State of California
The Natural Resources Agency
Department of Fish and Wildlife

California Coastal Salmonid Monitoring Program Annual Report:

Results of regional spawning ground surveys and estimates of total salmonid redd construction in Redwood Creek, Humboldt County California, 2011.

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Abstract

A total of 116 salmonid spawning ground surveys were conducted in 21 randomly sampled stream reaches throughout the Redwood Creek basin between 11/02/2011 and 03/20/2012. An additional 49 surveys were conducted in the 7 reaches of Prairie Creek in order to complete surveys in all of the reaches within the Life Cycle Monitoring sub-basin. Individual stream reaches were surveyed an average of 6 times over the study period with an average return interval of 20 days between surveys. Field staff observed 180 coho salmon, 469 Chinook salmon, 28 steelhead trout and 87 unidentified live fish over the survey period. A total of, 38 coho salmon, 32 Chinook salmon and 1 unknown individual salmonid carcasses were found. Field surveyors were able to assign species to 129 of the total 697 redds observed. After all unidentified redds were predicted to species likely to have built them, we estimated the total number of redds constructed across all reaches in the sample frame, expanded from the randomly sampled reaches to be 837 Chinook salmon, 501 coho, and 48 steelhead. The spawning ground survey period did not encompass the entirety of the spawning period for steelhead, and therefor the estimates presented should be considered only for the length of the study. We estimated a total of 379 coho salmon, 105 Chinook salmon, 11 and steelhead redds for all reaches within the Prairie Creek Life Cycle Monitoring sub basin.

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1 INTRODUCTION

Pacific Salmon (Oncorhynchus sp.) have experienced marked decline in abundance over the last 50 years. Due to this decline, coho salmon (*Oncorhynchus kisutch*) in the Southern Oregon/Northern California Coasts (SONCC) Evolutionary Significant Unit (ESU) were listed as threatened pursuant to the federal Endangered Species Act (ESA) in 1997 (NMFS 1997). This federal listing status was reviewed and reaffirmed in 2005 (NMFS 2005). 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 and coastal Chinook salmon (O. tshawytscha) south of the Klamath River to the Russian River are federally ESA listed. Recovery of salmon and steelhead listed under the Federal and California ESAs depends in part the increase in abundance of adults returning to spawn (Good et al. 2005). Delisting will depend on whether important populations have reached abundance thresholds, and whether these populations can be shown to be demographically connected across the landscape. (Spence et al. 2008, Williams et al. 2008).

In 2011, the California Department of Fish and Wildlife (CDFW) and NOAA Fisheries published the California Coastal Salmonid Population Monitoring plan (CMP)(Adams et al. 2011). Extensive spawning ground surveys are considered a primary survey method in the northern monitoring area and form the foundation of the CMP approach to track status and trends of adult abundance. These surveys are applied to a sample of stream reaches and the number of redds within the sample reaches expanded out to the total sample frame (e.g. population or other demographic unit). Two steps are required to estimate total redd abundance for the entire sample frame; 1) the total number of redds must be estimated for each sampled stream reach, 2) the total number of redds over the entire sample frame must be estimated from the sampled reaches.

The science of monitoring the population size of biologic organisms over space and time, by definition, implies methodical application of study design, data collection, analysis and reporting. Adams et al. (2011) recognized the need for standardized application of study design, data collection protocol and data structure. The CMP has made significant progress toward these goals by utilizing a spatially ballanced, design based sampling scheme, a consistent data collection protocol, and a single data base structure for housing field data. While these efforts are central components of a well designed monitoring program, the consistent analysis and reporting of these often large and increasingly complex data sets collected by multiple lead scientists, can be difficult to reproduce even from the most organized original data source. As the CMP matures from a new program, analysis techniques are likely to be improved upon and may lead to re-evaluation of historical data sets.

The term "literate programming" was introduced by Don Knuth in the early 1980's, with the idea that a computer program should be fully documented in a manner that is readable (Knuth, 1984). This transparency exposes results and conclusions drawn to independent testing, replication and improvement by other scientists, consistent with

principals of scientific research. This document is an example of the literate programming concept, utilizing a standardized set of queries to extract data from the data base, program R statistical software for analysis and graphics production (R Core Team 2013), and TEXas a document preparation system and markup language for creation of a dynamic reporting platform. The result is the consistently formatted, fully reproducible, readable and distributable document you are reading. The single source file, containing all analysis functions, type setting language and dynamic text can be easily distributed, shared, and improved by cooperating scientists, as it is entirely transparent with respect to source data, analysis methods, and results. This literate programming platform provides a useful means to standardize reporting structure, and provide for timely reporting of information to resource managers.

In the following pages, we provide a brief background on the sample frame construction, sampling design, survey methods, data collection, and redd species prediction methods for continuity, but a full treatise on these topics can be found elsewhere (Boydston and McDonald 2005, Adams et al. 2011, Gallagher et al. 2007, Garwood and Ricker 2011, Ricker et al. (in CMP Technical Team review)). We then describe a new approach to estimating total redd construction within a sample reach and apply the technique to estimate the total number of redds from data collected in Redwood Creek, Humboldt County, California during the 2011 anadromous salmonid spawning season.

2 MATERIALS AND METHODS

Study Area

We conducted repeated periodic surveys in a spatially balanced random sample of stream reaches selected from possible anadromous spawning stream reaches within the Redwood Creek, Humboldt County, California (Figures 1-3).

Figure 1: Map of the Prairie Creek portion of the Redwood Creek sample frame. All main reaches are indicated with alternating colors. Yellow reaches indicate small sub-reaches that are surveyed along with the main reach. Reach numbers indicate the Location Code of the reach.

