

How Do We Know How Many Salmon Returned to Spawn? Implementing the California Coastal Salmonid Monitoring Plan in Mendocino County, California

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Abstract

California's coastal salmon and steelhead populations are listed under California and Federal Endangered Species Acts; both require monitoring to provide measures of recovery. Since 2004 the California Department of Fish and Game and NOAA Fisheries have been developing a monitoring plan for California's coastal salmonids (the California Coastal Salmonid Monitoring Plan- CMP). The CMP will monitor the status and trends of salmonids at evolutionarily significant regional scales and provide population level estimates. For the CMP, data to evaluate adult populations are collected using a spatially balanced probabilistic design (e.g., Generalized Random Tesselation Stratified- GRTS). Under this scheme a two-stage approach is used to estimate status. Regional redd surveys (stage 1) are conducted in stream reaches in a GRTS sampling design at a survey level of 15 percent or ≥ 41 reaches, which ever results in fewer reaches, of available habitat each year. Spawner: redd ratios are derived from smaller scale census watersheds (stage 2) where "true" escapement is estimated using capture-recapture methods. These are used to estimate regional escapement from expanded redd counts. In 2008 and 2009 we applied the results of our previous studies to estimate salmonid escapement for the Mendocino coast region, the first implementation of the CMP in the state. Here we present the results of the first 3 years of this monitoring effort and discuss our findings in context of expanding the CMP to all of coastal California. We discuss sample frame development, sample size, and present escapement data for six independent and eight potentially independent populations and two Diversity Strata within the Central California Coho Salmon Evolutionarily Significant Unit.

Key words: coho salmon, population monitoring, spawning surveys, status, trends

Introduction

Recovery of salmon and steelhead listed under the Federal and California Endangered Species Acts primarily depends on increasing the abundance of adults returning to spawn (Good et al. 2005), and monitoring the trend in spawner escapement is the primary measure of recovery. In California watersheds north of Monterey Bay, Chinook (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), and steelhead (*O. mykiss*) are listed species. Delisting will depend on whether important populations have reached abundance thresholds (Spence et al. 2008).

In 2005, the California Department of Fish and Game (CDFG) and NOAA

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Fisheries published an action plan for monitoring California's coastal salmonids (Boydstun and McDonald 2005). This plan outlines a strategy to monitor salmonid populations' status and trends at evolutionarily significant regional spatial scales and provide population level estimates. The monitoring is similar to the adult component of the Oregon Plan, where data to evaluate regional populations' are collected in a spatially explicit rotating panel design. Crawford and Rumsey (2009) and the Salmon Monitoring Advisor (<https://salmonmonitoringadvisor.org/>) recommend a spawner abundance sampling design using a spatially balanced probabilistic approach (e.g., Generalized Random Tessellation Stratified -GRTS, Larsen et al. 2008). Similarly, Adams et al. (2010) propose a two-stage approach to estimate regional escapement. Under this scheme, first stage sampling is comprised of extensive regional spawning surveys to estimate escapement based on redd counts, which are collected in stream reaches selected under a GRTS rotating panel design at a survey level of 10 percent of available habitat each year. Second stage sampling consists of escapement estimates from intensively monitored census streams through either total counts of returning adults or capture-recapture studies. The second stage estimates are considered to represent true adult escapement and are used to calibrate first stage estimates of regional adult abundance by associating precise redd counts with true fish abundance (Adams et al. 2010).

The Action Plan was tested and further developed in a 3 year pilot study (Gallagher et al. 2010a, 2010b). This study compared abundance estimates derived from a regional GRTS survey design to abundance measured using a more intensive stratified random monitoring approach, evaluated sample size and statistical power for trend detection, and evaluated the quality of the stage two data for calibrating regional surveys. Gallagher et al. (2010a) recommended that annual spawner:red ratios from intensively monitored watersheds be used to calibrate redd counts for regional monitoring of California's coastal salmonid populations because they were reliable, economical, and less intrusive than tagging, trapping, underwater observation, weirs, and genetics. Converted redd counts were statistically and operationally similar to live fish capture-recapture estimates, but required fewer resources than the other methods they evaluated. Gallagher et al. (2010b) found that redd counts and escapement estimates using annual spawner:red ratios were reliable for regional monitoring using a 10 percent GRTS sample, and that increasing sample size above 15 percent did not significantly improve the estimates. Their evaluation of sample size suggested that a sample size of ≥ 41 reaches or 15 percent, whichever resulted in fewer reaches, would have adequate precision and sufficient statistical power to detect regional trends in salmon populations.

