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The Resources Agency

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COASTAL MENDOCINO COUNTY SALMONID LIFE CYCLE AND REGIONAL MONITORING: MONITORING STATUS AND TRENDS 2011

2010-11 Final Report

To

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Fisheries Restoration Grant Program

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Coastal Mendocino County Salmonid Monitoring Project

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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% 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 2008-09 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 three years (2008-09 to 2010-11) 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 major portions of the California Coastal Chinook Salmon Evolutionarily Significant Unit (ESU), the Central California Coho Salmon ESU, and the Northern California coastal Steelhead ESU. In addition, we present 2010-11 data from three life cycle monitoring streams and combine this information with previous years' data to evaluate status and trends for coho and steelhead.

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. mykis*s) 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 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://salmonmonitoring advisor.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. (2011) propose a two-stage approach to estimate regional escapement of California's coastal salmonids. 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% 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. 2011).

The Action Plan was tested and further developed in a three year pilot study (Gallagher et al. 2010 a-b). 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. (2010 a) recommended that annual spawner: redd 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: redd ratios were reliable for regional monitoring using a 10% GRTS sample, and that increasing sample size above 15% did not significantly improve the estimates. Their evaluation of sample size suggested that a sample size of ≥ 41 reaches or 15%, whichever resulted in fewer reaches, would have adequate precision and sufficient statistical power to detect regional trends in salmon populations.

The 10% sample size recommended by Boydstun and McDonald (2005) was provided with little justification. Their Mendocino Coast example 10% GRTS sample resulted in an annual sample of 203 reaches. This size sample 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 entire Mendocino coast region following Adams et al. (2011). The study's purpose was to 1) continue salmon life cycle monitoring (adults in- smolts out) in three streams (LCS) and provide spawner: redd ratios for calibrating regional redd surveys and, 2) conduct regional spawning surveys in the Mendocino coast region (*fig.* 1) to estimate to estimate Chinook salmon, Coho salmon, and Steelhead escapement and evaluate sample size at this scale. This effort provided a third year (2010-11) of escapement data for six independent and eight potentially independent populations and two Diversity Strata within the CCCESU as well as major populations within the California coastal Chinook salmon and Northern California coastal steelhead ESU's. Our work also increased the time series of smolt and adult data at the LCS streams to 11 years. We field verified and gained access to 41 reaches during summer 2010 and conducted spawning surveys in these reaches during winter 2010-11. We operated three LCS's to continue population monitoring on Caspar and Pudding creeks and the South Fork Noyo River.

Here we present the results of the first three years (2008-09 to 2010-11) of the regional 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 major portions of the California Coastal Chinook Salmon Evolutionarily Significant Unit (ESU), the Central California Coho Salmon ESU, and the Northern California coastal Steelhead ESU (Spence et al. 2008). In addition, we present 2010-11 data from three life cycle monitoring streams and combine this information with previous years' data to evaluate status and trends for coho and steelhead.

Materials and methods

Life Cycle Monitoring Streams

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. Beginning in 2005 we built and operated a floating board resistance weir in Caspar Creek 4.9 km from the Pacific Ocean.

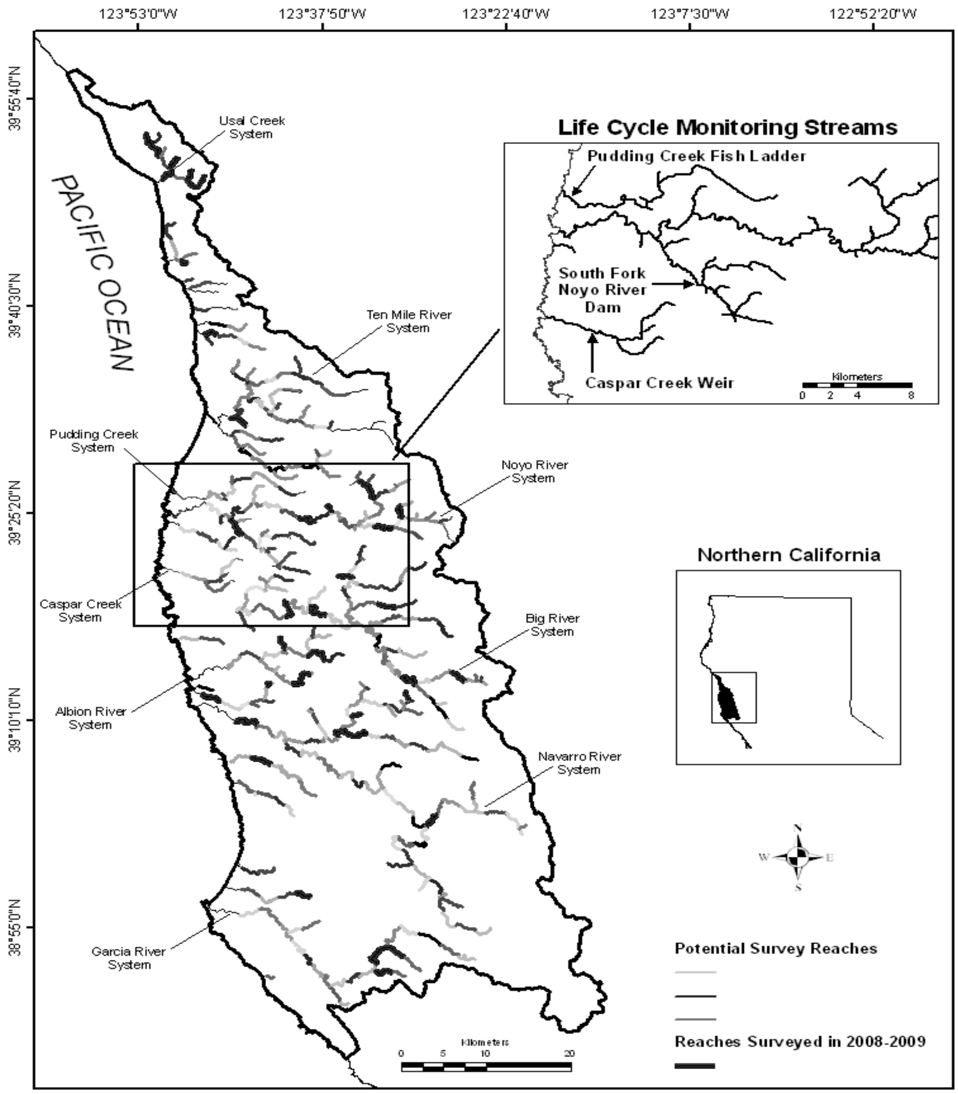

Figure 1- Study area, survey reaches and life cycle monitoring streams in Mendocino County, California.

Adult Abundance

To estimate escapement we marked and released fish with weekly time-specific individually numbered bi-colored floy tags (Szerlong and Rundio 2008). We estimated escapement using the Schnabel mark-recapture method (Krebs 1989) and conducted redd censuses in our LCS (see redd survey abundance estimation, below).

Recaptures were live fish observations made during spawning ground surveys. In order to evaluate tag loss, fish were also marked with weekly stream-specific operculum punches. Floy tags on carcasses were recovered and all carcasses inspected for operculum punches (and other marks) to estimate tag loss, residence time, and to calculate capture-recapture estimates from carcass data. Adult fish were captured, marked and released at the following locations: 1) a fish ladder and flashboard dam located 0.25 km from the Pacific Ocean on Pudding Creek, 2) an egg collecting station (ECS) on the South Fork Noyo River, and 3) a floating board resistance weir in Caspar Creek 4.9 km from the Pacific Ocean (*fig.* 1). Adult steelhead were also captured and marked in screw traps on Pudding Creek and the South Fork Noyo River and in fyke traps on Caspar Creek.

