reach estimates.

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1 INTRODUCTION

1.1 Background

Pacific Salmon (*Oncorhynchus sp.*) have experienced marked decline in abundance over the last 60 years. Due to this decline, coho salmon (*Oncorhynchus kisutch*) in the Southern Oregon and Northern California Coasts (SONCC) Evolutionary Significant Unit (ESU) were federally listed as threatened pursuant to the Endangered Species Act (ESA) in 1997 (NMFS 1997). This federal listing status was reviewed and reaffirmed in 2005 (NMFS 2005) and is currently under another review. The California Fish and Game Commission found coho salmon populations within the SONCC warranted listing as threatened species under the California Endangered Species Act (CESA) (CDFG 2002). All California steelhead (*O. mykiss*) south of the Klamath River are Federally ESA listed (NMFS 2006) and coastal Chinook salmon (*O. tshawytscha*) south of the Klamath River to the Russian River are federally ESA listed (NMFS 1999). In 2004 the California Department of Fish and Game developed a recovery strategy for coho salmon populations within California (CDFG 2004). This recovery strategy is intended to direct management and restoration actions needed to recover the species, and provides basin by basin threat assessments and attempts to prioritize management and restoration actions needed to recover the species. The Federal government requires that listed species have recovery plans developed that require objective, measurable criteria which when met, would result in the species being removed from the listing (16 USC 1531, Endangered Species Act 1973). Recovery of salmon and steelhead listed under the Federal and California ESAs can be measured in part on the increase in abundance of spawning adults (Good et al. 2005). Delisting will depend on abundance thresholds and the connectivity of populations to one another (Spence et al. 2008, Williams et al. 2008).

The California Department of Fish and Wildlife and the National Oceanic and Atmospheric Administration ~ Fisheries recognize four key parameters for assessing the long term viability of salmonid populations. These viable salmonid population (VSP) parameters are population size, population growth rate (productivity), population spatial structure, and life history diversity (McElhany et al. 2000). Monitoring these population parameters is essential to evaluating the success of recovery efforts.

To address data needs for viability assessment, the California Department of Fish and Wildlife (CDFW) and the National Oceanic and Atmospheric Administration ~ Fisheries (NOAA~Fisheries) cooperatively developed the draft Coastal California Salmonid Monitoring Plan (CMP)(Adams et al. 2011). Two complimentary tasks are considered high priority in the northern monitoring area and form the foundation of the CMP approach. The first task consists of probabilistic sampling of stream reaches within a defined region using spawning ground surveys (SGS) to establish the regional status and trends of adult salmonid abundance. The second task develops intensively monitored Life Cycle monitoring Stations (LCS) nested within the regional sample frame of the SGS.

Freshwater Creek is a LCS nested within the regional sample frame of the Humboldt Bay SGS. The nesting of the SGS within the LCS investigates the relationship between SGS observations and adult escapement.

This report summarizes the results of yearly abundance and survival monitoring efforts from November 2015 to June 2016, as well as integrates all years of project data to make inference on population trajectories.