The 10 percent sample size recommended by Boydstun and McDonald (2005) was provided with little justification. Their Mendocino Coast example 10 percent GRTS sample resulted in an annual sample of 203 reaches. This size sample draw would likely result in costly over sampling of more reaches than necessary to encompass intra-reach variance. NOAA (2007) wrote that the issue of sampling intensity for a Coastal Monitoring Plan (CMP) has not yet been resolved.

Beginning in 2008-09 we applied the results of our previous studies to estimate salmonid escapement for the Mendocino coast region. The study's purpose was to 1) provide spawner: redd ratios for calibrating regional redd surveys and, 2) conduct regional spawning surveys in the Mendocino coast region (*fig. 1*) to estimate escapement and assess sample size at this scale. We present the coho salmon results

from the first 3 years of study and discuss our findings in context of the CMP. We discuss sample frame development, sample size, and present escapement data for six independent and eight potentially independent populations and two Diversity Strata (National Marine Fisheries Service 2010) within the Central California Coho Salmon Evolutionarily Significant Unit.

Materials and methods

The three intensively monitored life cycle monitoring streams (LCS) (*fig. 1*) were selected for a variety of reasons. Pudding Creek has a fish ladder where fish can be marked and released and has been operated as a LCS by Campbell Timberlands management since 2006. The South Fork Noyo River has coho salmon data relating to the Noyo Egg Collecting Station, fish can be captured and marked there, and it has been operated as an LCS since 2000. Caspar Creek was chosen because of existing salmon monitoring data. In 2005 we built and operated a floating board resistance weir in Caspar Creek 4.9 km from the Pacific Ocean.

The Mendocino coast region extends from Usal Creek to Schooner Gulch (*fig. 1*). We followed Boydston and McDonald (2005) to define the sampling universe, to create a sample frame (the sample universe broken into sampling units), and to produce a GRTS draw (the spatially balanced random sample). We defined the sampling universe as all coho spawning habitat in coastal Mendocino County.

We estimated escapement using the Schnabel mark-recapture method (Krebs 1989) and conducted redd censuses in our LCS. We marked and released fish with floy tags and recaptures were live fish observations made during spawning surveys. To estimate redd abundance for calculating spawner: redd ratios we used redd count and measurement data collected during spawning surveys following Gallagher et al. (2007). Over and under-counting errors in redd counts (e.g., bias) were reduced following Gallagher and Gallagher (2005). Surveys were conducted fortnightly from early December to late April each year in all spawning habitat in each LCS.

To estimate regional abundance we conducted biweekly spawning surveys in 41 GRTS reaches from mid-November through April each year. Our methods for redd count and measurement data on spawning surveys were the same as for LCS. We used the average annual coho salmon spawner: redd ratios from our LCS to convert bias corrected redd counts into fish number for each reach (Gallagher et al. 2010a). We followed Adams et al. (2010) to estimate regional abundance where the average number of redds in our 41 reaches was multiplied by the total number of reaches in our sample frame. We estimated 95 percent confidence intervals using the Bootstrap with replacement and 1000 iterations.

