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Coastal Salmonid Monitoring Program Annual Report:

Results of regional spawning ground surveys and estimates of total salmonid redd construction in the Redwood Creek, Humboldt County California, 2013.

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Abstract

A total of 161 salmonid spawning ground surveys were conducted in 27 randomly sampled stream reaches throughout the Redwood Creek basin between 11/11/2013 and 04/16/2014. Individual stream reaches were surveyed an average of 6 times over the study period with an average return interval of 23 days between surveys. Field staff observed 721 coho salmon, 1021 Chinook salmon, 70 steelhead trout and 285 unidentified live fish over the survey period. A total of 74 coho salmon, 232 Chinook salmon and 37 unknown individual salmonid carcasses were found. Field surveyors were able to assign species to 305 of the total 1388 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 963 Chinook salmon, 705 coho salmon, and 82 steelhead. The spawning ground survey did not encompass the entirety of the spawning period or space for steelhead or Chinook in the Redwood Creek, and therefore the steelhead and Chinook redd abundance estimates herein should be considered to represent only the time period and area encompassed by the study. We estimated a total of 538 coho salmon, 151 Chinook salmon, 57 and steelhead redds for all reaches within the Prairie Creek Life Cycle Monitoring sub basin.[1]

[1]Compiled 2014-06-27 12:09:56

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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 Coast (SONCC) Evolutionarily 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 a 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 on 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 (SGS) 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. SGS surveys are applied to a sample of stream reaches, and the number of redds within the sampled reaches are then used to estimate the total number of redds within the sample frame (e.g. population or other demographic unit). Stream reaches are thus defined as the primary sampling units (PSU), for which redd counts per reach are obtained. Two steps are then required to expand redd counts within sampled reaches to the total redd escapement estimated for the entire sample frame: 1) redd counts within each PSU must be used to estimate the total number of redds within that PSU, and 2) estimates of total redd escapement from all PSUs sampled in a given year must be used to estimate the total redd escapement for the entire sample frame.

The science of monitoring the population size of biologic organisms over space and time 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 balanced, design-based sampling scheme, a consistent data collection protocol, and a single database 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 the 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 methods, results, and conclusions drawn from analyses 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 database, program R statistical software for analysis and graphics production (R Core Team 2013), and TEX as a document preparation system and markup language for the 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 standardized and timely reporting structure.

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 River, Humboldt County, California during the 2013 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 coho salmon spawning stream reaches within Redwood Creek, Humboldt County, California. (Figures 1-3).

Figure 1: Map of the Prairie Creek portion of the Redwood Creek sample frame. Sample frame reaches are indicated with alternating colors, and Location Code numbers are presented as table references.

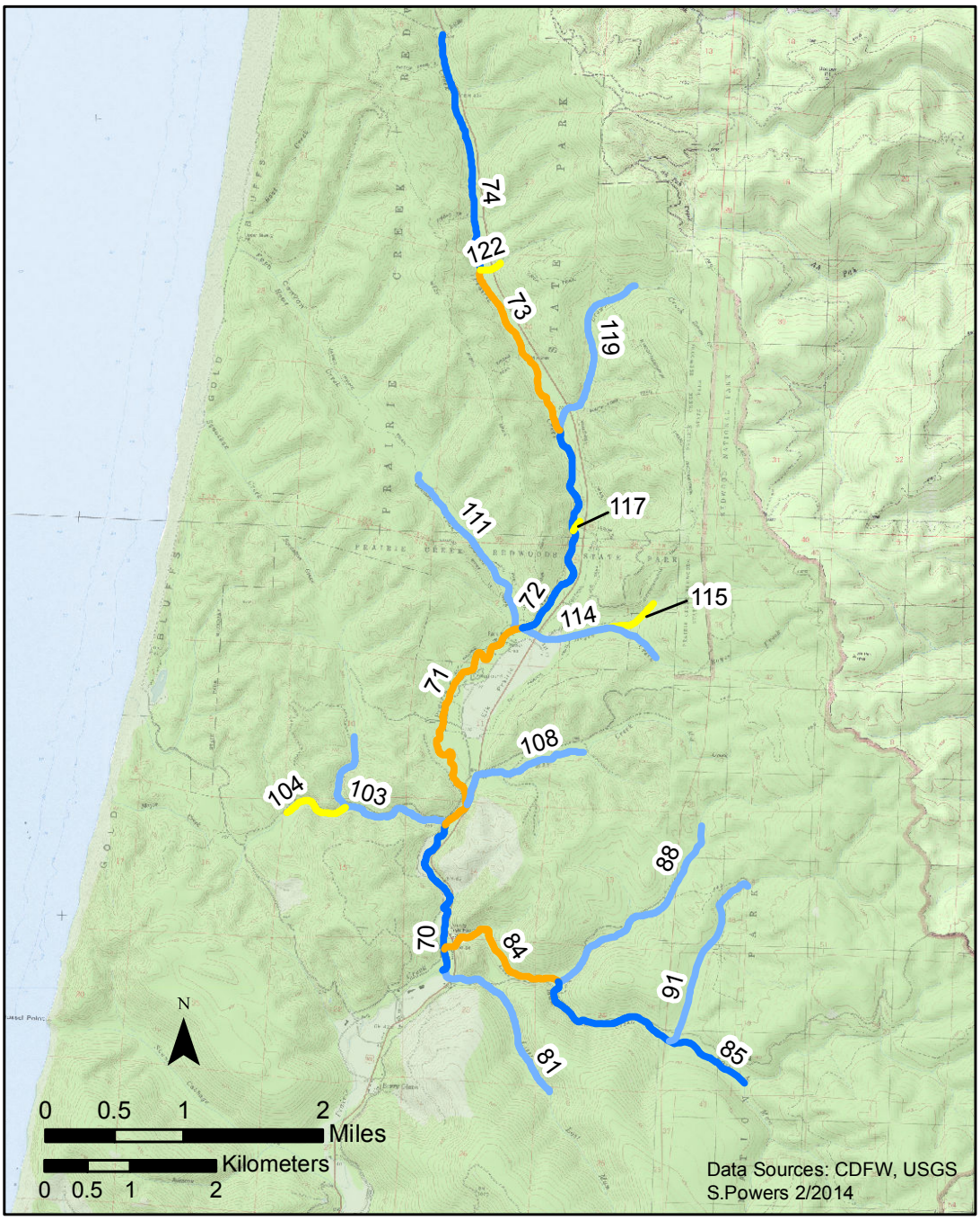


Figure 2: Map of the lower portion of the Redwood Creek sample frame. Sample frame reaches are indicated with alternating colors, and Location Code numbers are presented as table references.