1.2 Study Area

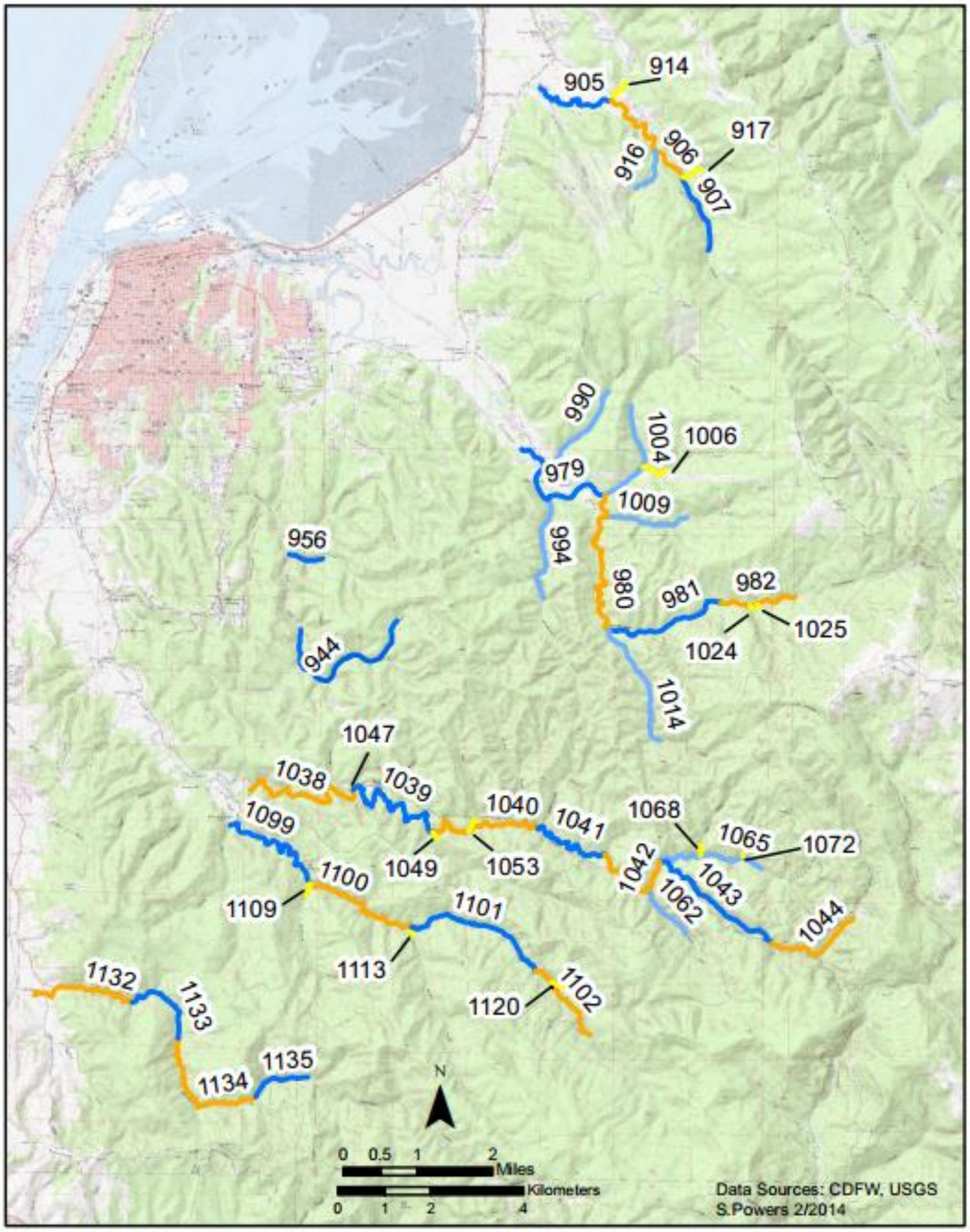

Figure 1. Humboldt Bay sampling frame. Reaches are depicted with alternating colors, and reach codes are presented as table references.

2 METHODS

2.1 Sample Frame Construction

Sampling frames were constructed with several factors presented by Garwood and Ricker 2011 including; documented historical salmonid distributions, documented barriers to anadromy, stream gradient, and field reconnaissance. Sample frames were constructed around coho salmon and may exclude habitat which is used by Chinook salmon and steelhead trout.

Each sampling frame was further divided into streams and then into survey reaches. From each sampling frame a portion of reaches was selected to survey. Reaches were assigned numbers in a fashion that ensured that selected survey reaches were balanced spatially within each stream (Garwood and Ricker 2011). Short sub-reaches less than 1000 meters were combined with the reach into which they flowed into.

2.2 Reach Selection

Reaches were selected for sampling from each frame using a General Randomized Tessellation Stratified (GRTS) sampling algorithm (McDonald 2003). GRTS sampling ensures a randomized spatially balanced draw from each stream. We sampled 22 reaches of a total possible 33 reaches to achieve a sampling rate of approximately 66%.