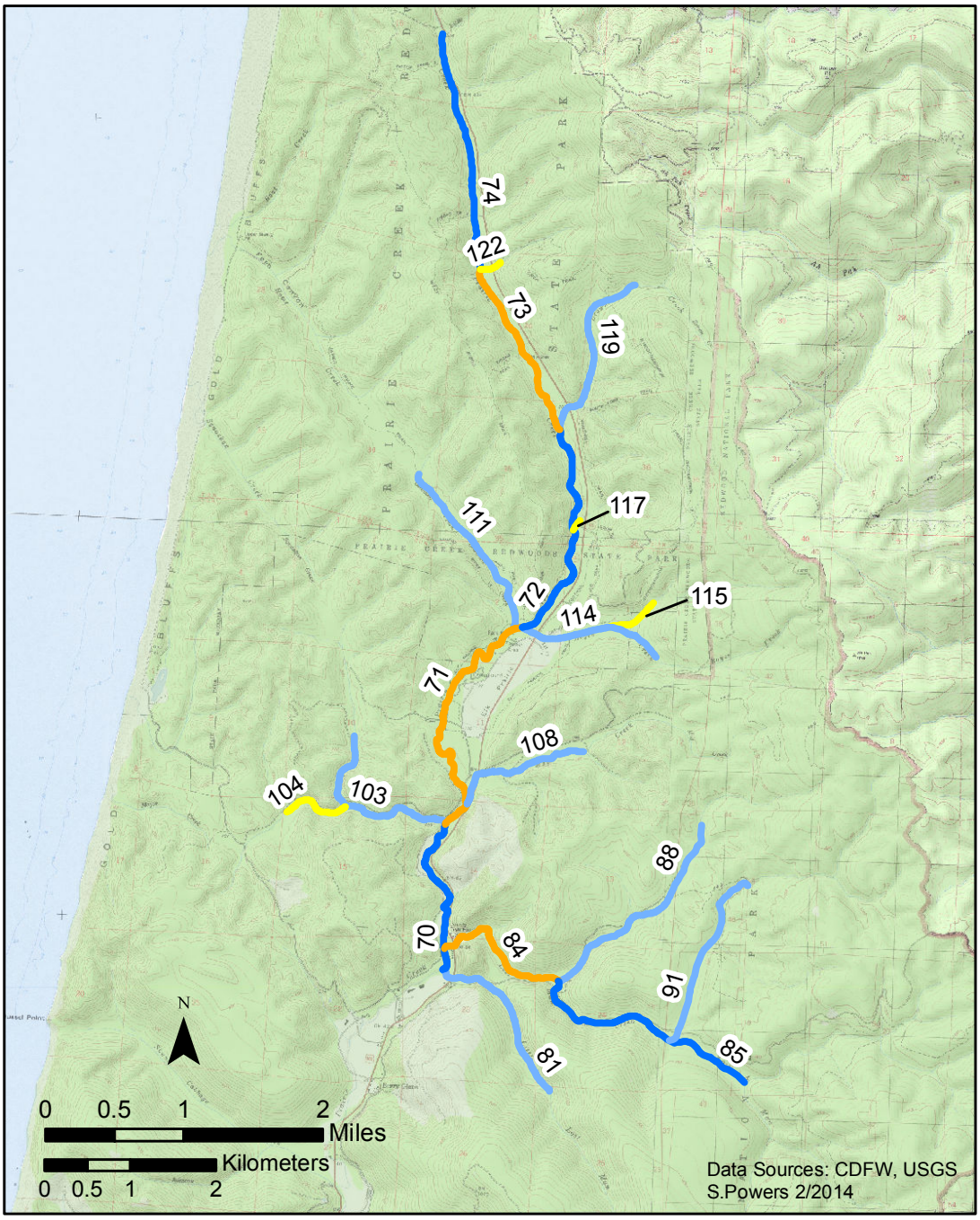


Figure 2: Map of the lower Redwood Creek portion of the Redwood Creek sample frame. All main reaches are indicated with alternating colors. Yellow reaches indicate small sub-reaches that are surveyed along with the main reach. Reach numbers indicate the Location Code of the reach.

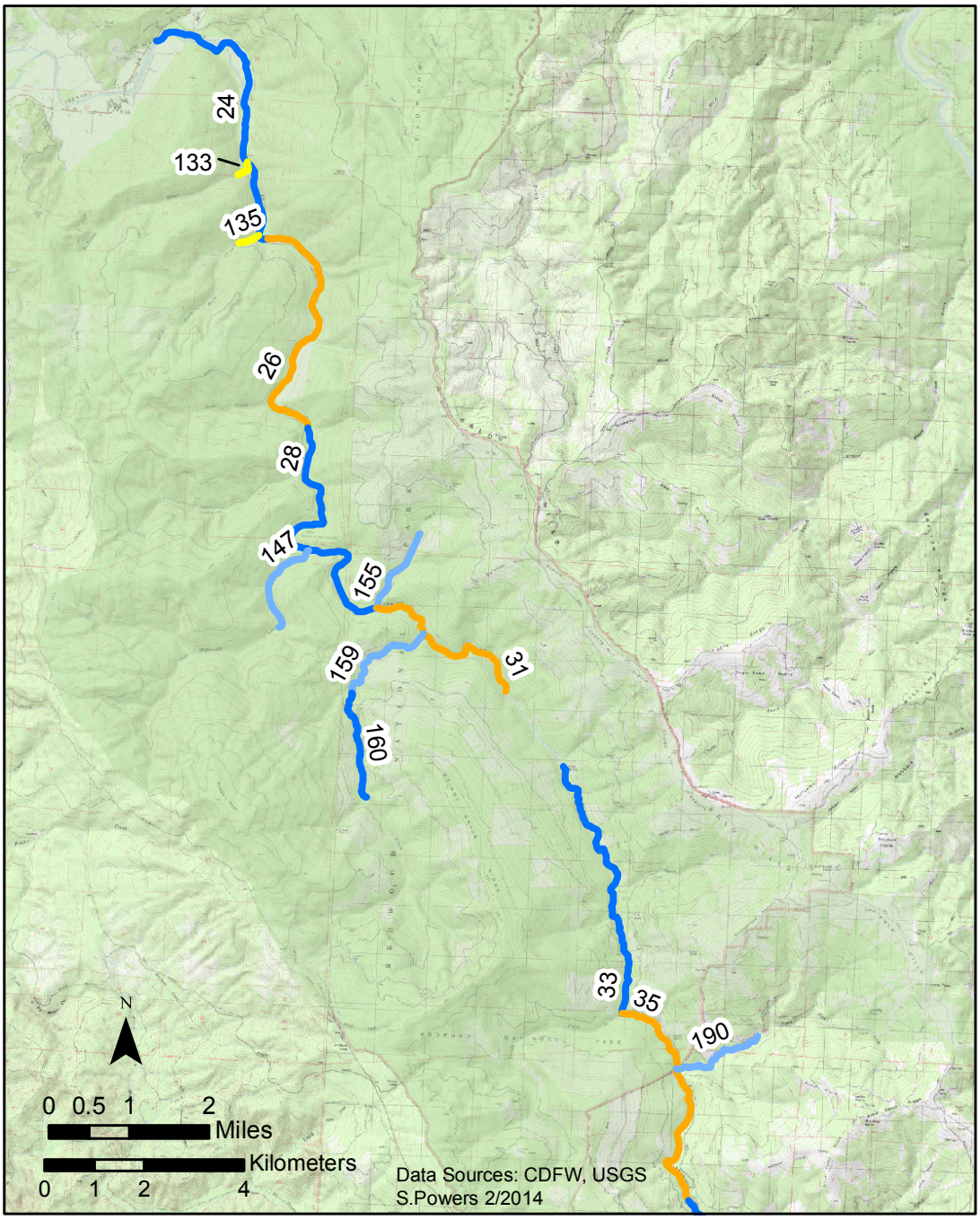
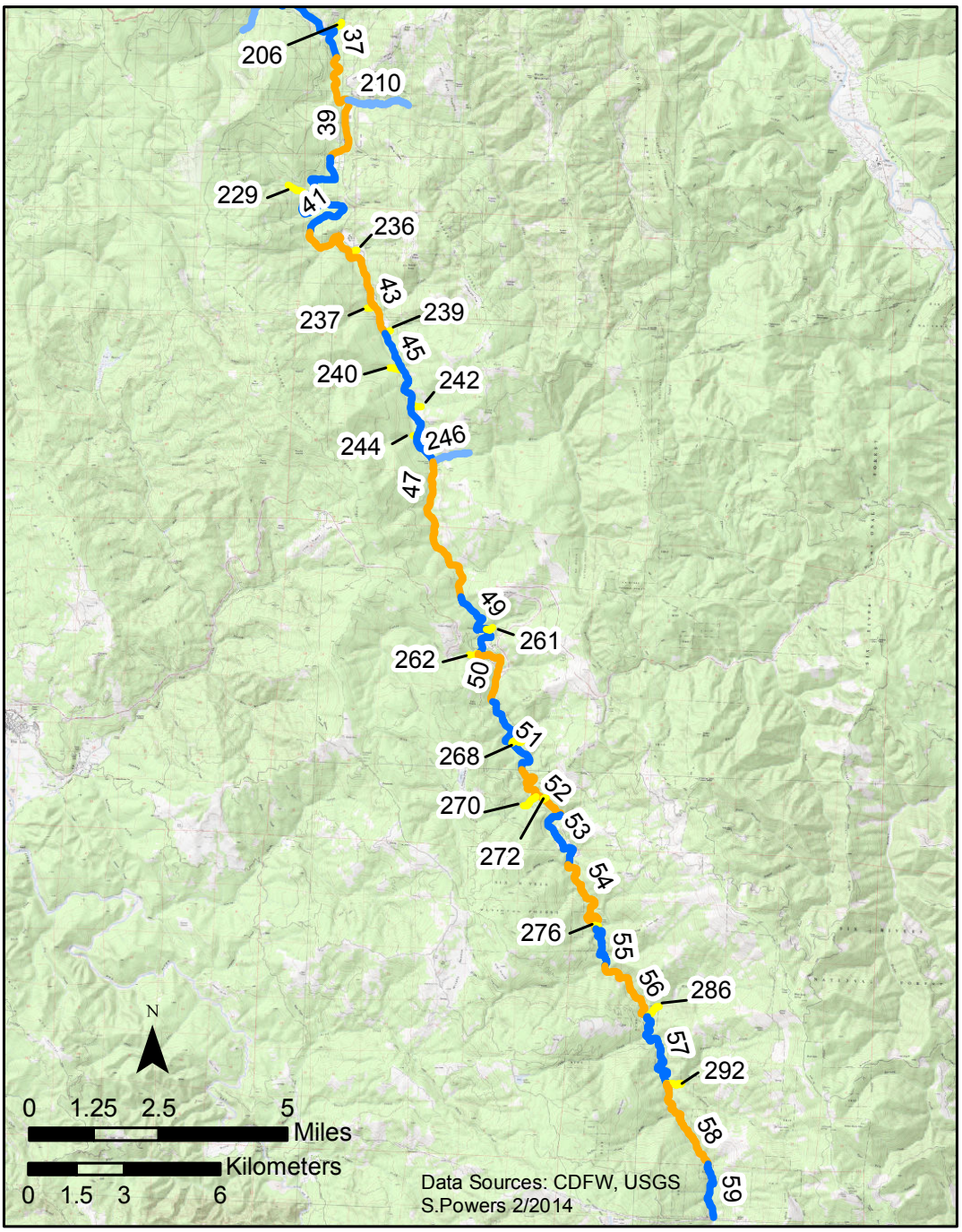