Redd Survey Abundance Estimation

To estimate escapement we used redd count and measurement data collected during spawning surveys following methods established in previous studies by the primary author of this report (Gallagher and Knechtle 2003, Gallagher et al. 2007). Over and under-counting errors in redd counts (bias corrected) were reduced following Gallagher and Gallagher (2005). These efforts included a formal written protocol, training of field staff, pairing experienced and inexperienced observers, marking and reexamining marked redds, estimating observer efficiency for each reach, measuring redds, using predictive models to determine redd species, having a test category for ambiguous redds (these were removed from further analysis), and surveying biweekly. Surveys were conducted approximately fortnightly from early-December 2010 to late-April 2011 in all spawning habitat in each stream.

We calculated spawner: redd ratios by dividing capture-recapture abundance estimates for coho and steelhead by the bias corrected redd counts for all available data. The average of these estimates were then used to convert regional redd counts into fish numbers.

Smolt Abundance

We used downstream migrant traps to estimate smolt abundance using capture-recapture methods in the LCS and Little River. Traps were placed in the streams in mid-March and checked daily until early-June 2011. One fyke trap was located about 5.0 km above the Pacific Ocean in the main stem of Caspar Creek. We deployed a screw trap about 50m below the ECS on the South Fork Noyo River. A fyke trap was fished in Little River about 2.5 km above the Pacific Ocean. Campbell Timberland Management operated a screw trap about 5 km upstream of the ocean in Pudding Creek. To further evaluate migration timing we installed two PIT tag antennae arrays about 0.5km from the ocean in Caspar Creek and one array on the Pudding Creek dam. In 2010 Campbell received a Mendocino County Fish and Game Commission grant and used this money to put another PIT tag antenna array in the fish ladder at Pudding Creek. Campbell continued efforts to devise and opportunistically operate a smolt capture trap in the fish ladder during spring 2011.

In general, we followed the methods of Barrineau and Gallagher (2001), except we used PIT tags as the primary mark for fish > 70 mm. One year and older coho and steelhead (> 70 mm FL) were also marked with a maxillary clip to assess PIT tag loss. We measured and weighed all steelhead and coho > 50 mm (FL). Captured fish were marked with a site and week specific mark (pit tag or fin clip) and released upstream of the traps. All other species captured were identified, counted, and released below the traps. We examined all steelhead and coho >50 mm for marks each day. Those without marks were marked and released at least 150 m above the traps. Recaptured fish were measured and released at least 150 m below the traps. Handled fish were anesthetized using Alka-Seltzer® except in Pudding Creek where MS 222 was used.

To estimate salmonid populations, capture probabilities, and timing for each trap all captures and recaptures were totaled by week and size/age class to create data matrices for input to DARR (Darroch Analysis with Rank Reduction), a software application for estimating abundance from stratified mark-recapture data (Bjorkstedt 2003). These matrices were run in DARR to produce population estimates and capture probabilities for both coho and steelhead. For coho and steelhead, we determined the following classes: < 70 mm (YOY), 71-120 mm (Y+), and > 120 mm (Y++). We developed these age/size classes based on Neillands (2003), Gallagher (2000), Shapovalov and Taft (1954), and through discussion with local biologists. Salmonids < 71 mm captured before fry were first observed in spring were assumed to be Y+. After which fork length frequencies were used to separate year classes.

Late-Summer Juvenile Abundance

We developed a 20 unit GRTS sample draw of 50m reaches in Pudding Creek for estimating summer rearing density following methods described above for regional sampling. Similarly we randomly selected ten 50 m units in Caspar Creek. Salmonid density was estimated in each reach using depletion electro-shocking. All salmonids > 60 mm fork length were given PIT tags and maxillary clips and all captured fish were examined for previously applied marks. We calculated the average and 95% CI density of salmonids by species in each stream and multiplied this by the total length of anadromy to estimate late-summer juvenile abundance.

Survival

We estimated apparent coho egg to smolt and smolt to adult survival for the three LCS streams over six years from smolt abundance data from 2000 to 2011 and adult return data from 2000 through 2010-11. To estimate egg abundance we used the relationship between fecundity and fork length from Shapovalov and Taft (1954) and the average length and the total number of females observed in each stream each year. Coho spawner/recruit ratios for eight consecutive years were estimated using data from this study. Over winter survival was estimated for Caspar and Pudding Creeks using data collected during summer electro-fishing: summer stream-level population estimates were divided into smolt abundance estimates the following spring and the estimated number of summer PIT tagged fish captured in downstream traps and detected in our arrays was divided by the total number of PIT tags deployed in summer.

Trends in Coho Salmon Abundance

Trends in coho and steelhead abundance, productivity, and survival over 11 years and nine complete coho life cycles were examined following McDonald (et al. 2007) using a trend detection package in R (www.r-project.org) developed for this purpose (Trent McDonald, Personal Communication). Coho salmon population trends and population viability were also examined following methods described by Spence et al. (2008). Trends in abundance versus year were examined with t-tests.

Regional Spawning Survey Abundance Estimation

The Mendocino coast region extends from Usal Creek to Schooner Gulch (*fig.* 1). We followed Boydstun and McDonald (2005) to define the sampling universe, create a sample frame (the sample universe broken into sampling units), and produce a GRTS draw (the spatially balanced random sample). We defined the sampling universe as all coho spawning habitat in coastal Mendocino County. To improve the utility of the data set to track population trends we used a three year rotating panel design with 40% of the selected reaches sampled every year (Trent McDonald Personal Communication). During 2008-09 we selected GRTS reaches 1 to 41, in 2009-10 we selected reaches 1 to 16 and 42 to 67, and for 2010-11 we selected reaches 1 to 16 and 68 to 93. Please see Gallagher and Wright (2011) for more details on development of the sample frame and reach selection.

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% confidence intervals using the Bootstrap with replacement and 1000 iterations.

Data Analysis

Mark-recapture escapement was estimated using the Schnabel method and confidence intervals were obtained from the Poisson distribution (Krebs 1989). To evaluate precision in our escapement estimates we evaluated confidence interval widths and coefficients of variation (CV). Narrower 95% confidence intervals (and thus smaller SD) and smaller CV's were deemed more precise and reliable than wider bounds. We compared species specific redd densities and reach level abundance with ANOVA or the Kruskal-Wallis ANOVA on ranks when Standard Kurtosis p-values were < 0.05. We evaluated sample size for our regional spawning ground surveys following Equation 1 and graphically with performance curves (Brower and Zar 1987). Finally, to further evaluate our regional estimates we compared our LCS redd census data to reach expanded population estimates using paired t-test treating streams as replicates. We accepted statistical significance at $p < 0.05$, although, endangered species management often accepts statistical significance at the $p < 0.10$ level (Good et al. 2005).

Equation 1

$$n \approx \frac{(100 t_{\alpha})^{2}}{r^{2}} \left(\frac{1}{\bar{x}} + \frac{1}{k} \right)$$

Where is the mean value expected in data, k is the negative binomial exponent, r is the desired level of error- the width of the 95% confidence intervals relative to the point estimates as a percent (10%, 25%, 30%, and 50%), and t_α is the probability of not achieving desired level of error (from Krebs 1989).

Results

Mendocino Coast Sample GRTS Draw

Each year, nine of the 41 GRTS reaches (21%) 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% sample. The GRTS sample resulted in sampling reaches in all independent populations in two coho salmon diversity strata within the CCC ESU. Sampling the 41 reaches selected for this study resulted in a 14% sample of all identified Chinook reaches (n = 16 of 113 identified Chinook reaches) for evaluating Chinook escapement sample size and reach variances.

Life Cycle Monitoring

Adult Escapement

During 2010-11 we tagged 10 coho salmon in Caspar Creek and observed eight untagged fish above the weir. Therefore we were not able to generate a capture-recapture estimate for coho salmon in this stream. Thus we used the live fish observations and the multi-year average residence time from Gallagher et al (2010b) to generate and Area-Under-the Curve (AUC) estimate of 27 coho salmon (95% CI 17-63). This estimate had a 95% confidence width of 84% (Tables 1 and 2). We tagged and released 24 coho salmon above the Noyo River ECS and observed five tagged and six untagged fish during spawning ground surveys. We estimated a total of 39 (95% CI 24-108, CV = 0.35, confidence limit width = 108%) coho salmon were above the ECS. In Pudding Creek we estimated there were 199 coho salmon (95% CI 53-270, CV = 0.14, confidence limit width 29%).