2.3 Reach Survey Protocol

Spawning ground surveys protocol closely followed Gallagher et al. (2007). Teams of two walked upstream on small streams or boated downstream in large stream reaches. Observations include carcasses, live fish, and redds. Live and dead fish were identified to species when possible. Carcasses were marked with tags to prevent counting during subsequent surveys. All redds were flagged, measured, and assigned a unique record number. Redds were assigned a species if a fish was observed constructing, defending, or holding on a redd. Newly observed redds were aged as catergory one-new to the survey and redds recaptured on subsequent surveys received categorical ages ranging from age two as still visible and measurable, age three as still visible but not measurable, and age four redds were no longer visible (flag only).

2.4 Assigning Species to Unknown Redds

In order to assign species to unknown redds Ricker et al. (2014) applied a K-nearest neighbors (kNN) algorithm. The kNN uses distance in X-Y space and time to nearest 3 known species red or live fish to make a prediction of species based on majority vote. Each unknown redd was assigned to a species for furtheranalysis of species specific red abundance.

We used Leave-one-out-cross-validation (LOOCV) to evaluate the KNN predictions. The LOOCV process involved removing each known redd sequentially from the data, predicting the red from the remaining data, and comparing the prediction to truth. Errors in prediction are not however propogated into the total error of within reach abundance. All kNN and LOOCV analysis were executed in program R with the "class" package (Venables and Ripley 2002) and "caret" package (Kuhn 2013).

2.5 Estimation of Within-Reach Redd Abundance

Estimation of the number of redds in each sample reach is derived by dividing the total redd count by the square root of the seasonally pooled redd survival rate. The redd survival rate is estimated as fraction of re-observed age 2 and 3 flagged redds (still visible) to age 4 (no longer visible) (Section 2.3) (Ricker et al. 2014, Schwarz et al 1993).

2.6 Estimation of Total Redd Abundance Within the Sample Frame

Total redd abundance expansion to the frame is estimated with a Simple Random Sample estimator (Adams et al. 2011). See Ricker et al. 2014 for standard error equations and calculation methods and Adams et al. 2011 for correction factors. Bootstrap re-sampling was implemented to estimate between-reach variance and within-reach variance (Ricker et al. 2014).

3 RESULTS

3.1 Reach Survey Frequency

Field staff conducted spawning ground surveys in twenty two reaches, in five streams, within the Humboldt Bay watershed between November 7, 2015 and June 14, 2016. Visitation rates to stream reaches averaged 4.1 times and the average number of days between visits was twenty nine days (Table 1).

3.2 Fish Observations

Live fish observations include 3 Chinook salmon, 509 coho salmon, 15 steelhead trout, and 22 unidentified live salmonid adults. Table 2 and Table 3 summarize and Figure 2 displays counts of live fish and carcass observations by week in Humboldt Bay. Non target live fish included 10 cutthroat trout and 14 pacific lamprey. Carcass observations include 2 Chinook salmon, 69 coho salmon, 0 steelhead trout, and 40 unidentified species. A total of six pacific lamprey carcasses were observed.

Sex ratios of male to female live fish and carcass observations were 0:1, 1:0.84, and 1:0.4 for Chinook salmon, coho salmon, and steelhead trout respectively. Descriptive statistics for live fish and carcasses are presented in (Table 4). Out of 111 carcass recoveries 44 were whole and measured for fork length.

Table 1. Summary of spawning ground survey statistics of the mean number of days between reach surveys and the maximum number of days between surveys.

Reach Code	Stream	Mean	Max	N
1039	Elk River	34.66	59	4
1041	Elk River	30.66	46	4
1043	Elk River	27.00	30	3
1062	Elk River	-	30	2
1065	Elk River	24.00	36	3
1100	Elk River	51.00	60	3
1101	Elk River	-	17	2
1132	Salmon Creek	-	90	2
1133	Salmon Creek	-	25	2
1135	Salmon Creek	-	37	2
905	Jacoby Creek	-	26	2
907	Jacoby Creek	-	22	2
916	Jacoby Creek	9.16	16	7
945	Ryan Creek	49	60	3
*979	Freshwater Creek	26.28	47	8
*980	Freshwater Creek	21.6	42	11
*981	Freshwater Creek	16.11	45	10
*982	Freshwater Creek	-	33	2
990	Freshwater Creek	20.5	30	3
994	Freshwater Creek	-	23	2
*1004	Freshwater Creek	18.42	41	8
1009	Freshwater Creek	18.8	45	7
*1014	Freshwater Creek	17.8	44	6

*Denotes reaches in which surveys continued through late May or early June to capture the entire steelhead spawning run.