Figure 3: Map of the upper Redwood Creek portion of the Redwood Creek sample frame. All main reaches are indicated with alternating colors. Yellow reaches indicate small sub-reaches that are surveyed along with the main reach. Reach numbers indicate the Location Code of the reach.



Sample Frame Construction

Using a simple set of inclusion rules, data regarding 1) documented salmonid distributions, 2) stream gradient and stream size thresholds where salmonid distributions are unknown, 3) migration barrier data, 4) expert knowledge of distribution and barriers, and 5) field reconnaissance, were used within a Geographic Information System to establish species specific spawning distributions needed to develop a sampling frame for abundance monitoring (Garwood and Ricker 2011).

Reaches were allowed to vary in length with start and end pionts established at either reliable on the ground land marks (e.g. stream confluences, bridge, etc.), or in some cases at suspected barriers to anadromy. Reach start and end points were flagged and GPS coordinates taken. All reaches within the sample frame were assigned numeric reach ID's (Location Code). The assignment of ID's progressed from north to south as streams entered the marine environment. Beginning with the lower most reach in the northern most main-stem, reach ordering progressed upstream to the top of the main-stem. The next reach in the ordering sequence was the lower most tributary to the main-stem. Ordering progressed up this tributary until it's end. This sequence of ordering continued through the dendridic pattern of the watershed. In this way, the frame was recursively sorted, from watershed to main stem to tributaries, and produced a unique ordering of the frame. When coupled with the sample draw mechanism (see Sample Reach Selection) this ordering ensured that selected sampled units were spatially balanced (Boydston and McDonald 2005).

Small reaches that were under 1000m in length were surveyed along with, and redd data combined with, the main reaches to which they flowed into (Garwood and Ricker 2011).

Sample Reach Selection

We used a General Randomized Tessellation Stratified (GRTS) routine (McDonald 2003) to select our sample reaches for surveying from the spatially ordered sampling frames. A GRTS sample draw was made consisting of the entire sample frame and output in reverse hierarchical ordering. The first 21 reaches of the total 46 coho salmon sample frame reaches were selected for surveying. Chinook salmon and steelhead estimates of total redd construction are therefor constrained to those that occurred within potential coho spawning space.

Reach Survey Protocol

Periodic spawning ground surveys were conducted using the protocols of Gallagher et al.(2007). Teams of two surveyors either walked smaller stream reaches in an upstream direction or floated larger stream reaches in a downstream direction. The project was staffed such that each reach could be surveyed every 10-14 days if stream flows, water visibility, and weather conditions allowed continuous access. When unsafe or poor survey conditions did not permit this optimal return interval, reaches were surveyed as condi-

tions became acceptable, with an attempt to maximize the total number of repeated surveys on all reaches.

All live and dead fish were identified to species if possible. Carcasses were assigned a condition code reflecting how fresh they appeared, measured to fork length when possible, inspected for external clips or marks, and tagged with a uniquely numbered metal disk fixed to the jaw with a metal staple (jaw tag). The jaw tag number of re-observed carcasses was recorded on subsequent surveys. All carcasses were left in the location they were found.