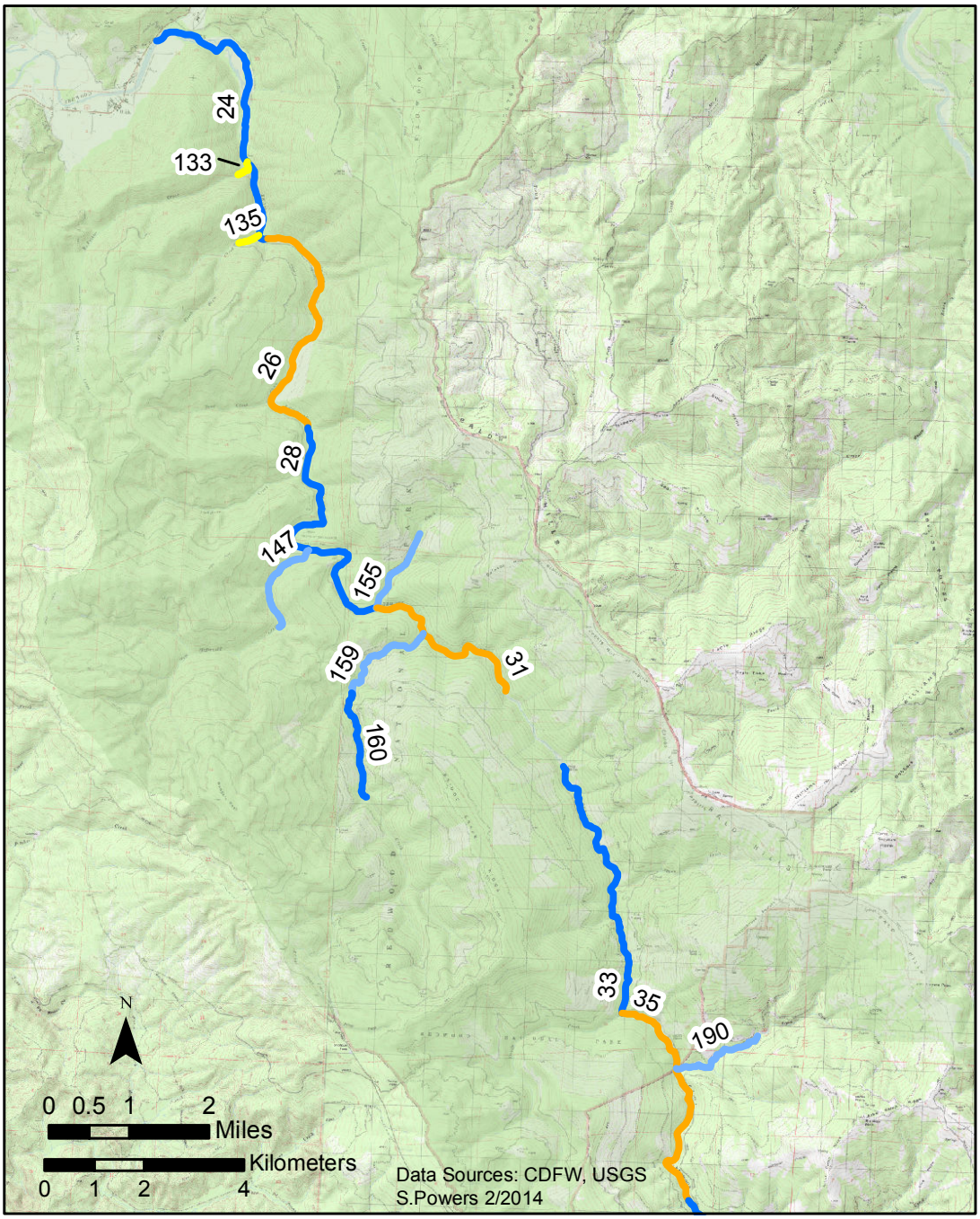
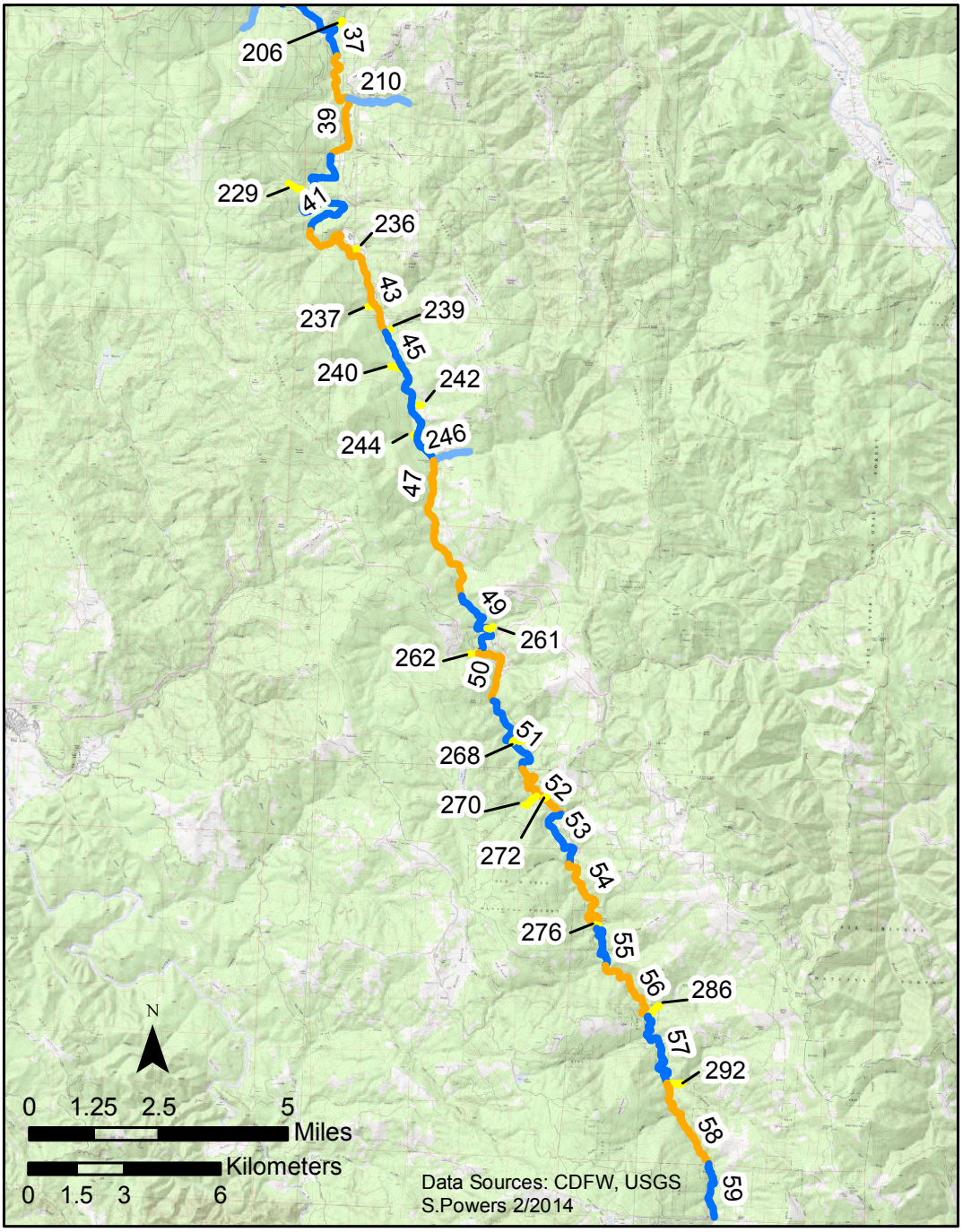