Table 2. Live fish observations by calendar week.

Week Beginning	Chinook	coho	steelhead	unidentified	Total
2015-11-16	0	0	0	0	0
2015-11-23	0	0	0	0	0
2015-11-30	0	0	0	0	0
2015-12-07	0	0	0	0	0
2015-12-14	0	36	0	0	36
2015-12-21	0	7	0	0	7
2015-12-28	1	83	0	1	85
2016-01-04	0	45	0	2	47
2016-01-11	1	207	0	8	216
2016-01-18	0	89	0	3	92
2016-01-25	1	15	0	0	16
2016-02-01	0	18	11	5	34
2016-02-08	0	7	3	3	13
2016-02-15	0	0	0	0	0
2016-02-22	0	0	0	0	0
2016-02-29	0	2	1	0	3
*2016-03-07	0	0	0	0	0
*2016-03-14	0	0	0	0	0
*2016-03-21	0	0	0	0	0
2016-03-28	0	0	0	0	0
2016-04-04	0	0	0	0	0
2016-04-11	0	0	0	0	0
2016-04-18	0	0	0	0	0
*2016-04-25	0	0	0	0	0
*2016-05-02	0	0	0	0	0
*2016-05-09	0	0	0	0	0
*2016-05-16	0	0	0	0	0
2016-05-23	0	0	0	0	0
2016-05-30	0	0	0	0	0
Total	3	509	15	22	549

*No surveys conducted during this week.

Table 3. Carcass observations by calendar week.

Week Beginning	Chinook	coho	steelhead	unidentified	Total
2015-11-16	0	0	0	0	0
2015-11-23	0	0	0	0	0
2015-11-30	0	0	0	0	0
2015-12-07	0	0	0	0	0
2015-12-14	0	0	0	0	0
2015-12-21	0	0	0	0	0
2015-12-28	0	1	0	1	2
2016-01-04	1	1	0	0	2
2016-01-11	0	12	0	1	13
2016-01-18	0	10	0	5	15
2016-01-25	0	4	0	2	6
2016-02-01	0	22	0	10	32
2016-02-08	1	11	0	15	29
2016-02-15	0	7	0	2	7
2016-02-22	0	0	0	3	3
2016-02-29	0	1	0	1	2
*2016-03-07	0	0	0	0	0
*2016-03-14	0	0	0	0	0
*2016-03-21	0	0	0	0	0
2016-03-28	0	0	0	0	0
2016-04-04	0	0	0	0	0
2016-04-11	0	0	0	0	0
2016-04-18	0	0	0	0	0
*2016-04-25	0	0	0	0	0
*2016-05-02	0	0	0	0	0
*2016-05-09	0	0	0	0	0
*2016-05-16	0	0	0	0	0
2016-05-23	0	0	0	0	0
2016-05-30	0	0	0	0	0
Total	2	69	0	40	111

*No surveys conducted during this week.