Redds were identified to species when fish were observed either digging or actively guarding the redd. If no species could be assigned by the field staff, the redd was treated as unknown species. All newly observed redds were measured for physical size, substrate size in the pot and tail spill areas, depth of pot in relation to the surrounding undisturbed substrate, geo-referenced, and physically marked with flagging tied to riparian vegetation in close proximity. The flagging indicated the unique record number of the redd, the distance and bearing from the flag to the redd, and a categorical 'Age'of (1) defined as: 'New since last survey'. On subsequent survey occasions new redds were flagged in the same manner and existing flags reconciled to the individual redds they marked, redd record numbers recorded from the flag, and re-assigned a categorical 'age' variable to reflect if the redd was: (2) still visible and measurable, (3) still visible but not measurable, (4) no longer visible, or (5) unknown due to visibility constraints.

Assigning Species to Redds

Because all redds were not identified to species at the time of observation, we used the K-nearest neighbors (kNN) algorithm to predict the species of redds most likely to have constructed them (Ricker et al. (in CMP Tech Team review)). The kNN algorithm is a simple non-parametric form of machine learning where an object is classified by a majority vote of it's k nearest neighbors in Euclidean distance. Euclidean distance is a measure of distance between individuals, and generalizes Pythagoras's theorem to multiple dimensions. We use UTME, UTMN and date as spatial and temporal dimensions, when UTMs were recorded and date only when UTMs were absent and calculate euclidean distance(d) between redd x_i and x_j (d_{ij}) as:

$$d_{ij} = \sum_{k=1}^{n} \sqrt{(x_{ik} - x_{jk})^2} \tag{1}$$

where:

k=redd attributes (UTME, UTMN, JDate)
for redds (1,2,3...n)

kNN selects classes based on the shortest euclidean distance, and because the spatial distance in meters, and the distance in time (number of days) are on distinctly different scales, we standardized attribute data values into z-scores by:

$$z_i = \frac{x_i - \mu}{\sigma} \tag{2}$$

We classified each redd by the majority vote of the three nearest neighbors (k=3) based on the previous work of Ricker and Stewart (2011) who used values of k from 3 to 10, and found a k of 3 to be the smallest number of neighbors that produced the highest accuracy of classification with the fewest ties. When ties were encountered in the vote, they were mitigated by using the majority vote of the entire data set.

Leave-one-out-cross-validation (LOOCV) was used to evaluate the classification performance of the kNN model. LOOCV is an iterative process in which each redd is removed in turn from the set of known species redds, the model re-fit to the data and the removed redd predicted to species. Known redd species are then paired with the LOOCV predictions. Overall model accuracy is assessed as the percentage of the total number of predictions that are correct. All nearest neighbor classifications, and LOOCV and performance were carried out using program R with the 'class' package (Venables and Ripley 2002), and 'caret' package (Kuhn 2013).

Estimation of Within Reach Redd Abundance

We view annual redd counts produced by periodic repeated surveys as the result of three basic underlying processes: 1) redds are recruited into the population over the spawning season, 2) "mortality" occurs when redds become obscured from view becoming no longer visible to field observers, and finally 3)fieldd observations are made of redds that remained visible to the next survey occasion. Both the recruitment and mortality processes operate simultaneously upon the population of redds over time. Because redds may be scoured or obscured between survey occasions, the total number of distinct observable redds at the time of surveys may be substantially less than the total number of redds actually constructed. Therefore, even if field observers have perfect detection for the new redds that are present at the time of surveys, redd counts may have substantial negative bias as an estimator of total redd construction (Jones 2012). Schwarz et al. (1993) developed a theoretical foundation for the problem of estimating a total from repeatedly sampling marking and releasing salmon returning to the Chase River, British Columbia., Canada. The estimator developed by these authors extends the Jolly-Seber capture-mark-recapture model to allow for the estimation of the population total by making assumptions about the recruitment process, estimating survival of fish between sampling occasions via capture-mark-recapture, then use these parameters to adjust counts for animals that enter the population and die between survey occasions. We apply this general approach to periodic redd surveys, assuming all newly deposited redds are recruited at the mid-point of each survey interval, and estimate redd survival between occasions by inspecting the number of individually flagged redds that remain visible between each subsequent survey occasion. In the context of repeated spawning ground surveys we estimate total redd abundance within a sample stream reach as:

$$\hat{\tau_j} = B_0 + \frac{\sum_{i=2}^{k} B_i - 1}{\sqrt{\hat{S}}} \tag{3}$$

where $\hat{\tau_j}$ is the estimated of the number of redds within a sample reach j, when B_i is the number of new redds on the ith survey occasion, k is the total number of survey occasions, and B_0 the number of redds observed on first survey of the season. The numerator of the second term is then the sum of all new redds observed from the second occasion to the last occasion, divided by the sqare root of $\hat{S}$ survival of flagged redds calculated as:

$$\hat{S} = \frac{\sum_{i=1}^{k-1} R_{i+1}}{\sum_{i=1}^{k-1} M_i} \tag{4}$$

where R_i denotes the number redds recaptured as still visible at occasion and i, M_i the number of newly marked redds at occasion i. The numerator is the sum of recaptured redds R from the second survey occasion, to the last survey occasion, and denominator is the sum of marked redds M from the first occasion to the second to last occasion. The summation of R_i and M_i over $k-1$ occasions represents complete pooling of all survey occasions (or temporal strata) over the entire season.

For this flag based mark recapture, the standard mark recapture assumptions as applied to this model construct include:

1. Redds do not become detectable again after they have been classified as obscured from view (Age 4),

2. Redd flags are individually identifiable, and recorded properly,

3. All flagged redds regardless of species, survive with the same probability, (homogeneity of survival between redds) and in our pooled case all flagged redds survive with the same probability across all occasions (homogeneity of survival between occasions).

4. All unflagged and flagged redds on occasion i are observed,

5. Recruitment of new redds from the second occasion that redds are observed through the last occurs at the midpoint of the interval, and

6. Redds are considered obscured in the interval between occasion i and *i+1* if the flag (and redd) are not observed after occasion i.

Estimation of Total Redd Abundance Within the Sample Frame

Total redd abundance within the region of interest is estimated using a Simple Random Sample estimator for total as(Adams et al. 2011):

$$\hat{T} = N\left(\frac{\sum_{j=1}^{n} \hat{\tau}_j}{n}\right) \tag{5}$$

where N is the total number of reaches within the sample frame, n is the number of reaches in the sample, and $\hat{\tau}_j$ the estimate of the total number of redds in sampled reach j. The standard error of $se(\hat{T})$, was calculated using bootstrap resampling to estimate both the within and between reach variances, applying the finite population correction factor to only the between reach variance component (Adams et al. 2011):

$$se(\hat{T}) = N\sqrt{\left(1 - \frac{n}{N}\right)\hat{\theta}_b + \frac{1}{Nn}\left(\sum_{i=1}^{n} \hat{\theta}_w\right)} \tag{6}$$

where $\hat{\theta}_b$ is the between sample reach variance and $\hat{\theta}_w$ is the within sample reach variance.