Figure 3: Map of the upper portion of the Redwood Creek sample frame. Sample frame reaches are indicated with alternating colors, and Location Code numbers are presented as table references.



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).

Streams within the sample frame were segmented into one to three kilometer sample reaches with start and end points established at reliable on the ground land marks (e.g. stream confluences, bridge, etc.), and upstream extents established at barriers or model derived limits to species anadromy. Reach start and end points were flagged, and GPS coordinates were taken. All reaches within the sample frame were assigned numeric reach ID's (Location Code). The assignment of reach 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 its end. This sequence of ordering continued through the dendritic pattern of the watershed. In this way, the frame was recursively sorted, from watershed to main-stem to tributaries, resulting in 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).

Reaches that were less than 1000 meters in length were surveyed along with the main reaches to which they flowed into (Garwood and Ricker 2011), and redd data from these reaches were combined with the redds of the associated main reach.

Sample Reach Selection

Starting with the spatially ordered sampling frame constructed as described above, a General Randomized Tessellation Stratified (GRTS) routine (McDonald 2003) was used to produce a spatially balanced and randomized reordering of the sampling frame. The first 19 reaches in this reordered list of all 41 coho salmon sample frame reaches were selected for surveying in the 2013 spawning season. Because the spatial extent of Chinook salmon and steelhead trout spawning habitat may be greater than or less than the spatial extent of the coho salmon sampling frame, estimates of total redd construction for Chinook salmon and steelhead trout presented herein are therefore constrained to those occurring within the coho salmon sampling frame only.

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 conditions 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 and sex when 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. Lengths of live fish were visually estimated when possible.

Redds were identified to species when fish were observed either digging or actively guarding the redd, and the fish could be positively identified to species. If no species could be assigned by the field staff, the redd was recorded as unidentified 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 were 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 multivariate 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. Euclidean distance (d_{ij}), between redds x_i and x_j, was calculated as:

$$d_{ij} = \sum_{l=1}^{n} \sqrt{(x_{il} - x_{jl})^2} \tag{1}$$

where:

l = redd attributes (UTME, UTMN, JDate), and

$n = 3$ when all three attributes are used and $n = 1$ when only JDate is used.

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:

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

where x_i is the ith observed value of a redd attribute x, and μ and σ are the mean and standard deviation of all observed values of x, respectively.

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 to produce 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. Due to drought conditions, the timing and location of spawning was judged drastically different enough that only the current year's known redds were used as the training data for the kNN classifier.

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 is re-fit to the remaining data, and the removed redd is predicted to species. Redds of known species are then paired with the LOOCV predictions to evaluate model performance. Overall model accuracy is assessed as the percentage of the total number of predictions that were correct. All nearest neighbor classifications and LOOCV 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 thus becoming no longer visible to field observers, and finally 3) field observations are made of redds that remain visible to the next survey occasion. Both the recruitment and mortality processes operate simultaneously upon the population of redds over time, and survey occasions offer snapshots in time of the results of these two processes throughout the season. 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 using 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 that 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. The estimation of total redd construction within a survey reach can be described as a flag-based open population mark-recapture experiment in which redds are either marked and/or recaptured on each survey occasion, and redds are individually identified and marked with unique redd IDs applied to flagging. The population of redds is considered open because new redds are recruited into the population when they are constructed, and 'die' when they become obscured from view.