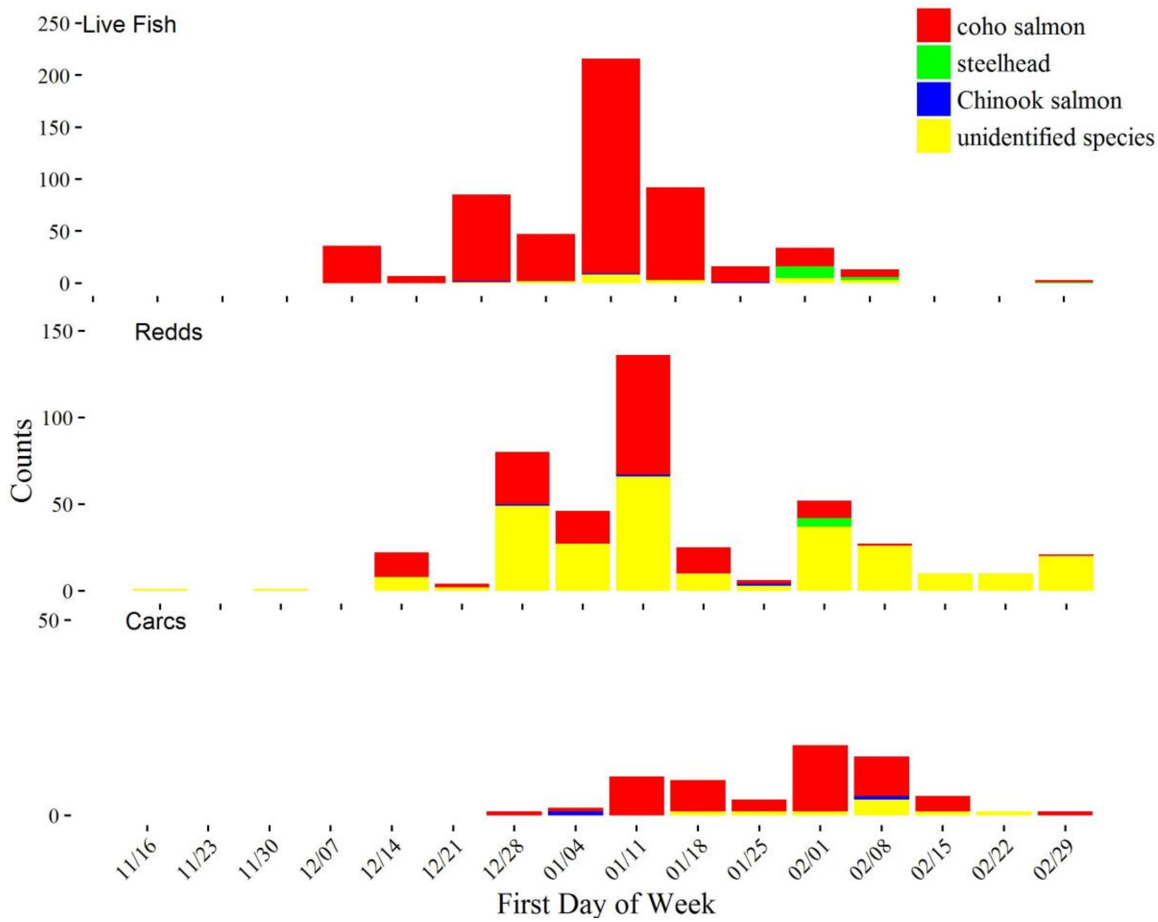

Figure 2. Stacked Bar Plot of live fish (A), individual redd, and carcass (C) observations by week. Please note redds don't include those from extended surveys in March and April.

Table 4. Descriptive statistics of live fish observations (L) and carcasses (C).

Species	Sex	Mean		Median		Min		Max		SD		N	
		L	C	L	C	L	C	L	C	L	C	L	C
Chinook	F	98	95	95	95	90	94	110	95	10.4	0.7	3	2
Chinook	M	-	-	-	-	-	-	-	-	-	-	-	-
Chinook	Unk	-	-	-	-	-	-	-	-	-	-	-	-
coho	F	59	61	60	60	40	50	70	70	5.3	4.8	192	18
coho	M	57	64	60	66	25	44	80	74	11.9	7.2	229	19
coho	Unk	51	61	55	61	25	52	70	69	14.1	12.2	17	2
steelhead	F	63	73	63	73	60	73	65	73	3.5	N/A	2	1
steelhead	M	66	-	70	-	55	-	75	-	8.2	-	5	-
steelhead	Unk	58	-	60	-	15	-	75	-	18.6	-	8	-
Unknown	F	60	-	60	-	55	-	65	-	5.0	-	3	-
Unknown	M	53	-	53	-	30	-	75	-	31.8	-	2	-
Unknown	Unk	48	67	50	67	20	65	65	68	12.9	2.12	16	2

3.3 Redd Observations

Out of 454 redds observed 171 redds were identified to species. The known species observations compared to the LOOCV predictions are displayed in Table 5. The KNN predictions, correctly predicted redds divided by the total known redds, were 94.1% accurate.