Bootstrap resampling was used to estimate the between reach variance ($\hat{\theta}_b$) and within reach variance ($\hat{\theta}_w$). The bootsrap process followed eight steps. For each of 5000 bootstrap iterations:

1. $\hat{S}*$ from Equation (4) was estimated as $\sim$ Binomial(n,p), where n is the number of redds flagged (M) and p is the proportion of flagged redds (M) recaptured as still visible (R), where M and R are pooled across all survey occasions.

2. $\hat{S}*$ was used in equation (3) estimate redd abundance $\hat{\tau}*$ for the sample reach for the iteration, where new redds from the second occasion through last are pooled. This process was repeated 5000 times, yielding 5000 bootstrap replicates for redd abundance for the reach ($\hat{\tau}*$).

3. Steps 1-2 were repeated for each reach in the GRTS sample.

4. If any of the 5000 $\hat{S}*$ estimates from step 1 were zero, counts of individual redds were used in place of $\hat{\tau}*$ for all 5000 replicates.

5. The variance of the 5000 $\hat{\tau}*$ estimates is used as the estimated within reach variance ($\hat{\theta}_w$) of redd abundance for each reach.

6. For each sampled reach, the mean of the 5000 $\hat{\tau}*$ estimates was calculated.

7. The variance of the means calculated in step 6 was used as the variance between reaches ($\hat{\theta}_b$).

8. Both the within reach ($\hat{\theta}_w$) and between reach bootstrap variances ($\hat{\theta}_b$) were used in Equation (6) to estimate $se(\hat{T})$.

95 % confidence intervals are constructed as:

$$\hat{T} \pm t_{(1-\alpha/2,df)} * se(\hat{T}) \tag{7}$$

3 RESULTS

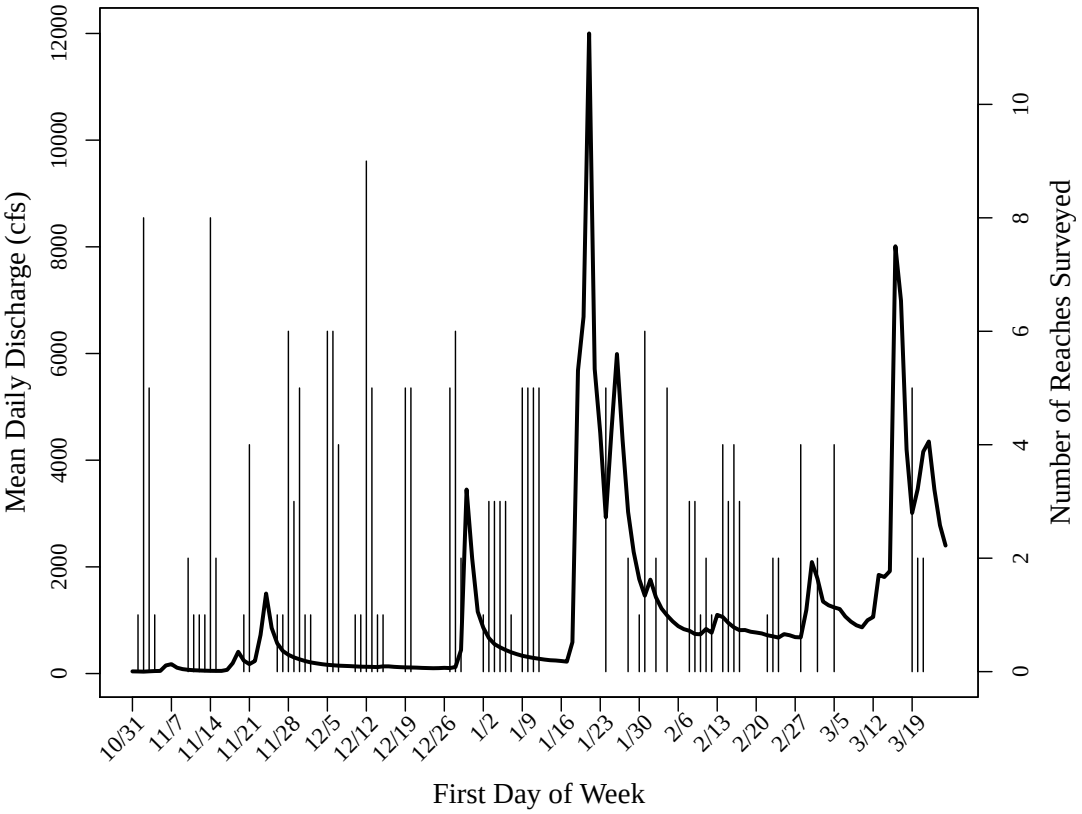
A total of 116 salmonid spawning ground surveys were conducted in 21 randomly sampled stream reaches throughout the Redwood Creek basin between 11/02/2011 and 03/20/2012. An aditional 49 surveys were conducted in the 7 reaches of Prairie Creek in order to complete surveys in all of the reaches within the Prairie Creek Life Cycle Monitoring sub-basin. The average interval between surveys over all reaches (mean of means) was 20 days (Table 1).

The stream discharge gauge on Redwood Creek near Orick was used as a proxy for the dicharge pattern exibited in Redwood Creek. Relative to this proxy discharge, stream reaches varied from 4160 to 277 in the maximum cubic feet per second dischage acceptable for surveying (Table 1). Figure (3) depicts the pattern of stream discharge at the the Redwood Creek near Orick guaging station relative to the number and timing of surveys that occured over the seanon.

Table 1: Survey statistics indicating the mean number of days between survey occasions, the standard deviation of the intervals between survey occations, the maximum number of days between survey occasions, the total number of survey occasions by sampled stream reach, and the maximum flow of from the nearest USGS stream gauge that the reach was surveyed.

Location Code	Stream Name	Mean	SD	Max	N	MaxFlow
24	Redwood Creek	22	12	44	6	674
28	Redwood Creek	14	13	44	9	674
33	Redwood Creek	42	9	49	3	718
37	Redwood Creek	16	9	28	7	742
39	Redwood Creek	17	4	23	5	277
43	Redwood Creek	16	6	27	7	802
51	Redwood Creek	20	8	32	5	1090
52	Redwood Creek	32		32	2	1090
56	Redwood Creek				0	
57	Redwood Creek				0	
59	Redwood Creek				0	
70	Prairie Creek	17	8	32	9	3010
71	Prairie Creek	17	7	29	7	1460
72	Prairie Creek	19	7	29	6	2930
73	Prairie Creek	17	4	23	6	3030
74	Prairie Creek	18	4	23	5	3030
81	Little Lost Man Creek	15	3	21	9	4160
84	Lost Man Creek	16	8	29	7	1430
85	Lost Man Creek	21	5	28	5	1090
88	Larry Dam Creek	16	3	22	8	3010
91	Lost Man Trib-U	16	2	21	8	4160
103	Streelow Creek	16	3	22	8	3010
108	May Creek	15	4	22	9	3010
111	Godwood Creek	15	4	21	9	3460
114	Boyes Creek	15	4	21	9	2930
119	Brown Creek	16	2	21	8	3460
160	Bridge Creek	37	10	49	4	698
190	Coyote Creek	24	17	44	4	814

Plot of the daily average stream flow from the nearest USGS gauging station (Left Y axis), and the number of survyes that occured (Right Y axis) over the survey period.