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

Stream	N	Number of Adults			Precision
		2009	2010	2011	
Mendocino Coast	41	887 (415 to 1545)	898 (555 to 1308)	1427 (861 to 6078)	61%
Lost Coast DS	32	672 (295 to 1083)	1059 (515 to 1711)	1212 (390 to 3871)	69%
Navarro Point DS	9	158 (41 to 342)	513 (108 to 989	542 (342 to 1477)	94%
Albion River[4]	3	8 (0 to 22)	0	162 (0 to 980)	148%
Big River [4]	6	80 (0 to 210)	134 (20 to 214)	160 (0 to 972)	122%
Big Salmon Cr.[1]	2	0	ns	ns	na
Brush Cr.[1]	1	0	0	0	na
Caspar Cr. [2]	6	7 (2 to 255)	5 (3-9)	36 (25 to 73)	na
Cottaneva Cr.	1	0	0	ns	na
Garcia River [4]	3	69 (0 to 206)	9 (0 to 18)	90 (0 to 463)	166%
Greenwood Cr.[1]	1	9	ns	ns	na
Little River [2]	2	4	2	8	na
Navarro River	6	124 (18 to 124)	452 (159 to 790)	420 (0 to 1920)	103%
Noyo River	10	294 (82 to 573)	286 (58 to 650)	411 (161 to1226)	79%
South Fork Noyo River [2 4]	12	19	63 (42 to 112)	39 (27 to 108)	47%
Pudding Cr.	9	50 (32 to 96)	9 (4 to 27)	199 (153 to 270)	46%
Ten Mile R.[5]	1	0	190 (4 to 454)	395 (48 to 1642)	113%
Usal Cr.	3	10 (2 to 18)	2 (0 to 5)	0)	104%
Wages Cr. [1]	1	0	0	0	na

[1] Only one reach was surveyed in this stream so confidence bounds were not calculated.
[2] Life cycle monitoring station complete census, fish per redd times redd count.
[3] Low flows limited the number of fish that passed the weir and spawned above the egg collecting station in 2009.
[4] Four reaches in 2010 and 2011.
[5] Six reaches in 2010 and 2011.

We captured and tagged 28 steelhead in Caspar Creek and recaptured five tagged and one untagged fish. Thus we estimated there were 31 (95% CI 18-74, CV = 0.38, 95%, confidence limit width = 93%) steelhead in this stream (Table 3). We tagged and released 21 steelhead above the Noyo River ECS and observed five tagged and six unmarked steelhead during spawning ground surveys. We estimated there were 60 (95% CI 32-188, CV = 0.45, confidence limit width = 125%) steelhead above the ECS. In Pudding Creek we estimated there were 18 steelhead (95% CI 8-149, CV = 0.71, confidence limit width = 400%).

Of the 25 coho salmon adults captured with PIT tags (0 in Caspar, 0 in SF Noyo, and 25 in Pudding Creek); one did not have a maxillary clip. We did not capture any adult salmon missing maxillary clips that had PIT tags. Thus PIT tag loss was 0% and maxillary clip loss was 4.0%.

Of the recaptured PIT tagged adult coho salmon adults in Pudding Creek during 2010-11: one was marked as a smolt in 2008 and one during summer 2008 electro-fishing, 20 were marked as smolts during 2009, and four were marked as smolts during 2010. The two fish originally marked during 2008 (~ 80mm when first captured and 690mm as adults) returned as four years olds spending about two years in freshwater and two in the ocean. There was no difference between the size of these adults and the 25 fish that showed a three year life history ($t = 0.47$, $p = 0.65$, d.f. = 23). The four fish that returned as adults after spending only approximately 8.5 months in the ocean were considerable smaller as adults than the rest of the fish that returned to Pudding Creek during 2010-11 ($t = -9.3$, $p < 0.001$, d.f. = 26) with an average fork length of 426mm. These fish averaged 126mm as smolts and, based on the size at capture as smolts, three of these may have been two-year freshwater residents. One of these five fish was determined to be a female; the other three were deemed males. The female: male ratio of the returned PIT tagged adult coho salmon in Pudding Creek was 0.94:1.00 in 2010-11.

For 2011 the steelhead female to male ratio was 1.00:1.00 in Caspar Creek and in the South Fork Noyo River it was 1.67:1.00. In Pudding Creek we only captured female steelhead.

Table. 2. Coho salmon redd count and escapement estimates (95% confidence limits) for coastal Mendocino County California 2011: na = not available. Precision is the 95% confidence limit half widths relative to the mean these data are three year averages.

Stream	Number of Reaches	Number of Coho Salmon Redds			Number of Coho Salmon Adults			Confidence Width	Coeffiecient of Variation
		Low 95% CI	Point Estimate	High 95% CI	Low 95% CI	Point Estimate	High 95% CI		
Mencodino Coast	41	447	517	1088	861	1427	6078	62%	204%
Lost Coast Diversity Strata	37	203	439	693	390	1212	3871	56%	241%
Navarro Point Diversity Strata	18	178	196	264	342	542	1477	22%	224%
Albion River	4	0	59	176	0	162	980	150%	200%
Big River	4	0	58	174	0	160	972	150%	200%
Brush Creek [1]	1	-	0	-	-	0	-	na	na
Caspar Creek [2, 3]	6	-	13	-	25	36	73	84%	na
Elk Creek	2	-	0	-	-	0	-	na	na
Garcia River	4	0	33	90	0	90	436	120%	151%
Hare Creek [1]	1	-	0	-	-	0	-	na	na
Little River [2]	2	-	3	-	-	8	-	na	na
Navarro River	12	0	152	344	0	420	1920	113%	213%
Noyo River	28	84	149	219	161	411	1226	46%	307%
South Fork Noyo River [2]	13	-	13	-	24	39	108	107%	35%
Pudding Creek [2]	9	-	68	-	153	199	270	29%	14%
Ten Mile River	10	25	143	294	48	395	1642	94	196%
Usal Creek	3	-	0	-	-	0	-	na	na
Wages Creek	2	-	0	-	-	0	-	na	na na

1 Only one reach was surveyed in this stream so confidence bounds can not be calculated.

2 Life cycle monitoring station complete census. Casapar Creek is fish per redd times redd count for 2011.

3 Escapement etimated using AUC. 2 fish marked at weir 8 obs durving spawning, none were marked. Used SF noyo oe and 2001 to 2008 rt.

We used our LCS redd census and mark-recapture data (Tables 2-3) to calculate average annual spawner: redd ratios for calibrating regional redd counts. We estimated an average 2.76 (95% CI 1.92-5.58) coho salmon per redd for 2010-11. Because we could not make a mark-recapture estimate for coho salmon in Caspar Creek, we did not use these data for calculating spawner: redd ratios for this species. We estimated 2.16 (95% CI 1.17-6.98) steelhead per redd from our mark-recapture experiments and redd surveys in our LCS streams in 2010-11.

Table. 3. Steelhead redd count and escapement estimates (95% confidence limits) for coastal Mendocino County California 2011: na = not available. Precision is the 95% confidence limit half widths relative to the mean these data are three year averages.