Table 5. Confusion matrix of the known species redds in columns crossed with LOOCV redd predictions in rows.

	Chinook	coho	steelhead
Chinook	0	0	0
coho	3	161	5
steelhead	0	2	0

Newly constructed redd observations for coho and unidentified species peaked during the second week of January when 135 anadromous salmonid redds were counted (Table 6, Figure 2). Steelhead redd observations peaked during the first week in February when 5 redds were tallied. Reach 1039, in Elk river, had the highest count of redds (Table 7). Non-target redd totals were 14 cutthroat redds and 608 pacific lamprey redds (See Appendix, Table 12).

3.4 Total Redd Abundance

Total redd abundance estimates for Chinook salmon in Humboldt Bay tributaries in 2015 were not generated due to low sample sizes. Total redd abundance estimates, in all 31 reaches, for coho salmon and steelhead trout with 95% confidence intervals was 617 (430, 849) and 96 (21,185) respectively. Estimates and descriptive statistics of surveyed reaches are presented in Table 8.

Table 6. Counts of newly constructed known redds by calendar week.

Week Beginning	Chinook	coho	steelhead	unidentified	Total
2015-11-16	0	0	0	1	1
2015-11-23	0	0	0	0	0
2015-11-30	0	0	0	1	1
2015-12-07	0	0	0	0	0
2015-12-14	0	14	0	8	22
2015-12-21	0	2	0	2	4
2015-12-28	1	30	0	49	80
2016-01-04	0	19	0	27	46
2016-01-11	1	69	0	66	135
2016-01-18	0	15	0	10	25
2016-01-25	1	2	0	3	6
2016-02-01	0	10	5	37	52
2016-02-08	0	1	1	25	27
2016-02-15	0	0	0	10	10
2016-02-22	0	0	0	10	10
2016-02-29	0	1	0	20	21
*2016-03-07	0	0	0	0	0
*2016-03-14	0	0	0	0	0
* 2016-03-21	0	0	0	0	0
2016-03-28	0	0	0	0	0
2016-04-04	0	0	0	3	3
2016-04-11	0	0	0	4	4
2016-04-18	0	0	0	0	0
*2016-04-25	0	0	0	0	0
*2016-05-02	0	0	0	0	0
*2016-05-09	0	0	0	0	0
*2016-05-16	0	0	0	0	0
2016-05-23	0	0	0	3	3
2016-05-30	0	0	0	3	3
Total	3	163	6	282	454

*No surveys conducted during this week.

Table 7. Counts of anadromous salmonid redds within each survey reach. Survey reach numbers are labled in figure 1.

Location Code	Chinook	coho	steelhead	unidentified	Total
905	0	6	0	6	12
907	0	1	0	2	3
916	0	18	0	14	32
945	0	1	0	14	15
979	0	1	0	20	21
980	0	7	0	44	51
981	3	9	1	22	36
990	0	1	0	4	5
994	0	7	0	10	17
1004	0	22	0	35	57
1006	0	3	0	9	12
1009	0	2	0	6	8
1014	0	6	0	9	15
1039	0	29	0	31	60
1041	0	12	0	13	25
1043	0	4	2	2	8
1062	0	0	1	0	1
1065	0	14	0	7	21
1100	0	14	2	23	39
1101	0	6	0	4	10
1133	0	0	0	6	6
1135	0	0	0	1	1
Total	3	163	6	282	454

Table 8. Estimated number of redds in 23 surveyed reaches in Humboldt Bay and in the Freshwater Creek Life Cycle Monitoring Station (LCS) where all 9 reaches were surveyed. Estimated Descriptive statistics are between sample reaches.