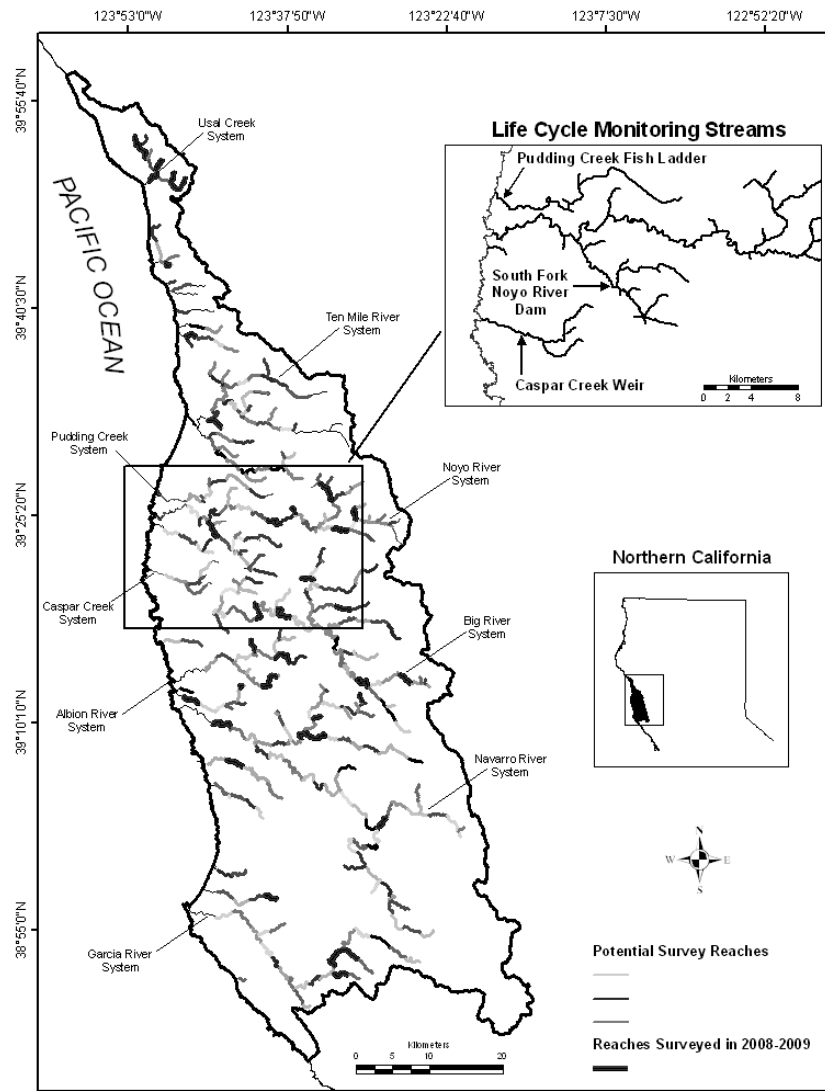


Figure 1—Study area, survey reaches and life cycle monitoring streams in Mendocino County, California.

Results

Each year, nine of the 41 GRTS reaches (21 percent) were unavailable for sampling because landowners denied us permission to enter. These reaches were replaced by the next nine in the list to fill out our required sample size of $n = 41$ or a 12 percent sample. The GRTS sample resulted in sampling reaches in all independent populations in two coho salmon diversity strata within the CCC ESU.

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Each year sampling 41 reaches encompassed the variation in coho salmon redd density within coastal Mendocino County and redd density was not significantly different among streams (*fig. 2*). Because redd density was not statistically different among streams we used the average of all reaches to estimate total redd counts and escapement for the region and for individual populations within the region. We estimated an average of 877 (95 percent CI 377 to 1,515) coho salmon redds and 1,167 (95 percent CI 488-2,068) adult coho salmon in coastal Mendocino County over 3 years (*table 1*). Regional coho salmon confidence limit widths averaged 64 percent with $n = 41$ and decreased to 47 percent when we included reaches from the LCS's ($n = 80$). Escapement estimates for the two diversity strata and for individual streams had increased confidence limit widths due to smaller sample sizes (*table 1*).

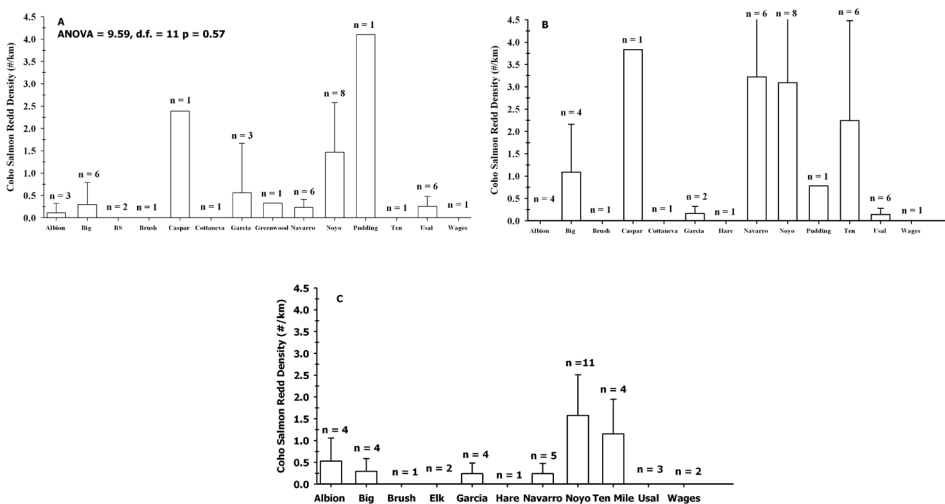


Figure 2—Average coho salmon density by stream for regional surveys in coastal Mendocino County California 2009 to 2011. A. 2009. B. 2010. C. 2011. Numbers above estimates are sample sizes (the number of reaches surveyed). Thin lines are 95 percent confidence limits.