Stream	Number of Reaches	Number of Steelhead Redds			Number of Steelhead Adults			Confidence Width	Coeffiecient of Variation
		Low 95% CI	Point Estimate	High 95% CI	Low 95% CI	Point Estimate	High 95% CI		
Mencodino Coast	41	661	1203	1858	775	2600	12,962	50%	196%
Lost Coast Diversity Strata	37	347	718	1157	406	1551	8069	56%	219%
Navarro Point Diversity Strata	18	221	564	1039	259	1219	7246	73%	150%
Albion River	4	0	9	18	0	19	126	100%	115%
Big River	4	29	73	145	34	157	1012	80%	100%
Brush Creek [1]	1	-	0	-	-	0	-	na	na
Caspar Creek [2]	6	-	23	-	18	31	74	93	38%
Elk Creek	2	0	28	55	0	59	384	100	331%
Garcia River	4	104	358	611	122	773	4263	71%	86%
Hare Creek [1]	1	-	3	-	-	6	-	na	na
Little River [2]	2	-	9	-	-	19	-	na	na
Navarro River	12	29	134	257	34	290	1792	85%	173%
Noyo River	28	67	143	254	78	309	1774	66%	186%
South Fork Noyo River [2]	13	-	20	-	32	60	188	125%	45%
Pudding Creek [2]	9	-	43	-	8	18	149	400%	71%
Ten Mile River	10	21	109	223	25	236	1553	92%	111%
Usal Creek	3	0	40	110	0	86	767	138%	133%
Wages Creek	2	85	85	85	184	184	184	0	0%

1 Only one reach was surveyed in this stream so confidence bounds can not be calculated.

Smolt Abundance

Coho smolt abundance estimates were highest in Pudding Creek and lowest in Little River in spring 2011 (Table 4). We marked 416 coho salmon and 532 steelhead with pit tags captured in our fyke trap on Caspar Creek during spring 2011. At the screw trap on the South Fork Noyo River we captured and pit tagged 988 coho salmon and 536 steelhead. We estimated Caspar Creek smolt production of 1,525 (SE = 228) coho salmon and 2,442 (SE = 764) steelhead during spring 2011 (Tables 4 and 5). In Pudding Creek we marked 1,882 coho salmon and 2,855 steelhead with PIT tags and estimated 5,181 (SE = 164) coho smolts and 14,284 (SE = 1,036) steelhead smolts. Our smolt estimates for the South Fork Noyo River were 6,038 (SE = 1,457) steelhead and 2,472 (SE = 376) coho salmon. In the three streams where we used PIT tags we recaptured a number of coho salmon in the smolt traps during spring that were first marked and classified as year old fish during downstream trapping the year before. The average percentage of total captured fish displaying this two-year stream residency pattern was 0.85% (range 0.20% to 1.22%) 2006 to 2007, 0.69% (range 0.09% to 1.62%) in 2007 to 2008, 1.19% (range 0.54% to 2.13%) during 2008 to 2009, and 0.50% (range 0.22% to 0.76%) 2009 to 2010. We did not capture any coho in Pudding Creek that displayed two-year freshwater residence during 2011. Note that we did not use PIT tags in the South Fork Noyo River and Caspar Creek smolt traps during spring 2010 because so few adults had spawned the year before.

Table. 4. Coho salmon smolt abundance estimates for Life Cycle Monitoring Streams in Mendocino County California spring 2011. Numbers under the point estimates are standard deviations double for 95% confidence limits.

	YOY			Coho Salmon	Y+	
Trap Location	Total Captured	N	Capture Probability	Total Captured	N	Capture Probability
Caspar Mainstem	485	1,940 3,360	0.25	432	1,525 228	0.28
Little River	26	Insuficient Data	Insuficient Data	0	0	N/A
SF Noyo	234	1,432 1,696	0.13	1,047	2,472 376	0.52
Pudding Creek	2773	no data no data	no data	2409	5181 164	0.52

Late-Summer Juvenile Abundance

We PIT tagged 55 coho salmon in Pudding Creek during fall 2010 electro-fishing operations. We did not tag any coho salmon during fall 2010 electro-fishing. The average coho salmon density in Caspar Creek was 0.16 (SD = 0.16) fish per meter and we estimated there were 2287 (95%ci 695- 3879) coho juveniles in this stream during fall 2010. We estimated there were 4,101 (95% ci 0 to 8,351) coho in Pudding Creek in September 2010.

Table. 5. Steelhead smolt abundance for streams in Mendocino County California spring 2011. Numbers in under the point estimates are SD double for 95% confidence limits.

	YOY			Y+ < 120			Y++		
Trap Location	Total Captured	N	Capture Probability	Total Captured	N	Capture Probability	Total Captured	N	Capture Probability
Caspar Creek	1,559	Insufficient Data	Insufficient Data	531	3,194 869	0.24	116	430 131	0.25
Little River	82	Insufficient Data	Insufficient Data	484	1,569 234	0.36	89	577 403	0.26
SF Noyo	916	6,412 2,968	0.14	790	5,216 1,222	0.20	39	761 262	0.05
Pudding Creek	nd	nd	nd	2283	12198 723	???	362	2086 313	

Survival

Coho salmon egg to smolt survival (freshwater) ranged from 1% to over 20% over the last ten years and was very similar among the three LCS (*Fig.* 2a). From our summer population and smolt trap captures we estimated 2010-11 over-winter (parr to smolt survival) in Caspar Creek at 0.67 (95% CI 0.37-1.54) and in Pudding Creek it was 0.63 (95% CI 0.38-2.02). Coho smolt to adult (marine) survival was similar among streams over ten years and ranged from 0.002 to 0.17 (*Fig.* 2b, Table 6). Treating years as replicates smolt to adult survival was not significantly different among streams (ANOVA = 1.79,d.f. 2,21, $p = 0.19$). Treating streams as replicates smolt to adult survival was significantly different over nine years (ANOVA H = 22.73, df = 9, $p = 0.005$). Examined individually there was no difference among years (Dunn's $q < 2.88$, $p > 0.05$).

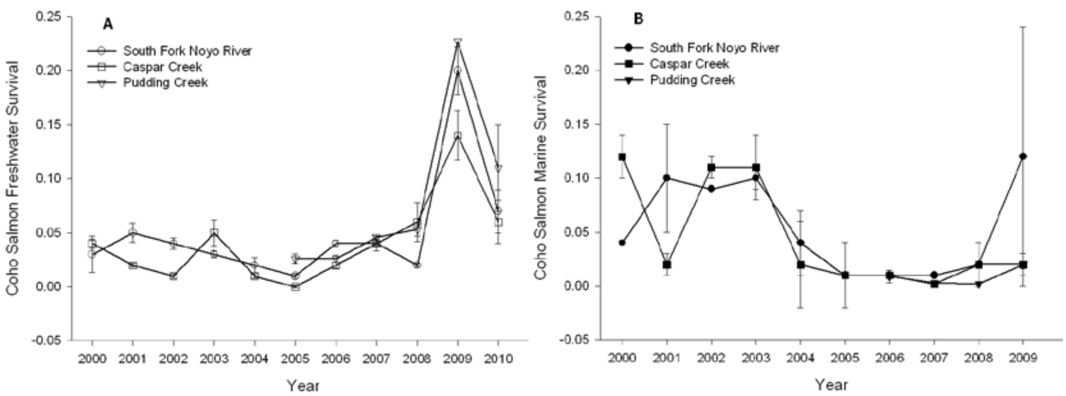

Figure 2- Coho salmon freshwater and marine survival 2000 to 2010. A. Freshwater survival. B. Marine survival.

Based on our downstream trapping and adult mark-recapture population estimates the 2009 smolt to 2010-11 adult survival averaged 4.01% (Table 6). In the South Fork Noyo River the smolt to adult survival thus estimated was 0.125 (12.50%). Based on the number of PIT tagged fish released and subsequently recaptured as adults, smolt to adult survival in the South Fork Noyo River was 0.016 (1.60%). Smolt to adult survival has increased over the past two years (2010 and 2011) relative to the period from 2006 to 2009. Smolt to adult survival in Pudding Creek from smolts PIT tagged in 2009 to adult returns in 2010-11 was 0.99%. These estimates are very similar to our apparent survival estimates based on abundance estimates of these two life stages (Table 6).