	Humboldt Bay		LCS	
	coho	steelhead	coho	steelhead
Redd Estimate	587	59	323	1
Standard Error	6.24	1.92	12.65	-
Variance	858.1	77.0	1281.2	-
95% Confidence Interval	(529,629)	(42,77)	(252,395)	-

4 DISCUSSION

This year's reach survey frequency is less than in recent years (Table 9) due to heavy rainfall in an El Nino weather cycle. Table 9 below includes randomly selected reaches and additional reaches surveyed in the LCM, for a total of 23 reaches during each year.

Table 9. Reach survey frequency by year in Humboldt Bay tributaries.

Year	Mean # surveys per reach	Mean # days between surveys
2010-2011	6.8	20
2011-2012	7.2	20
2012-2013	8.3	16
2013-2014	3.8	26
2014-2015	5.6	25
2015-2016	4.1	29

The timing of the rainfall events in January (Figure 3) prevented surveys from occurring as frequently as the protocol suggests (every ten days). Normally surveys are delayed for 4-6 days after a significant rainfall event. Minimum visibility conditions to conduct redd surveys is 50cm which is usually reached as streams approach median winter base flows (Figure 3). If the storm frequency is once a week only a few reaches in the frame can be surveyed between storm events. Some reaches were visited only two times during the entire spawning season (Table 1). Infrequent reach visitation could decrease the chances of observations of both carcasses and new redds.

High water during the historical peak of the coho spawning season, in January, most likely obscured redds and decreased carcass and live fish observations. Redds constructed during this period may have been obscured and were unavailable for surveyors to observe during a subsequent survey (Jones 2012). Flood events could have moved carcasses into deep pools and high onto the flood plain impeding observations. As the water visibility decreases the chances of viewing live fish decreases. All of these factors could lead to a lower estimate of redds within the Humboldt Bay sample frame during an El Nino water year.