To examine if we could use the regional average redd density to estimate redd abundance for streams we did not survey, we tested LCS redd census and estimates made by multiplying regional average density by LCS stream length with paired t-tests. Coho salmon census redd counts were not significantly different than estimates made by multiplying regional redd density by stream length ($t = 1.079$, $df = 4$, $p = 0.35$, $\alpha = 0.06$).

Confidence limit half widths for our regional sampling were greater than 30 percent (*table 1*). From our 2009 and 2010 regional data it appears to attain confidence limits with 30 percent precision and 90 percent certainty following our study design we need to sample 184 reaches (*table 2*). This level of sampling would require sampling more than half of the entire region for coho salmon. Variation around the mean coho salmon redd density peaked at $n = 41$ and remained constant after $n = 58$ reaches (*fig. 3*). The coefficient of variation (cv) in coho salmon redd density averaged 221 percent ($n = 41$) and improved insignificantly with continued sampling (cv = 220 percent, $n = 80$) over 3 years.

Table 1—Coho salmon escapement estimates (95 percent confidence limits) for coastal Mendocino County California 2009 to 2011: ns = not surveyed, na = not available, and DS = diversity strata. Precision is the 95 percent confidence limit half widths relative to the mean these data are three year averages.

Stream	N	Number of Adults			Precision %
		2009	2010	2011 ^a	
Mendocino Coast	41	887 (415 to 1545)	898 (555 to 1308)	1575 (534 to 2947)	61
Lost Coast DS	32	672 (295 to 1083)	1059 (515 to 1711)	1318 (328 to 2700)	69
Navarro Point DS	9	158 (41 to 342)	513 (108 to 989)	176 (18 to 369)	94
Albion River ^c	3	8 (0 to 22)	0	99 (0 to 297)	148
Big River ^c	6	80 (0 to 210)	134 (20 to 214)	147 (0 to 435)	122
Big Salmon Cr. ^b	2	0	ns	ns	na
Brush Cr. ^b	1	0	0	0	na
Caspar Cr. ^c	6	6	5 (3-9)	30	na
Cottaneva Cr.	1	0	0	ns	na
Garcia River ^c	3	69 (0 to 206)	9 (0 to 18)	65 (13 to 130)	166
Greenwood Cr. ^b	1	9	ns	ns	na
Little River ^c	2	4	2	2	na
Navarro River	6	124 (18 to 124)	452 (159 to 790)	137 (0 to 420)	103
Noyo River	10	294 (82 to 573)	286 (58 to 650)	494 (24 to 583)	79
South Fork Noyo River ^{c, d}	12	19	63 (42 to 112)	20	na
Pudding Cr. ^c	9	50 (32 to 96)	9 (4 to 27)	na	97
Ten Mile R. ^f	1	0	190 (4 to 454)	295 (0 to 630)	113
Usal Cr.	3	10 (2 to 18)	2 (0 to 5)	7 (0 to 20)	104
Wages Cr. ^b	1	0	0	0	na

^a Preliminary data.

^b Only one reach was surveyed in this stream so confidence bounds were not calculated.

^c Life cycle monitoring station complete census.

^d Low flows limited the number of fish that passed the weir and spawned above the egg collecting station in 2009.

^e Four reaches in 2010 and 2011.

^f Six reaches in 2010 and 2011.

Table 2—Estimated sample sizes (number of reaches) for five desired levels of precision (width of the 95 percent confidence limits relative to the mean) in coho salmon redd densities for regional monitoring.

Precision	Confidence limits	
	90%	95%
10%	1635	2370
20%	413	593
30%	184	263
40%	103	148
50%	66	95

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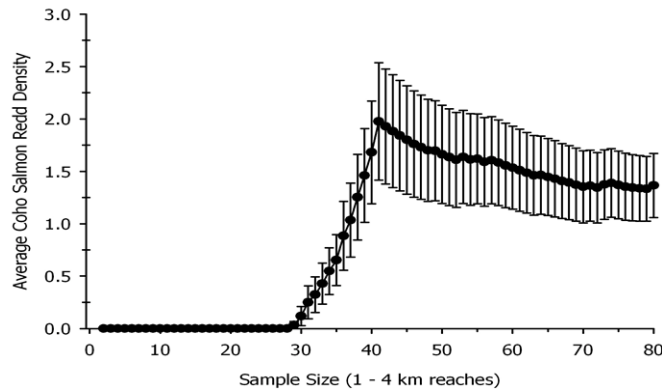


Figure 3—Cumulative mean coho salmon redd density (\pm SE) plotted against the number of sample reaches surveyed in coastal Mendocino County, California during 2010.