Coho salmon recruits per spawner ratios were less than 1.00 for the 2002-03 to 2005-06, the 2003-04 to 2006-07, the 2004-05 to 2007-08, the 2005-06 to 2008-09 and the 2006-07 to 2009-10 cohorts (Table 6). Treating years as replicates, recruits per spawner estimates were not significantly different among streams (ANOVA = 0.49, df = 3, 30, p = 0.69). When streams were treated as replicates, recruits per spawner estimates were significantly different over nine years (ANOVA H = 26.79, df = 8, p < 0.001). Examined by year recruits per spawner were only significantly different between 2001-04 and 2005-08 (Dunn's q = 3.41, p < 0.05). There were no other significant differences in recruits per spawner for the other years data (Dunn's q <3.09, p > 0.05).

Table. 6. Coho salmon survival and spawner: recruit ratios for several Mendocino County, California streams 2000 to 2011.

	Variable	Noyo Ecs			Pudding Creek			Caspar Creek			Little River		
		Low ^	Estimate	High	Low ^	Estimate	High	Low ^	Estimate	High	Low ^	Estimate	High
chrt 1													
	1999-2000 Adults	-	190	-	nd	nd	nd	0	87	186	0	16	67
	2001 Smolts	1596	4152	6708	nd	nd	nd	3355	3799	4243	259	264	280
	2001 Smolts/ 2000 Adults	-	22	-	-	-	-	-	44	23	-	17	4
	2002-2003 Adults	-	401	-	333	367	401	70	91	112	42	45	48
	Survival 01 Smolt to 03 Adult	0.06	0.10	0.25	nd	nd	nd	0.02	0.02	0.03	0.16	0.17	0.17
	Recruits/Spawner (03/00)	-	2.11	-	nd	nd	nd	na	1.05	0.60	nd	2.81	0.72
	2004 Smolts	7289	7975	8661	nd	nd	nd	4371	5753	7135	2038	2202	2366
	2004 Smolts / 2003 Adults	-	20	-	-	-	-	62	63	64	49	49	49
	2005-2006 Adults	178	285	588	588	709	888	48	126	4961	1	14	27
	Survival 04 Smolt to 06 Adult	0.02	0.04	0.07	nd	nd	nd	0.01	0.02	0.70	0.00	0.01	0.01
	Recruits/Spawner (06/03)	0.44	0.71	1.47	1.77	1.93	2.21	0.69	1.38	44.29	0.02	0.31	0.56
	2007 Smolts	3212	3488	3764	15313	17609	19905	2843	3505	4167	1855	2175	2495
	2007 Smolts / 2006 Adults	18	12	6	26	25	22	59	28	1	1855	155	92
	2008-2009 Adults	-	19	-	32	50	96	-	6	-	-	4	-
	Survival 07 Smolt to 09 Adult	-	0.01	-	0.002	0.003	0.005		0.002	-	- -	0.002	-
	Recruits/Spawner (09/06)	-	0.07	-	0.05	0.07	0.11		0.05	-	- -	0.29	-
chrt 2	2000-2001 Adults [9]	-	220	-	nd	279	nd	97	106	115	6	20	33
	2002 Smolts	5994	7562	9130	nd	nd	nd	1922	2224	2526	1441	1575	1709
	2002 Smolts/2001 Adults		34						21			79	
	2003-2004 Adults	530	647	706	1067	1204	1600	178	238	298	28	91	154
	Survival 02 Smolt to 04 Adult	0.09	0.09	0.08	nd	nd	nd	0.09	0.11	0.12	0.02	0.06	0.09
	Recruits/Spawner (04/01)	2.41	2.94	3.21	nd	nd	nd	1.84	2.25	2.59	4.67	4.55	4.67
	2005 Smolts	9261	13727	18193	-	-	-	3792	4482	5172	1834	1974	2114
	2005 Smolts / 2004 Adults	17	21	26	-	-	-	21	19	17	66	22	14
	2006-2007 Adults	76	114	202	295	401	601	28	54	196	3	5	6
	Survival 05 Smolt to 07 Adult	0.01	0.01	0.01	-	-	-	0.01	0.01	0.04	0.002	0.003	0.003
	Recruits/Spawner (07/04)	0.14	0.18	0.29	0.28	0.33	0.38	0.16	0.23	0.66	0.11	0.05	0.04
	2008 Smolts	2829	2971	3113	10842	11390	11938	1786	2134	2491	800	863	923
	2008 Smolts / 2007 Adults	37	26	15	4	9	27	64	40	13	267	173	154
	2010 Adults	42	63	112	4	9.00	27.00		46.00			2.00	
	Survival 08 Smolt to 10 Adult	0.01	0.02	0.04	0.000	0.001	0.002		0.02			0.002	
	Recruits/Spawner (10/07)	0.55	0.55	0.55	0.01	0.02	0.04		0.85			0.40	
chrt 3	2000 Smolts	2102	2763	3424	nd	nd	nd	2889	3259	3629	917	975	1033
	2001-2002 Adults	76	112	148	438	524	610	352	386	420	50	88	126
	Survival 00 Smolt to 02 Adult	0.04	0.04	0.04	nd	nd	nd	0.12	0.12	0.12	0.05	0.09	0.12
	2003 Smolts	4789	5357	5925	nd	nd	nd	4258	4976	5694	1885	2115	2345
	2003 Smolts / 2002 Adults	63.013158	48	40				12	13	14	38	24	19
	2004-2005 Adults	-	536	-	899	1167	1773	298	548	798	0	152	535
	Survival 03 Smolt to 05 Adult	0.09	0.10	0.11	nd	nd	nd	0.07	0.11	0.14	0.00	0.07	0.23
	Recruits/Spawner (05/02)	7.05	4.79	3.62	2.05	2.23	2.91	0.85	1.42	1.90	0.00	1.73	4.25
	2006 Smolts	4760	5980	7200	21862	25656	29450	1893	2253	2613	1176	1294	1412
	2006 Smolts / 2005 Adults		11		24	22	17	6	4	3	-	9	3
	2007-2008 Adults [8]	16	54	∞	153	228	450	6	16	∞	1	2	4
	Survival 06 Smolt to 08 Adult	0.003	0.01	na	0.0070	0.0089	0.0153	0.00	0.01	na	0.001	0.002	0.003
	Recruits/Spawner (08/05)	0.03	0.10	na	0.17	0.20	0.25	0.02	0.03	na	0.00	0.01	0.01
	2009 Smolts	287	313	339	14367	16309	18251	1424	2044	2664	698	836	974
	2009 Smolts / 2008 Adults	18	6		94	72	41	237	128	-	517	414	245
	2010-2011 Adults	24	39	108	153	199	270	25	36	73	-	8	-
	Survival 09 Smolt to 11 Adult	0.084	0.125	0.319	0.011	0.012	0.015	0.0176	0.0176	0.027		0.010	
	Recruits/Spawner (11/08)	1.50	0.72	-	1.00	0.87	0.60	4.17	2.25	-	-	3.96	-

^ Adult and smolt data ranges are 95% ci's.
ECS adult escapement from carcass capture-recapture 2001-02, live fish mark-recaptue for 2004-2006, and relase counts other years.
Smolt estimates are from Harris 2000 to 2009. I believe that hatchery numbers are removed from estimates. No hatchery influence after 2004.
Pudding Creek adult escapement from live fish mark-recapture for 2004-2009 and 1 redd per female for other years (95%ci based on redd count SE and n = 3 reaches).
Caspar from live fish capture-recapture for 2005-06 and 1 redd per female for other years (95%ci based on redd count SE and n = 3 reaches).
Little River adult escapement from 1 redd per female (95%ci based on redd count SE and n = 2 reaches).
Hare Creek adult escapement from 1 redd per female (95%ci based on redd count SE and n = 4 reaches 2002-03 and 5 reaches 2005-06 and 2007-08).
Noyo River adult escapement from live fish caprure-recapture 2002-03 and1 redd per female for other years (95%ci based on redd count SE and n = 9 reaches).
[8] Ecs and caspar mark-recapture from Schnabel method without recaptures so upper 96% confidence bounds are infinite.
[9] Pudding adult estimate from Harris 2001 raw redd count of 138 times 2.