Redd survival from survey occasion i - 1 to occasion i, S_i, can be estimated as the proportion of redds that were newly observed and flagged or previously flagged and recaptured on occasion i - 1, M_{i-1}, that are still visible on occasion i, R_i:

$$\hat{S}_i = \frac{R_i}{M_{i-1}} \tag{3}$$

Ideally, total redd construction between each successive survey occasion would be estimated separately, and the sum of these estimates would yield an estimate of total redd construction for the entire survey season. However, when the mark-recapture framework is applied to real survey data, several conditions preclude this ideal scenario. Zero redd survival leads to estimator failure, which can occur when substantial rain events lead to high stream discharge and "mortality" of all redds within a reach (Jones 2012). Also, very low survival between survey occasions results in large expansions of the observed redds, which can be unrealistically high. One way to potentially alleviate these issues is to combine adjacent survey occasions (pooling) to create temporal strata in which survival is sufficiently high to avoid estimator failure and unreasonable expansions. Given real world data, however, there can be no guarantee that pooling would result in temporal strata which would always alleviate these issues. Additionally, the choice of pooling algorithms can give conflicting results, and there is little agreement in the literature for choosing alternative algorithms (Arnason et al. 1996, Bjorkstedt 2000). Consequently, we have chosen to pool all survey occasions to construct a reach and year-specific pooled survival that can be applied to redd counts for estimation of total redd construction within a given reach and year. This pooled survival is defined as follows:

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

where R_i denotes the number of redds recaptured as still visible at occasion i, and M_i

is the sum of newly marked redds and recaptured redds that were still visible 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 and recaptured redds that were still visible, 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. Using this pooled survival to estimate total redd construction from redd counts obtained during survey occasions, we assume that all redds are recruited at the mid-point between survey occasions (Schwarz et al. 1993). To assume such a recruitment model, we divide the sum of newly observed and flagged redds by the square root of survival to estimate the total number of redds within a reach from the second survey occasion to the last (Sykes and Botsford 1986):

$$\hat{\tau}_j = B_0 + \frac{\sum_{i=2}^{k} B_i - 1}{\sqrt{\hat{S}_p}} \tag{5}$$

where $\hat{\tau}_j$ is the estimated total number of redds within a sample reach j; B_i is the number of new redds on the ith survey occasion; k is the total number of survey occasions; and B_0 is the number of redds observed on the 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.

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

1. Field surveyors correctly identify all redds as redds, and no redds are missed during each survey occasion.

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

3. All redd flags are seen, individually identifiable, and recorded properly,

4. All flagged redds survive with the same probability, regardless of species (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).

5. Recruitment of new redds occurs at the mid-point of the interval between survey occasions, starting with the second survey during which redds are observed.

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 (Adams et al. 2011):

$$\hat{T} = N\left(\frac{\sum_{j=1}^{n} \hat{\tau}_j}{n}\right) \tag{6}$$

where N is the total number of reaches within the sample frame, n is the number of reaches in the sample, and $\hat{\tau}_j$ is the estimated total number of redds in sample reach j from equation (5). The standard error of $\hat{T}$ was calculated by partitioning variance into within-reach and between-reach variance components, and applying the finite population correction factor to only the between-reach variance component (Adams et al. 2011):

$$se(\hat{T}) = N\sqrt{\left(1 - \frac{n}{N}\right)\hat{\theta}_b + \frac{1}{Nn}\left(\sum_{i=1}^{n} \hat{\theta}_w\right)} \tag{7}$$

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

Bootstrap resampling was used to estimate both the between-reach variance ($\hat{\theta}_b$) and within-reach variance ($\hat{\theta}_w$) as follows:

1. For a single reach, a simulated number of redds surviving from the first survey occasion to the second from the last survey occasion, R^*, was generated as a binomial random variable with the number of trials equal to the total number of flagged redds observed from the first survey occasion to the second from the last (the denominator in equation (4)), and the probability of success equal to our estimated pooled survival, $\hat{S}_p$ from equation (4). The random variable R^* is analogous to the numerator of equation (4).

2. Simulated survival for the bootstrap iteration, S^*, was then calculated as R^* divided by the sum of flagged redds from the second survey occasion to the last. This is equivalent to calculating $\hat{S}_p$ from equation (4).

3. S^* was then substituted for $\hat{S}_p$ in equation (5) to generate a simulated total number of redds, τ^*.

4. Steps 1-3 were repeated for each of 2000 bootstrap replicates for each reach within the GRTS sample.

5. If any of the 2000 S^* estimates from step 2 were zero, counts of individual redds were used in place of τ^* for all 2000 replicates.

6. Within-reach variance, $\hat{\theta}_w$, was defined as the variance of the 2000 simulated τ^* for each reach.

7. For each sampled reach, the mean of the 2000 simulated τ^*s, $\bar{\tau}^*$, was calculated.

8. Between reach variance, $\hat{\theta}_b$, was defined as the variance of all $\bar{\tau}^*$ calculated in step 7.

These bootstrap estimates of within-reach and between-reach variances were then used to estimate the standard error for our estimate of total redd construction within the sample frame, se($\hat{T}$), using equation (7). 95 % confidence intervals were then constructed as:

$$\hat{T} \pm t_{(1-\alpha/2,df)} * se(\hat{T}) \tag{8}$$

3 RESULTS

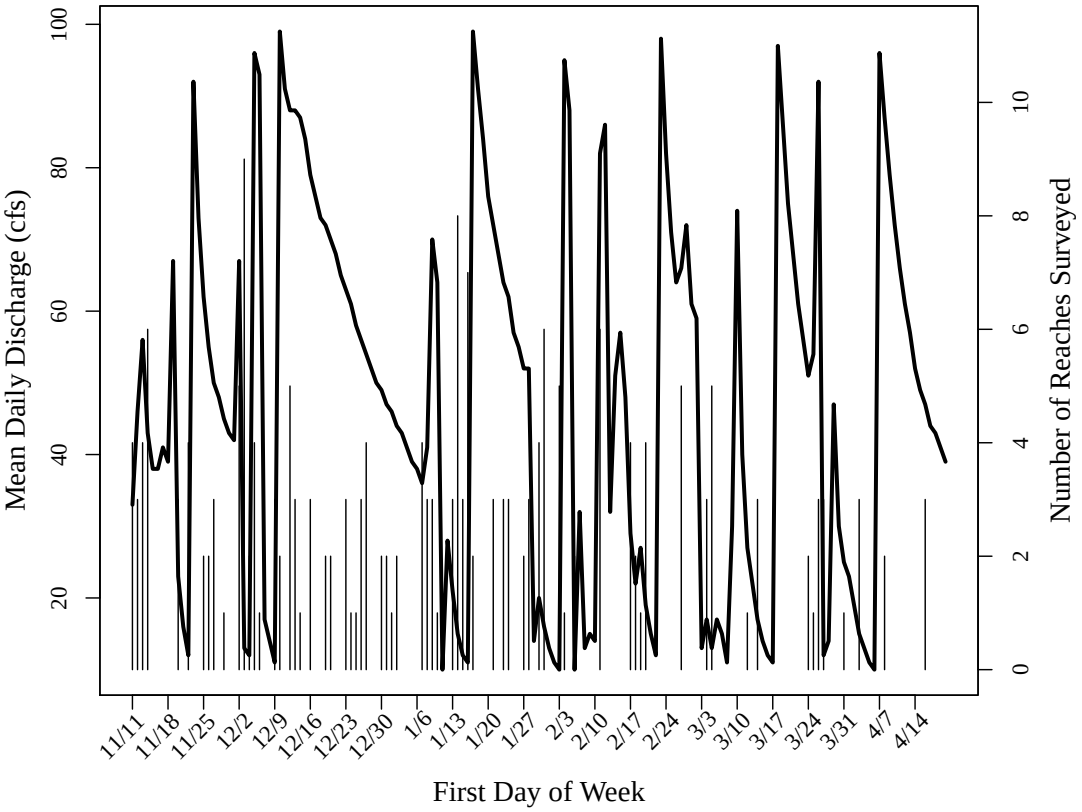
A total of 161 salmonid spawning ground surveys were conducted in 27 randomly sampled stream reaches throughout the Redwood Creek River basin between 11/11/2013 and 04/16/2014. The average interval between surveys over all reaches (mean of means) was 23 days (Table 1).

The stream discharge gauge for Redwood Creek near Orick, CA was used as a proxy for the discharge pattern exhibited in the sample reaches of the Redwood Creek basin. A maximum proxy gauge discharge at which conditions were acceptable for surveys to occur was evaluated for each of the 27 sample reaches and varied from 19 to 99 cubic feet per second discharge at the proxy gauge (Table 1). Figure 4 depicts the pattern of stream discharge at the the Redwood Creek near Orick, CA gauging station relative to the number and timing of surveys that occurred over the season.

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

Location Code	Stream Name	Mean	SD	Max	N	MaxFlow
28	Redwood Creek	19	24	79	9	96
33	Redwood Creek	42		42	2	96
35	Redwood Creek	42		42	2	99
37	Redwood Creek	10	3	15	7	99
41	Redwood Creek	13	4	19	6	99
45	Redwood Creek	14	3	19	6	99
53	Redwood Creek				0	
54	Redwood Creek				0	
70	Prairie Creek	16	16	56	9	88
71	Prairie Creek	15	10	43	10	92
72	Prairie Creek	10	5	22	12	96
73	Prairie Creek	11	3	17	11	82
74	Prairie Creek	11	3	16	6	82
81	Little Lost Man Creek	23	13	39	6	95
84	Lost Man Creek	14	9	35	11	88
85	Lost Man Creek	16	8	27	9	92
88	Larry Dam Creek	17	9	35	8	66
91	Lost Man Trib-U	38	22	62	4	19
103	Streelow Creek	14	4	22	9	88
108	May Creek	30	16	45	5	29
111	Godwood Creek	14	3	19	9	88
114	Boyes Creek	21	11	40	7	87
119	Brown Creek	28	12	44	5	92
147	Tom McDonald Creek	65	7	71	3	64
155	Harry Weir Creek			0	1	64
159	Bridge Creek	43	27	60	4	64
246	Minor Creek				0	

Figure 4: Time series of mean daily stream discharge at the nearest USGS gauging station, the Redwood Creek near Orick, CA (Left Y axis), and the number of surveys that were conducted on each day of the survey period (Right Y axis).



Fish Observations

Field staff observed 721 coho salmon, 1021 Chinook salmon, 70 steelhead trout and 285 unidentified live fish over the survey period. Total discoveries of 74 coho salmon, 232 Chinook salmon and 37 unidentifiable individual salmonid carcasses were made (Table 3). Peak counts of live fish occurred the week of 01/27/2014 followed by the peak in new carcass discoveries the week of 01/27/2014 (Figure 6).