Discussion

Boydston and McDonald (2005) suggested their example sample frame would need refinement which might reduce the sample frame by 30 to 40 percent. We reduced a list of 2033 stream reaches to 339, an 83 percent reduction by identifying known coho salmon streams (Spence et al. 2008) and using local knowledge to define coho salmon spawning habitat. The sample frame we produced is for Chinook, steelhead, and coho, with species designation for each reach (e.g., soft stratification, Larsen et al. 2008). Soft stratification is simpler and cheaper than having one sample frame for each species because each reach covers multiple species thus reducing logistics and field time.

Adams et al. (2010) suggest a 3, 12, 30 year revisit design based on the life cycles of salmonids present. In 2009 we sampled the first 41 reaches on our GRTS draw. The Action Plan states that 40 percent of the GRTS sample reaches should be assigned as annual samples. During 2010 we sampled reaches 1 to 16 and 42 to 66 and in 2011 we sampled reaches 1 to 16 and 67 to 92. On average 21 percent of selected reaches were not available to sample because landowners denied us permission to enter. All unavailable reaches were on private land were replaced with reaches that were also on private land, reducing this source of bias in our study³.

For the third consecutive year we produced coho salmon escapement estimates for the entire coast of Mendocino County consisting of two diversity strata within the CCC Coho salmon ESU, six independent populations, and eight potentially independent populations. While the precision of these estimates (95 percent confidence half widths) was lower than expected, we now have estimates, with statistical certainty, of how many salmon escaped in this area. We believe, given the variance in redd density we observed, if we are confident in our regional estimates we can have confidence in individual population estimates despite the large confidence widths.

³ C. Jordan, NOAA Fisheries, Northwest Fisheries Science Center, personal communication.

In our earlier studies we suggested (Gallagher et al. 2010 b) if redd density variation in the pilot study area was representative of coastal California as a whole, a sample size > 41 reaches for coho salmon should have confidence interval widths of 30 percent and sufficient statistical power for monitoring escapement trends. Our present application of these sample sizes to the entire area of coastal Mendocino County resulted in escapement estimates with larger confidence widths than we expected. We attribute this in large part to low abundance. When we included all reaches surveyed during each year, a systematic rather than design based GRTS sample, precision in our estimates improved. However, the coefficient of variation did not improve with increased sample size and variation about the mean (*fig. 3*) peaked out at $n = 41$ and did not substantially decrease after about 58 reaches (~15 percent). Redd density (an index of abundance) in LCS was lower between 2009 and 2011 than observed since 2000 and was outside the range of data we used earlier (Gallagher et al. 2010b) to develop sample size estimates. Courbios et al. (2008) found that a larger sampling fraction and higher redd abundance resulted in better accuracy for GRTS. At low redd abundance none of their sampling designs were accurate. In a GRTS sampling design for bull trout in the Columbia Basin, Jacobs et al. (2009) found that accuracy ranged from 15 percent to 35 percent and was dependent on redd distributions within basins and that there was no reduction in accuracy with sample sizes between 10 and 50 sites. Our results are similar in that increased sample size appears to only marginally improve the precision of our estimates.

Crawford and Rumsey (2009) suggest that salmon monitoring programs strive for estimates that have a coefficient of variation (CV) of ± 15 percent. Our regional CVs for coho salmon averaged 221 percent ($n = 41$) to 220 percent ($n = 80$) and increased sample size did not substantially improve them. Given the cost to survey one reach for a season (\$3,000/ reach, Gallagher et al. 2010b) and the fact that increasing our sampling fraction to 30 percent would result in sampling 184 reaches (\$552,000/year), which appears would not greatly improve precision, we recommend continued evaluation of smaller sampling fractions. The use of standardized data collection procedures and trained staff (Gallagher et al. 2007) will continue to contribute to increased precision in regional escapement monitoring. Finally, for regional monitoring at low abundance, managers may have to accept larger uncertainties in escapement estimates. However, management for recovery primarily means listing decisions, and a delisting decision will likely be based on data from sustained higher abundance levels when both precision and accuracy levels would be much improved.

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