Trends in Coho Abundance, Productivity, and Survival

There was no significant regional trend in coho salmon escapement over the last 11 years (*Fig.* 3a). When examined by year class no cohort showed a significant negative trend in escapement over multiple generations (*Fig.* 3b-d). If we lower the acceptance probability to $p < 0.10$ two of the three cohorts exhibited significant negative escapement trends. When evaluated by spawners per intrinsic potential-km^{-1} (Bjorkstedt et al. 2005) and using the geometric mean approach of Spence et al. (2008) there were significant trends in coho salmon abundance in all of the study streams over the past ten years (Tables 7-8). Based on risk categories in Spence et al. (2008) extinction risks of these populations were moderate to high (Tables 7-8).

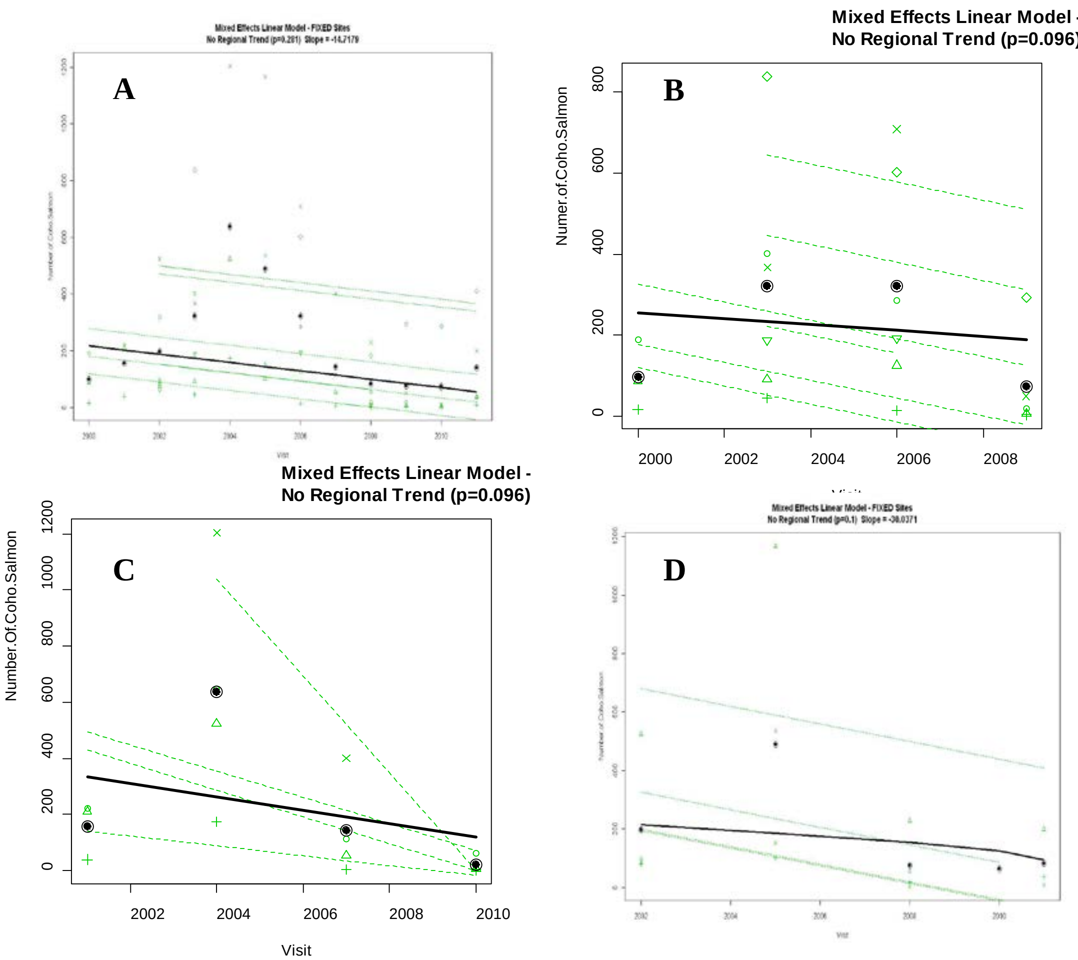

Figure 3- Coho salmon escapement trends 2000 to 2011. A. All years combined. B. Cohort 1. C. Cohort 2. D. Cohort 3.

There were no significant regional trends in coho salmon smolt abundance over the past eleven years (*Fig.* 4). Similarly, there were no significant trends in coho salmon smolt abundance for three cohorts over three to four generations (*Fig.* 4).

Coho salmon productivity (recruits per spawner) showed no trend over the past nine years (*Fig.* 5). When examined by year class two of three cohorts showed significant negative production trends (*Fig.* 5). Freshwater productivity, as measured by smolt recruitment (smolts year n+3/smolts year n), showed significant negative trends of the past nine years. Two of the three cohorts also exhibited significant negative trends in freshwater productivity (*Fig.* 6).

Table. 7. Coho salmon population viability based on Spence et al. (2008) for several coastal Mendocino County streams 2000 to 2011.

Stream	Harmonic Mean (per generation)		Number of Years	Extinction Risk	Spawners/ IP-KM
	Population Size	Effective Population Size [2]			
South Fork Noyo River	336	67	10	Moderate	9
Pudding Creek	715	143	8	Moderate	17
Caspar Creek	120	24	10	Moderate	11
Little River	27	5	10	High 2	6

[1] Harmonic mean times 0.20.
[2] Spence et al. (2008) state that small stable populations are exempt.

Table. 8. Coho salmon population trends based on Spence et al. (2008) for several coastal Mendocino County streams 2000 to 2011.

Stream	Geometric Mean	Number of Years	Slope	Negative Trend	Population Size ≤ 500
	Population Size				
South Fork Noyo River	138	10	-2.26	yes p = 0.02	Yes
Pudding Creek	263	8	-2.12	yes p = 0.002	Yes
Caspar Creek	65	10	-1.89	yes p = 0.003	Yes
Little River	15	10	-1.68	yes p = 0.005	Yes

Coho salmon smolt to adult (marine) survival showed a significant negative trend over the past nine years (*Fig.* 7a). Only one of three cohorts showed a significant negative trend in smolt to adult survival over three generations at $p < 0.05$ (*Fig.* 7 b-d). There was no significant trend in freshwater (egg to smolt survival) over the past nine years (*Fig.* 8 a). Only one of three cohorts showed a significant positive trend in freshwater survival at $p < 0.10$ (Fig 8 c).

Regional Spawning Survey Abundance Estimation

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.* 9). 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% CI 377 to 1,515) coho salmon redds and 1,167 (95% CI 488-2,068) adult coho salmon in coastal Mendocino County over three years (Tables 1-2). Regional coho salmon confidence limit widths averaged 64% with n = 41 and decreased to 47% when we included reaches from the LCS's (n =80). Escapement estimates for the two coho salmon diversity strata and for individual streams had increased confidence limit widths due to smaller sample sizes (Table 1).