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

Week Beginning	Chinook	coho	steelhead	unidentified	Total
2013-11-11	100	0	4	16	120
2013-11-18	8	1	0	3	12
2013-11-25	55	0	0	0	55
2013-12-02	57	2	0	21	80
2013-12-09	62	0	0	38	100
2013-12-16	38	0	0	18	56
2013-12-23	80	93	0	24	197
2013-12-30	131	0	0	36	167
2014-01-06	158	16	0	14	188
2014-01-13	86	187	0	20	293
2014-01-20	79	7	7	31	124
2014-01-27	155	256	0	56	467
2014-02-03	8	22	0	0	30
2014-02-10	4	91	0	5	100
2014-02-17	0	41	13	1	55
2014-02-24	0	3	15	0	18
2014-03-03	0	1	6	1	8
2014-03-10	0	0	8	1	9
2014-03-17	0	0	0	0	0
2014-03-24	0	1	9	0	10
2014-03-31	0	0	4	0	4
2014-04-07	0	0	0	0	0
2014-04-14	0	0	4	0	4
Total	1021	721	70	285	2097

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

Week Beginning	Chinook	coho	unidentified	Total
2013-11-11	0	0	0	0
2013-11-18	0	0	0	0
2013-11-25	0	0	0	0
2013-12-02	3	0	0	3
2013-12-09	7	0	0	7
2013-12-16	9	0	0	9
2013-12-23	17	1	0	18
2013-12-30	52	1	3	56
2014-01-06	11	2	10	23
2014-01-13	17	6	1	24
2014-01-20	10	2	3	15
2014-01-27	100	14	4	118
2014-02-03	4	4	0	8
2014-02-10	2	11	3	16
2014-02-17	0	12	1	13
2014-02-24	0	10	0	10
2014-03-03	0	10	10	20
2014-03-10	0	1	1	2
2014-03-17	0	0	0	0
2014-03-24	0	0	1	1
2014-03-31	0	0	0	0
2014-04-07	0	0	0	0
2014-04-14	0	0	0	0
Total	232	74	37	343

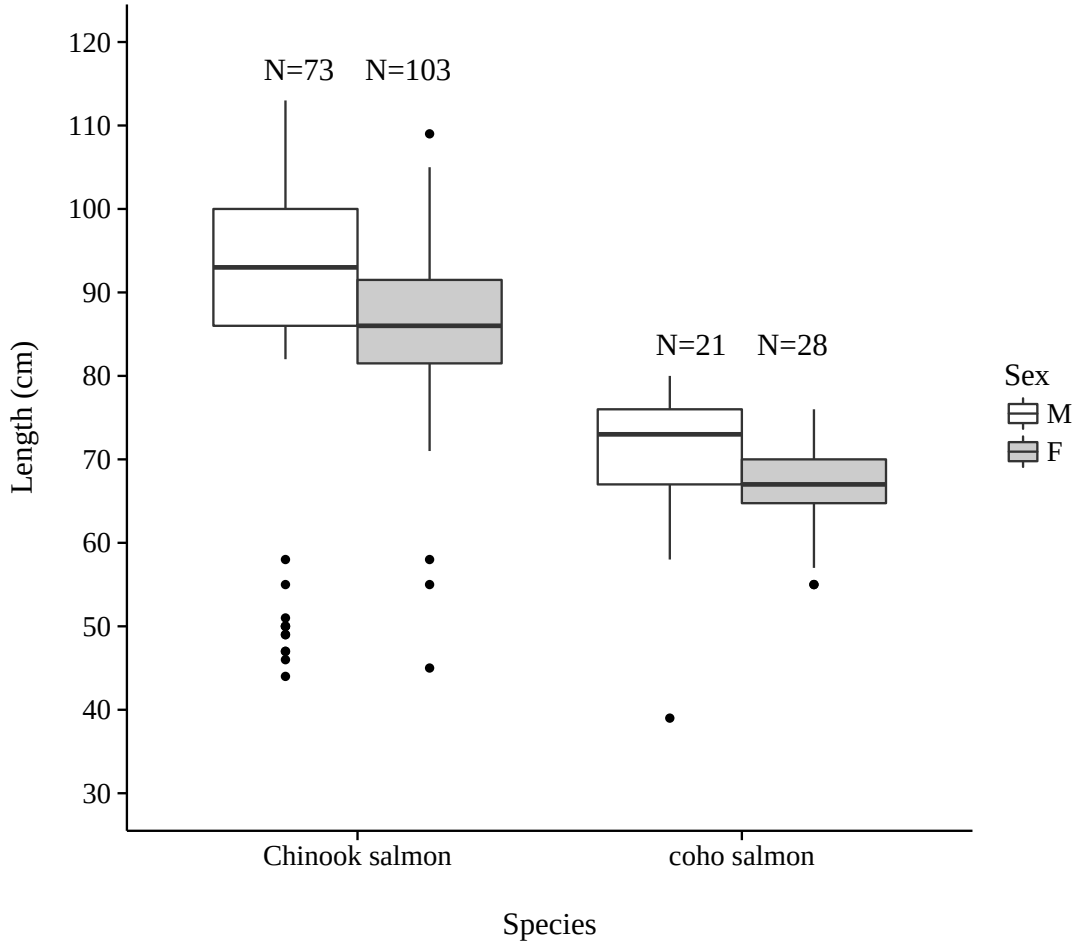


Figure 5: Box and whisker plots for lengths of carcasses by species and sex.

Female to male sex ratios calculated from both live fish observations were found to be 1:0.81, 1:0.93, and 1:1.5 for Chinook salmon, coho salmon and steelhead respectively. Descriptive statistics of ocular estimates of live fish fork length are displayed in Table 4. Fork lengths of measured carcasses are displayed in Figure 5.

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	84	85	40	100	8	185
Chinook salmon	M	86	90	30	110	14	150
Chinook salmon	U	83	85	45	100	14	53
coho salmon	F	64	65	40	90	8	201
coho salmon	M	67	70	15	90	10	186
coho salmon	U	61	60	40	80	10	27
steelhead	F	67	67	60	75	5	10
steelhead	M	65	65	50	75	6	15
steelhead	U	63	65	45	72	7	26
unidentified species	F	76	80	45	100	14	17
unidentified species	M	48	45	40	60	10	3
unidentified species	U	53	50	20	80	16	35

Redd Observations

Field surveyors were able to identify 305 of the total 1388 redds observed to the species having made them. Of the 1083 redds where a kNN prediction of species was made, 0 used the julian date attribute only. The other 1083 predictions were made using UTME, UTMN and julian date attributes. The number of known species species compared to the cooresponding LOOCV prediction is displayed in confusion matrix format in Table 5. The sum of number of correctly classified redds along the diagonal divided by all known redds indicateds that overall the kNN classifier was 93.8% accurate at predicting the species likely to have constructed them. The model predictions improves upon the 52.1% that would have been correctly classified by chance given only the proportion of known species redds observed.