Fish Observations

Field staff observed 180 coho salmon, 469 Chinook salmon, 28 steelhead trout and 87 unidentified live fish over the survey period. Total discoveries of, 38 coho salmon, 32 Chinook salmon and 1 unknown individual salmonid carcasses were made (Table 3). Peak counts of live fish occurred the week of 12/19/2011 followed by the peak in new carcass discoveries the week of 02/06/2012 Figure 5).

Table 2: Counts of live fish observations for target species by calendar week.

Week Beginning	Chinook	coho	steelhead	unidentified	Total
2011-10-31	5	0	0	0	5
2011-11-07	0	0	0	0	0
2011-11-14	30	1	0	1	32
2011-11-21	11	0	0	0	11
2011-11-28	35	0	0	4	39
2011-12-05	145	0	0	1	146
2011-12-12	9	0	0	0	9
2011-12-19	129	8	1	64	202
2011-12-26	9	0	0	0	9
2012-01-02	71	34	1	5	111
2012-01-09	15	17	0	4	36
2012-01-16	0	0	0	0	0
2012-01-23	7	77	6	6	96
2012-01-30	3	37	8	2	50
2012-02-06	0	4	3	0	7
2012-02-13	0	0	0	0	0
2012-02-20	0	1	7	0	8
2012-02-27	0	1	0	0	1
2012-03-05	0	0	1	0	1
2012-03-12	0	0	0	0	0
2012-03-19	0	0	1	0	1
Total	469	180	28	87	764

Table 3: Counts of carcass observations for target species by calendar week.

Week Beginning	Chinook	coho	steelhead	unidentified	Total
2011-10-31	0	0	0	0	0
2011-11-07	0	0	0	0	0
2011-11-14	0	0	0	0	0
2011-11-21	0	0	0	0	0
2011-11-28	1	0	0	0	1
2011-12-05	4	0	0	0	4
2011-12-12	0	0	0	0	0
2011-12-19	3	0	0	0	3
2011-12-26	1	0	0	0	1
2012-01-02	4	1	0	1	6
2012-01-09	7	2	1	0	10
2012-01-16	0	0	0	0	0
2012-01-23	6	10	0	0	16
2012-01-30	0	3	0	0	3
2012-02-06	5	15	2	0	22
2012-02-13	1	7	1	0	9
2012-02-20	0	0	0	0	0
2012-02-27	0	0	0	0	0
2012-03-05	0	0	0	0	0
2012-03-12	0	0	0	0	0
2012-03-19	0	0	0	0	0
Total	32	38	4	1	75

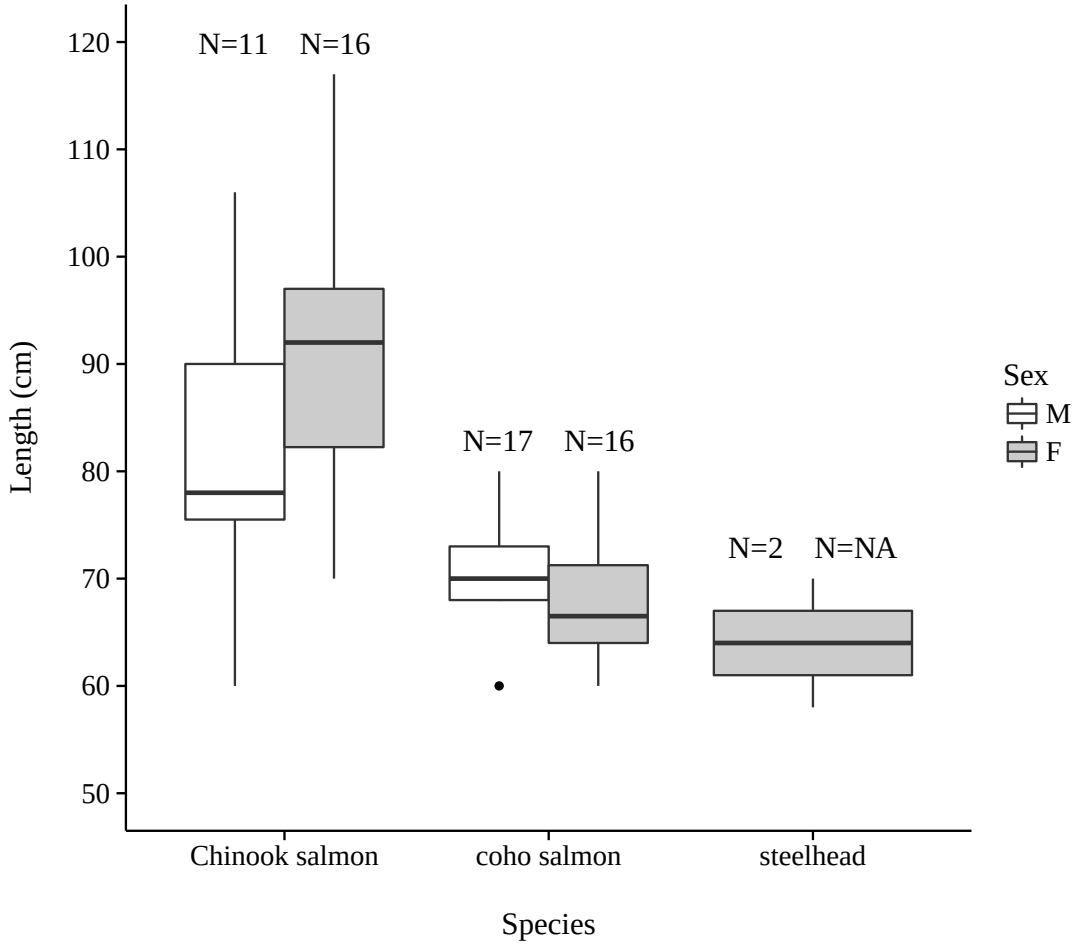


Figure 4: Box and whisker plots for lengths of carcasses by species and sex.

Female to male sex ratios calculated from both live fish observations were found to be 1:1.09, 1:0.96, and 1:1.14 for Chinook salmon, coho salmon and steelhead respectively. Descriptive statistics of occular estimates of live fish fork length are displayed in Table 4. Fork lengths of measured carcasses are displayed in Figure 4.