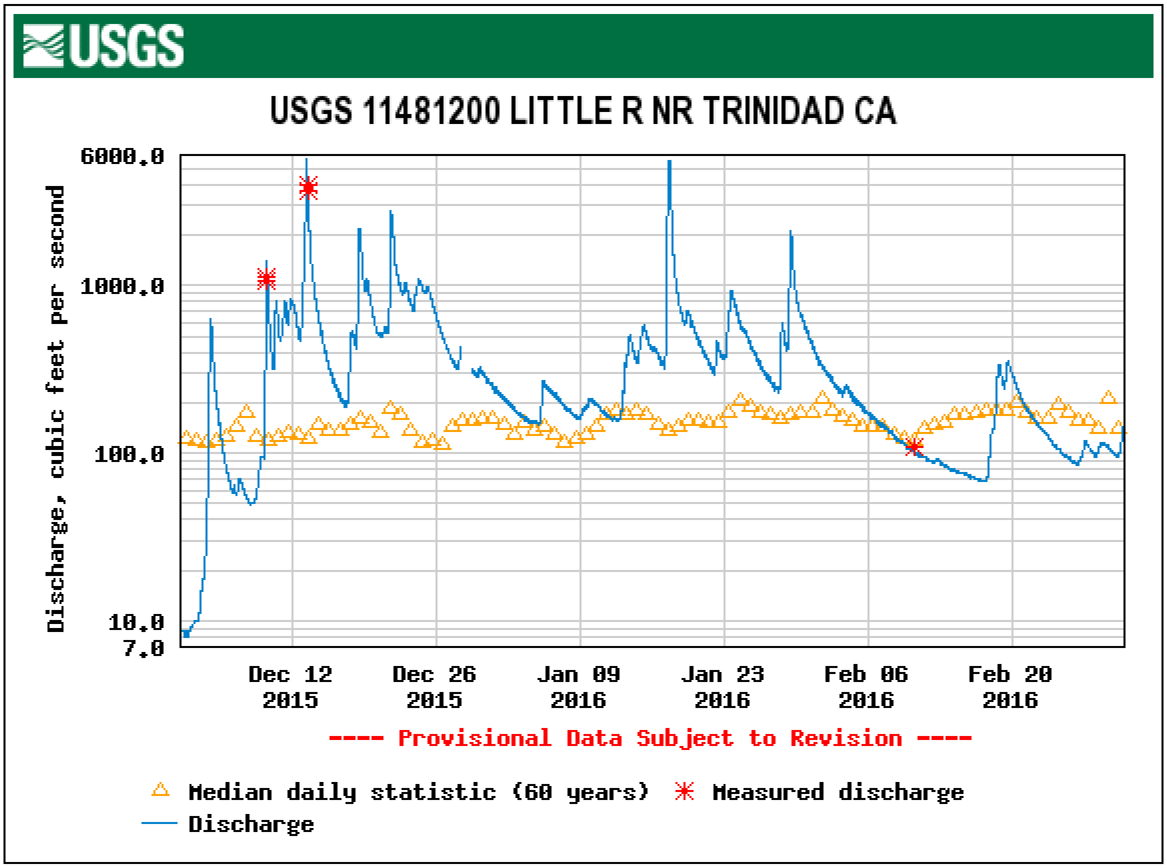

Figure 3. Discharge in Little River, used as a proxy for Humboldt Bay, December 2015 through February 2016.

The Coho redd estimate total for 2015 was lowest when compared to the last five years (Table 10) in the Humboldt Bay estimate. For the Freshwater Creek Life Cycle Monitoring Station coho had the third highest redd estimate when compared to the last five years (Table 11). The high estimate within the Freshwater Creek LCM compared to the Humboldt Bay estimate may be due to the survey frequency in the LCM (**Table 1**). More frequent surveys in the LCM are required to estimate the adult coho population by recapturing marked carcasses.

Estimates for low density species such as Chinook salmon, in both Humboldt Bay and the Freshwater Creek LCM (2011 to 2015), and Steelhead, in the LCM (2010 to 2013), continue to challenge the protocol and the ability to analyze the data with the tools available in Adams et al. (2011). Steelhead estimates may also be influenced by the lack of surveys later in the season which could capture the spawning activity.

Table 10. Redd estimates with 95% confidence intervals for three species during six years in Humboldt Bay.

Year	Chinook	coho	steelhead
2010-2011	19 (2,37)	1099 (719,1478)	11 (3,19)
2011-2012	0	1738 (1014,2463)	19 (4,33)
2012-2013	0	763 (511,1016)	172 (73,272)
2013-2014	0	630 (123,1138)	35 (10,61)
2014-2015	0	1632 (1171,2094)	226 (127,326)
2015-2016	3(3,3)	617 (430,849)	97 (21,184)

Table 11. Redd estimates with 95% confidence intervals for three species during six years in Freshwater Creek Life Cycle Monitoring Station.

Year	Chinook	coho	steelhead
2010-2011	12 (12,12)	231 (223,239)	4 (4,4)
2011-2012	0	420 (391,449)	7 (7,7)
2012-2013	0	244 (240,249)	13 (13,13)
2013-2014	0	127 (87,168)	2(2,2)
2014-2015	0	453 (367,538)	72 (57,88)
2015-2016	3 (3,3)	322 (251,394)	1(1,1)

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6 APPENDIX

Table 12. Counts of newly constructed redds by calendar week for non-target species.

Week Beginning	cutthroat	Pacific Lamprey
2015-11-16	0	0
2015-11-23	0	0
2015-11-30	0	0
2015-12-07	0	0
2015-12-14	0	0
2015-12-21	0	0
2015-12-28	0	0
2016-01-04	1	0
2016-01-11	0	0
2016-01-18	0	0
2016-01-25	0	0
2016-02-01	0	0
2016-02-08	10	0
2016-02-15	2	1
2016-02-22	0	0
2016-02-29	0	0
*2016-03-07	0	0
*2016-03-14	0	0
*2016-03-21	0	0
2016-03-28	0	3
2016-04-04	0	52
2016-04-11	0	130
2016-04-18	0	165
*2016-04-25	0	0
*2016-05-02	0	0
*2016-05-09	0	0
*2016-05-16	0	0
2016-05-23	0	91
2016-05-30	1	166
Total	14	608

*No surveys conducted during this week.