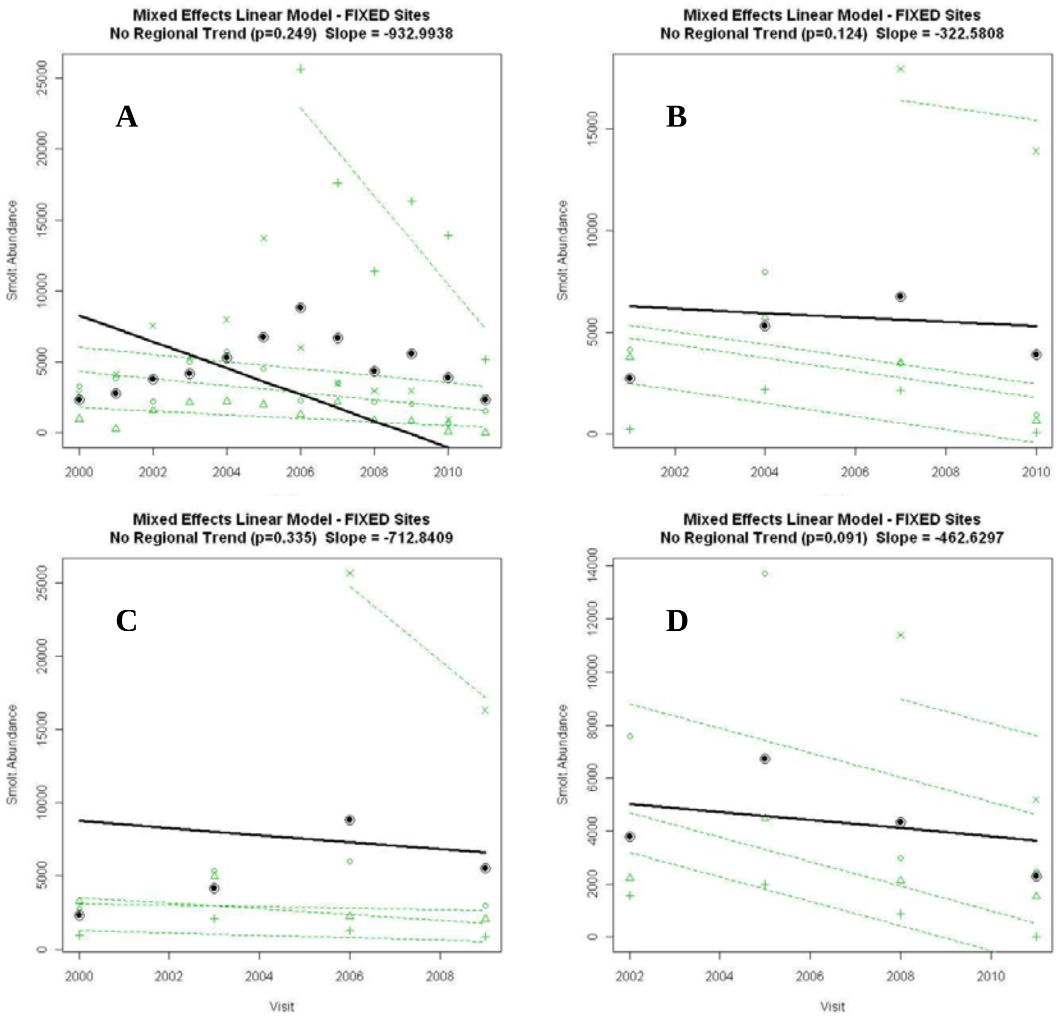

Figure 4. Coho salmon smolt abundance trends in coastal Mendocino County 2000 to 2011. A. All years. B. Cohort 1. C. Cohort 2. D Cohort 3.

We estimated there were 2,600 steelhead in coastal Mendocino County during 2011 and 95% confidence limit widths were 50% at n = 41 (Table 3). We estimated there were 48 Chinook salmon in coastal Mendocino County during 2011 (Table 9).

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% (Tables 1-2, 9). From our 2009-10 regional data it appears to attain confidence limits with 30% precision and 90% certainty following our study design we need to sample 184 reaches (Table 10). 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.* 10). The coefficient of variation (cv) in coho salmon redd density averaged 221% (n = 41) and improved insignificantly with continued sampling (cv = 220%, n = 80) over three years.

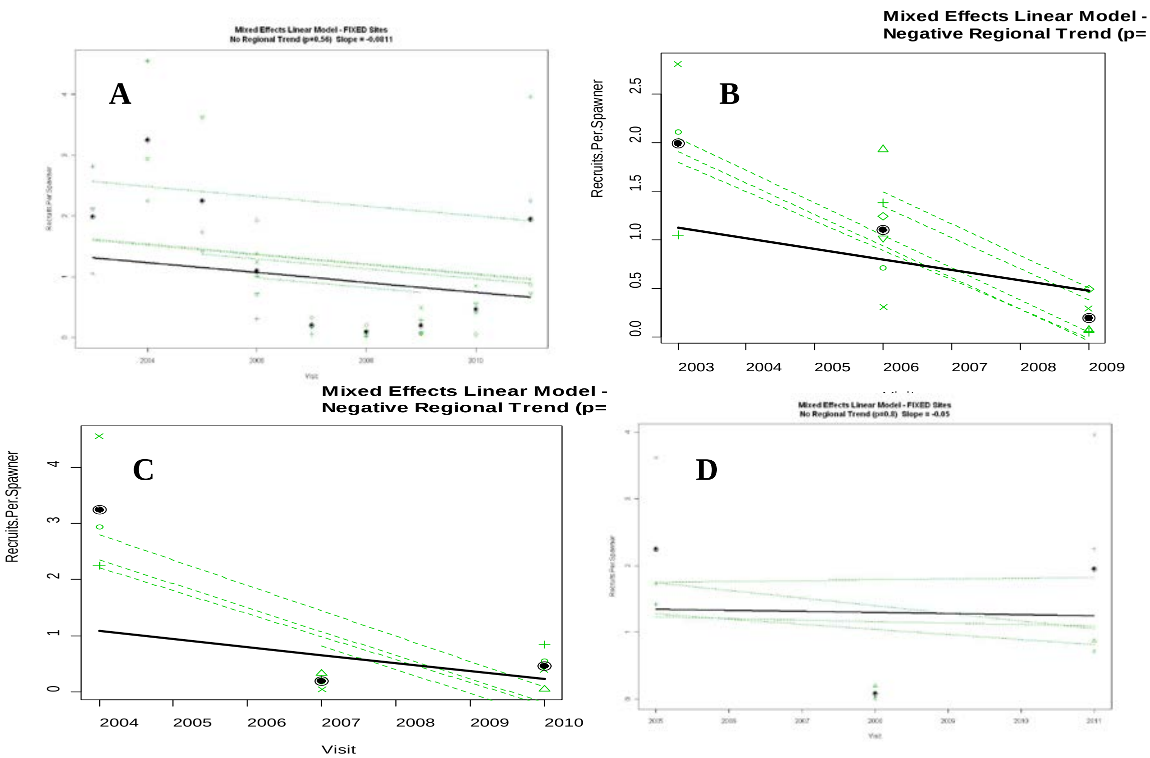

Figure 5. Coho salmon recruits per spawner (population productivity) trends in coastal Mendocino County 2000 to 2011. A. All years. B. Cohort 1. C. Cohort 2. D Cohort 3.

Discussion

Mendocino Coast Sample GRTS Draw

Boydstun and McDonald (2005) suggested their example sample frame would need refinement which might reduce the sample frame by 30-40%. We reduced a list of 2033 stream reaches to 339, an 83% 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% of the GRTS sample reaches should be assigned as annual samples. During 2010 we sampled reaches 1-16 and 42 to 66 and in 2011 we sampled reaches 1 to 16 and 67 to 92. On average 21% 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 study (C. Jordan NOAA Fisheries, Northwest Fisheries Science Center, Personal Communication).

Table 9. Estimated number of Chinook salmon redds and adult escapement for coastal Mendocino County during 2011.