Table 4: Descriptive statistics of occular estimates of fish length for target species by reach.

CommonName	Sex	Mean	Median	Min	Max	SD	N
Chinook salmon	F	81	80	45	120	11	116
Chinook salmon	M	76	80	30	150	20	126
Chinook salmon	U	81	82	20	120	19	34
coho salmon	F	65	65	50	80	6	83
coho salmon	M	63	65	30	80	10	80
coho salmon	U	67	70	60	70	4	5
steelhead	F	58	60	50	65	4	7
steelhead	M	59	64	37	75	14	8
steelhead	U	59	60	50	68	5	13
unidentified species	F	66	70	60	70	5	5
unidentified species	M	55	55	50	60	7	2
unidentified species	U	62	65	30	90	19	12

Redd Observations

Field surveyors were able to identify 129 of the total 697 redds observed. Of the 568 redds where a kNN prediction of species was made, 5 used the julian date attribute only. The other 563 predictions were made using UTME, UTMN and julian date attributes. Cross validation using the known species as the test set, indicated the kNN classifier was 90.3% accurate at predicting redds to species.

Peak observations of newly constructed redds occurred during the week of 01/09/2012, when 119 anadromous salmonid redds were observed (Table 5, Figure 5).

Table 5: Counts of redd observations for target species by calendar week.

Week Beginning	Chinook	coho	steelhead	unidentified	Total
2011-10-31	0	0	0	2	2
2011-11-07	0	0	0	5	5
2011-11-14	2	1	0	14	17
2011-11-21	3	0	0	3	6
2011-11-28	11	0	0	31	42
2011-12-05	4	0	0	64	68
2011-12-12	1	0	0	3	4
2011-12-19	6	0	0	84	90
2011-12-26	1	0	0	7	8
2012-01-02	16	18	0	66	100
2012-01-09	1	12	0	106	119
2012-01-16	0	0	0	0	0
2012-01-23	1	30	1	41	73
2012-01-30	5	11	2	33	51
2012-02-06	0	1	0	35	36
2012-02-13	0	0	0	59	59
2012-02-20	0	0	1	9	10
2012-02-27	0	0	0	4	4
2012-03-05	0	0	1	0	1
2012-03-12	0	0	0	0	0
2012-03-19	0	0	0	2	2
Total	51	73	5	568	697

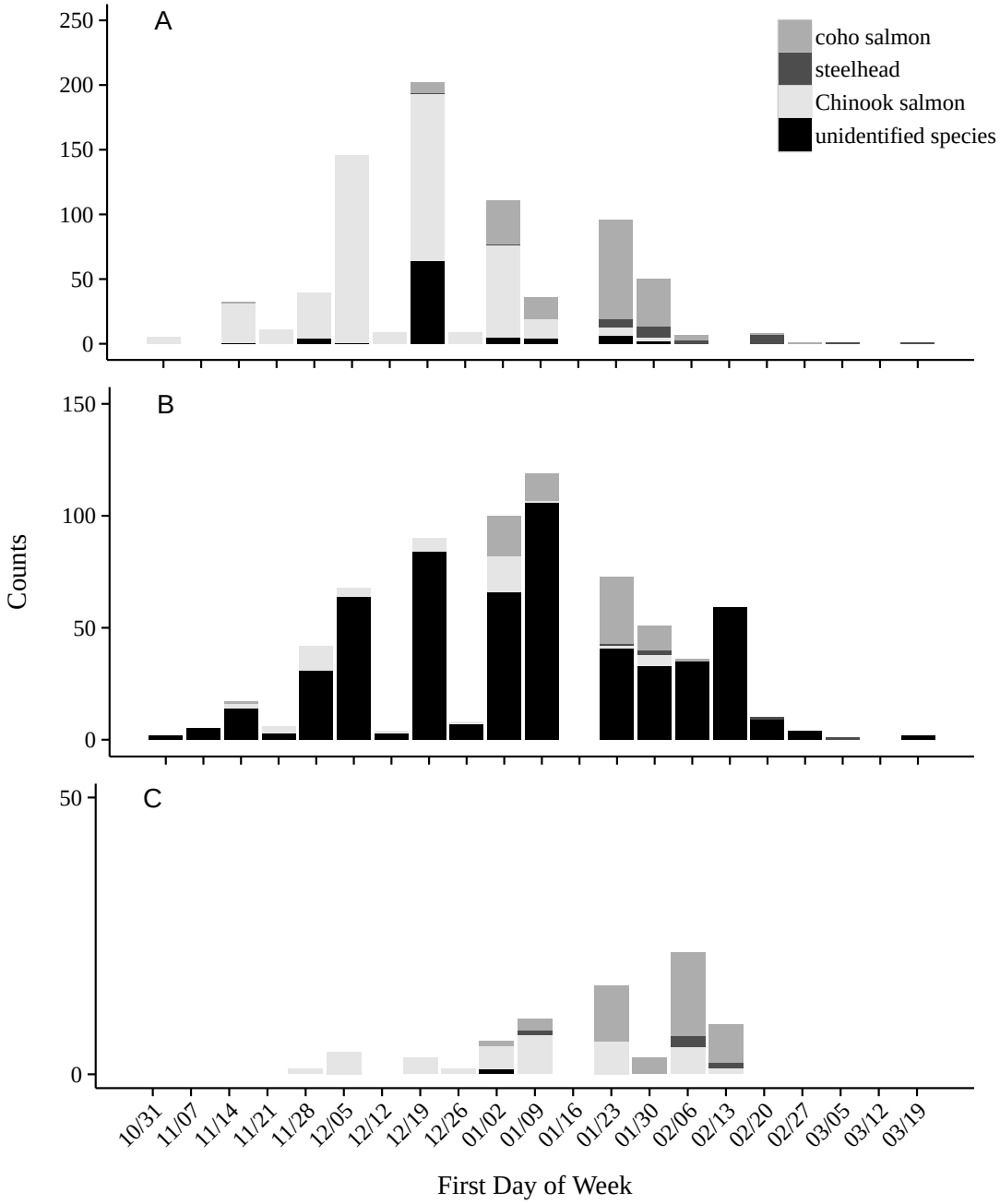


Figure 5: Stacked barplot of live fish (A), individual redd (B), and individual carcass (C) observations by week.

Total Redd Abundance

Total redd abundance estimates of Chinook salmon, coho salmon and steelhead trout for Redwood Creek, in 2011, with 95% confidence intervals, are 837 (277,1397), 501 (171,832), and 48, and (22,74), respectively (Table 6). Counts of other anadromous fish redds are listed in Appendix A.

We estimated a total of 105 Chinook salmon, 379 (367,390) coho salmon, and 11 (11,11) steelhead redds for all reaches, both GRTS drawn and non-GRTS drawn, within the spawning distribution of the Prairie CreekLife Cycle Monitoring sub basin (7).