Table 5: Confusion matrix of the known species redds indexed by columns crossed with the LOOCV predictions indexed by rows.

	Chinook salmon	coho salmon	steelhead
Chinook salmon	128	4	0
coho salmon	7	152	5
steelhead	0	3	6

Peak observations of newly constructed redds occurred during the week of 01/27/2014, when 201 anadromous salmonid redds were observed (Table 6, Figure 6).

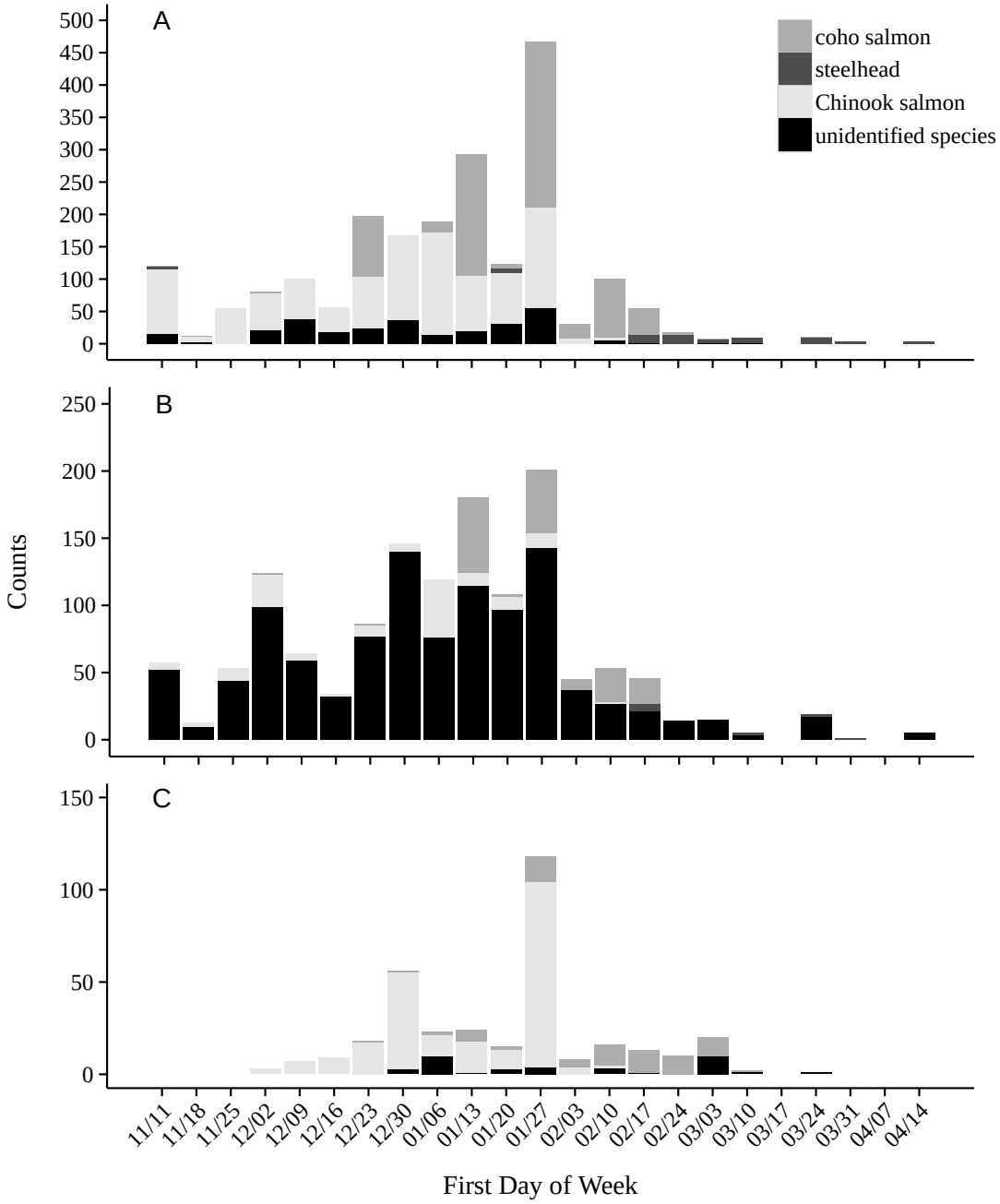


Figure 6: Stacked barplot of live fish (A), individual redd (B), and individual carcass (C) observations by week.

Table 6: Counts of redd observations for target species by calendar week.

Week Beginning	Chinook	coho	steelhead	unidentified	Total
2013-11-11	5	0	0	52	57
2013-11-18	3	0	0	10	13
2013-11-25	9	0	0	44	53
2013-12-02	24	1	0	99	124
2013-12-09	5	0	0	59	64
2013-12-16	2	0	0	32	34
2013-12-23	8	1	0	77	86
2013-12-30	6	0	0	140	146
2014-01-06	43	0	0	76	119
2014-01-13	9	56	0	115	180
2014-01-20	9	2	0	97	108
2014-01-27	11	47	0	143	201
2014-02-03	0	8	0	37	45
2014-02-10	1	25	0	27	53
2014-02-17	0	19	6	21	46
2014-02-24	0	0	0	14	14
2014-03-03	0	0	0	15	15
2014-03-10	0	0	2	3	5
2014-03-17	0	0	0	0	0
2014-03-24	0	0	2	17	19
2014-03-31	0	0	1	0	1
2014-04-07	0	0	0	0	0
2014-04-14	0	0	0	5	5
Total	135	159	11	1083	1388

Location Code	Chinook	coho	steelhead	unidentified	Total
24	15	0	0	162	177
26	5	0	0	68	73
28	28	0	0	162	190
31	49	0	0	94	143
33	2	0	0	27	29
35	8	0	0	25	33
37	1	0	0	53	54
41	7	0	0	33	40
45	1	0	0	17	18
70	5	1	2	79	87
71	10	32	0	70	112
72	0	34	1	69	104
73	0	22	1	19	42
74	0	6	0	7	13
81	0	3	2	21	26
84	3	5	1	33	42
85	0	3	0	31	34
88	0	3	0	3	6
91	0	2	1	4	7
103	0	4	0	17	21
104	1	3	0	7	11
108	0	15	0	8	23
111	0	15	0	16	31
114	0	8	0	12	20
115	0	0	0	2	2
117	0	0	0	1	1
119	0	1	3	1	5
133	0	1	0	8	9
135	0	1	0	5	6
147	0	0	0	21	21
159	0	0	0	8	8
Total	135	159	11	1083	1388

Table 7: Counts of unique salmonid redds observed by survey reach. Location Codes correspond to labeled reaches in Figure 1.

Total Redd Abundance

Total redd abundance estimates of Chinook salmon, coho salmon and steelhead trout for Redwood Creek River in 2013, with 95% confidence intervals, were 963 (320,1606), 705 (217,1192), and 82 (36,128), respectively (Table 8). Counts of other anadromous fish redds are listed in Appendix A.

Table 8: Estimated total number of redds by species, with standard errors (SE) and 95 percent confidence intervals. Components of estimated variance are broken down into that due to: (1) within-reach variance, or estimation of the number of redds within the reach, and (2) between-reach variance (sampling error), or estimation of total redds in the entire frame by expansion from the sample reaches.

	Chinook	coho	steelhead
Redd Est.	963	705	82
SE	301.545	231.822	21.931
Tot Within Reach Var	5.714	25.733	0.000
Tot Between Reach Var	2593.011	1130.854	10.131
% Within	0.220	2.225	0.000
% Between	99.780	97.775	100.000
95% CI	(320,1606)	(217,1192)	(36,128)

Table 9: 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.	151	538	57
SE	1.617	10.159	0.444
Tot Within Reach Var	2.616	103.207	0.197
Tot Between Reach Var	0	0	0
% Within	100	100	100
% Between	0	0	0
95% CI	(147,154)	(517,560)	(56,58)

4 DISCUSSION

The primary objective of the regional spawning ground 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. new redds are constructed and existing redds are obscured). Field observers record redds that: 1) remain visible between survey occasions (some function of recruitment and survival), and 2) redds that they observe, assuming they are still visible (observation probability). 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 observation probability of new unflagged redds, without invoking the assumption that observers locate the flags used to mark redds with the same probability as observers locate 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 observed that uses the survival of flagged redds between successive surveys to account for redds that entered the population and were obscured between surveys, and an assumed recruitment model. This requires us to invoke the assumption that the observation probability of new redds at all survey occasions is 1.

Another critical assumption invoked by our implementation of the Schwarz et al.(1993) estimator is that all redds survive with equal probability within a reach. The pooling of all periods implemented here is necessary in most sample reaches because the relatively small number of redds marked and recaptured leads 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 survival of individual redds is violated the bias tends to result in inflated estimates of total (Schwarz et al. 1993), and the pooling of strata may increase the bias. More importantly, we feel that 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 which 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. 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 independent double observer trials (Jones 2012), and double dependent observer trials (Ricker 2011) indicate the probability 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 distributions, 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 be fully aware of the analytical processes and be able to build upon past work as techniques and protocols are improved, or new ideas are 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'.

The sample frame and survey period for this project is focused upon estimating coho redd abundance for the Redwood Creek watershed. The spawning ground survey did not encompass the entirety of the spawning period or space for steelhead or Chinook in Redwood Creek, and therefore the steelhead and Chinook redd abundance estimates herein should be considered to represent only the time period and area encompassed by the study.

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7 APPENDIX A

Location Code	cutthroat	rainbow	Total
24	0	0	0
26	0	0	0
28	0	0	0
31	0	0	0
33	0	0	0
35	0	0	0
37	0	0	0
41	0	0	0
45	0	0	0
70	10	40	50
71	57	0	57
72	4	0	4
73	3	0	3
74	3	0	3
81	2	0	2
84	0	0	0
85	13	0	13
88	2	0	2
91	0	0	0
103	0	0	0
104	0	0	0
108	6	0	6
111	0	0	0
114	5	0	5
119	0	0	0
133	0	0	0
135	0	0	0
147	0	0	0
159	0	0	0
Total	105	40	145

Table 10: Counts of live fish observations for all non-target species by reach

Week Beginning	cutthroat	rainbow	Total
2013-11-11	0	0	0
2013-11-18	0	0	0
2013-11-25	0	0	0
2013-12-02	0	0	0
2013-12-09	5	0	5
2013-12-16	0	0	0
2013-12-23	0	0	0
2013-12-30	0	0	0
2014-01-06	57	40	97
2014-01-13	8	0	8
2014-01-20	0	0	0
2014-01-27	23	0	23
2014-02-03	12	0	12
2014-02-10	0	0	0
2014-02-17	0	0	0
2014-02-24	0	0	0
2014-03-03	0	0	0
2014-03-10	0	0	0
2014-03-17	0	0	0
2014-03-24	0	0	0
2014-03-31	0	0	0
2014-04-07	0	0	0
2014-04-14	0	0	0
Total	105	40	145

Table 11: Counts of live fish observations for all non-target species by calendar week