Table 6: Estimated total number of redds by species. Components of estimated variance are broken down into that due to; estimation of the number of redds within the reach, and estimation of redds by expanding the sample reaches to the entire frame (sample error).

	Chinook	coho	steelhead
Redd Est.	837	501	48
SE	257.160	156.671	12.581
Tot Within Reach Var	49.945	9.314	0.000
Tot Between Reach Var	1411.359	501.647	2.890
% Within	3.418	1.823	0.000
% Between	96.582	98.177	100.000
95% CI	(277,1397)	(171,832)	(22,74)

Table 7: Estimated total number of redds by species within the Life Cycle Monitoring Station where all reaches were survyed in addition to the GRTS sample reaches.

	Chinook	coho	steelhead
Redd Est.	105	379	11
SE	3.886	5.824	0.000
Tot Within Reach Var	15.102	33.919	0.000
Tot Between Reach Var	0	0	0
% Within	100	100	100
% Between	0	0	0
95% CI	(97,113)	(367,390)	(11,11)

4 DISCUSSION

The primary objective of the regional spawning survey component of the Coastal Monitoring Program is to estimate annual status, and thence population trajectory or trend from a time series of status estimates. The CMP implements spawning ground surveys using the number of redds as the population metric from which adult abundance is derived (Adams et al. 2011). Redd counts however, can represent only a fraction of the true number of redds deposited. The fraction of the true number of redds that the counts represent is likely a function of the frequency and magnitude of annual stream discharge which governs both the recruitment of new fish and subsequent redd deposition (Goin 2010), and the redd survival process (Jones 2012). If annual counts are a fraction of the total, and this fraction is both unknown and variable between years, the estimation of status will remain unknown and the analysis of trend may be of limited value.

In general, the relationship between counts (C) and total (N) when detection is imperfect is $N = C/p$ where p is probability of detection. In the context of redd counting during repeated spawning ground surveys, the population of redds can be considered 'open' over the course of a single spawning season (i.e. both new redds are constructed and existing redds obscured). Field observers record redds that; 1) remain visible between survey occasions (survive), and 2) redds theythey observe given they are still visible (detection). The estimation of p in the general case would then be the product of these two separately estimated parameters (Hankin, unpublished). The field protocol of Gallagher et al. (2007), however, does not allow for the direct estimation of detection probability of new, unflagged redds without invoking the assumption that observers locate the flags used to mark redds with the same probability as new unflagged redds (Gallagher et al. 2005). The protocol does, however, allow for the estimation of redd survival, given the re-observation of flagged redds, and the determination of whether the flagged redd is still visible. We have employed an estimator for population total described by Schwarz et al. (1993) to expand the number of new redds seen by the survival of flagged redds between successive surveys to account for redds that entered the population and were obscured between surveys, invoking an alternative assumption that the detection probability of new redds at all survey occasions is 1.

Critical assumptions invoked by our implementation of the Schwarz et al.(1993) estimator include the equality of survival of individual redds. The pooling of all periods implemented here is necessary in most sample reaches, because the relative small number of redds marked and recaptured, lead to estimator failure. As a result of the pooling process, individual redds that persist over more than one occasion having a high survival probability relative to other redds are included again as marked at the next occasion, and so on. If this assumption of equal suvival of individual redds is violated the bias tends to results in inflated estimates of total (Schwarz et al. 1993), and the pooling of strata may increase the bias. More importantly, we feel the Complete pooling of all strata also requires invoking the more restrictive assumption that survival probabilities are constant over the course of the entire season. This is most likely not the case in most seasons, as redd survival is largely a function of stream discharge that can fluctuate

quite dramatically over the spawning period. More unsettling, is that the directionality of this bias is unknown, and one could conceive of conditions in which this bias both inflates or deflates the estimate of total. The protocol of Gallagher et al. (2007) does not allow for the collection of the data required to construct a recruitment model. Instead we assume that redds were recruited instantaneously at the mid-point between surveys. In the completely pooled case this assumption is analogous to all redds being deposited at the mid-point of the season where the season begins at the second survey occasion where redds were observed through the last. Alternative choices can be made regarding the assumed recruitment pattern (Schwarz et al. 1993), but we feel the assumption of recruitment occurring at the mid-point of the season best captures the concept of there being a peak of redd deposition near or at the middle of the spawning period. We also make the explicit assumption that the detection of new redds is perfect. While this assumption is unlikely to be strictly met, both independant double observer trials (Jones 2012), and double dependant observer trials (Ricker 2011) indicate the probabiltiy of detection is high enough to cause little downward bias in the resulting estimates.

As with any model, assumptions must be made regarding the necessary conditions for the estimator to remain unbiased. The responsibility of both the analyst and the consumer of the information is to assess whether the assumptions being made are reasonable and more importantly if not, how unacceptable is the uncertainty or bias that is introduced. This should be a continued area of research for the within reach redd abundance model presented here.

As the CMP spawning ground survey is implemented across new areas in Northern California and extended to multiple species spawning distribution, new challenges will be presented. One of the major considerations in a programmatic approach to data collection, analysis, and multi-spatial scale inference is that the scientific community is fully aware of the analytical processes, and are able to build upon past work as techniques and protocols are improved, or new ideas introduced. We feel that fully documenting the analysis procedures used, and applying them consistently across both time and space is imperative to the success of the CMP. This document is intended to provide a platform for this scientific transparency and consistency. To that end, the files used to generate this report can be downloaded at: http//CMPASP.info/ navigating to 'Download Files' then 'Tools and Utilities' and finally 'CMP Analysis'.

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7 APPENDIX A

Location Code	cutthroat	Total
24	0	0
28	0	0
33	0	0
37	0	0
39	0	0
43	0	0
51	0	0
52	0	0
70	0	0
71	0	0
72	6	6
73	3	3
74	2	2
81	0	0
84	0	0
85	2	2
88	0	0
91	0	0
103	0	0
104	0	0
108	0	0
111	4	4
114	0	0
115	0	0
119	1	1
159	0	0
272	0	0
Total	18	18

Table 8: Counts of live fish observations for all non-target species by reach

Week Beginning	cutthroat	Total
2011-10-31	0	0
2011-11-07	0	0
2011-11-14	0	0
2011-11-21	0	0
2011-11-28	0	0
2011-12-05	0	0
2011-12-12	9	9
2011-12-19	0	0
2011-12-26	0	0
2012-01-02	4	4
2012-01-09	2	2
2012-01-16	0	0
2012-01-23	2	2
2012-01-30	0	0
2012-02-06	0	0
2012-02-13	1	1
2012-02-20	0	0
2012-02-27	0	0
2012-03-05	0	0
2012-03-12	0	0
2012-03-19	0	0
Total	18	18

Table 9: Counts of live fish observations for all non-target species by calendar week