Stream	Number of Reaches	Number of Chinook Salmon Redds			Number of Chinook Salmon Adults [1]			Confidence Width
		Low 95% CI	Point Estimate	High 95% CI	Low 95% CI	Point Estimate	High 95% CI	
Mencodino Coast	17	0	19	342	0	48	855	900%
Lost Coast Diversity Strata	12	0	13	240	0	33	600	na
Navarro Point Diversity Strata [2]	5	0	6	102	0	14	255	
Albion River [2]	1	0	1	18	0	3	45	
Big River [2]	4	0	5	96	0	13	24	
Garcia River [2]	2	0	2	33	0	5	83	
Navarro River [2]	3	0	4	69	0	10	173	
Noyo River	6	0	4	51	0	7	128	
Ten Mile River [2]	3	0	4	75	0	10	188	

1 Escapement estimate assumes 2.5 fish per redd.

2 Chinook salmon redds and adults were not observed in these reaches. Estimates are based on regional average Chinook salmon redd density.

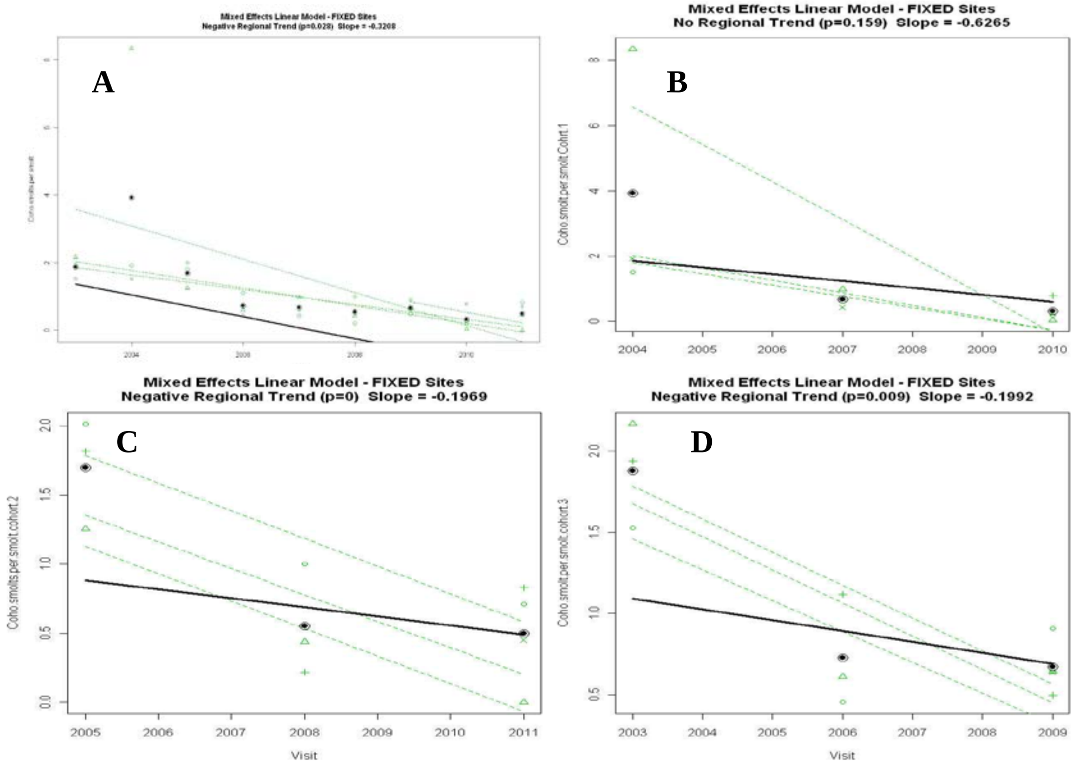

Figure *6*. Coho salmon smolts per smolt (freshwater productivity) trends in coastal Mendocino County 2000 to 2011. A. All years. B. Cohort 1. C. Cohort 2. D Cohort 3.

Life Cycle Monitoring

Adult Escapement

For both 2009-10 and 2010-11 our coho salmon escapement estimates in Caspar Creek were based on AUC because we did not capture and tag any fish at our weir. Abundance was low in all three streams in 2010-11 and although higher than the previous two years, this low abundance resulted in low precision in our escapement estimates. In Caspar Creek and the South Fork Noyo River our precision was above the 30% recommended by Jacobs and Nickelson (1998) for monitoring coho salmon. Because we captured and tagged many fish, it was within this limit for Pudding Creek coho salmon during 2010-11. Crawford and Rumssey (2009) suggest that salmon monitoring strive for CV's of ± 15%. The CV's for our coho mark-recapture experiments in Pudding Creek (14%) was within this limit where as the South Fork Noyo River (25%) were above it. However, Krebs (1989) states that CV's for fish populations generally range from 0.50-2.00 (50% to 200%), indicating that Crawford and Rumsey's suggestion that monitoring strives for CV's of ± 15% is optimistic and perhaps unattainable. Our lack of precision in our capture recapture data is likely the result of low overall spawner abundance, because in Pudding Creek where we tagged

122 coho salmon the precision in our escapement estimate was reasonable.

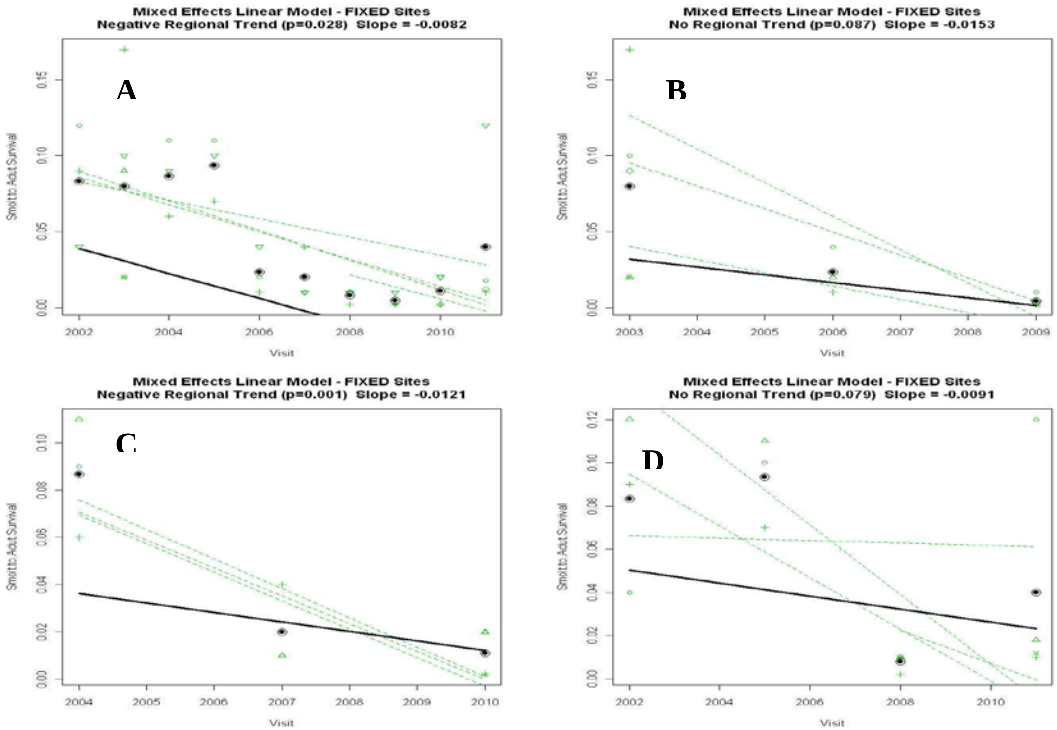

Figure *7*. Coho salmon smolt to adult survival trends in coastal Mendocino County 2000 to 2011. A. All years. B. Cohort 1. C. Cohort 2. D Cohort 3.

Our Steelhead mark-recapture escapement estimates were very imprecise again this year. Jacobs et al. (2001) defined ± 30% as target precision levels for steelhead redd count estimates in Oregon. Gallagher et al. (2010 b) state that for steelhead, managers may have to except lower precision in steelhead estimates or use redd areas. We attributed this to low abundance and difficulties capturing and observing steelhead. Over the past seven years precision in our steelhead escapement estimates has ranged from 40% to 221%, we have never achieved precision ≤ 30%.

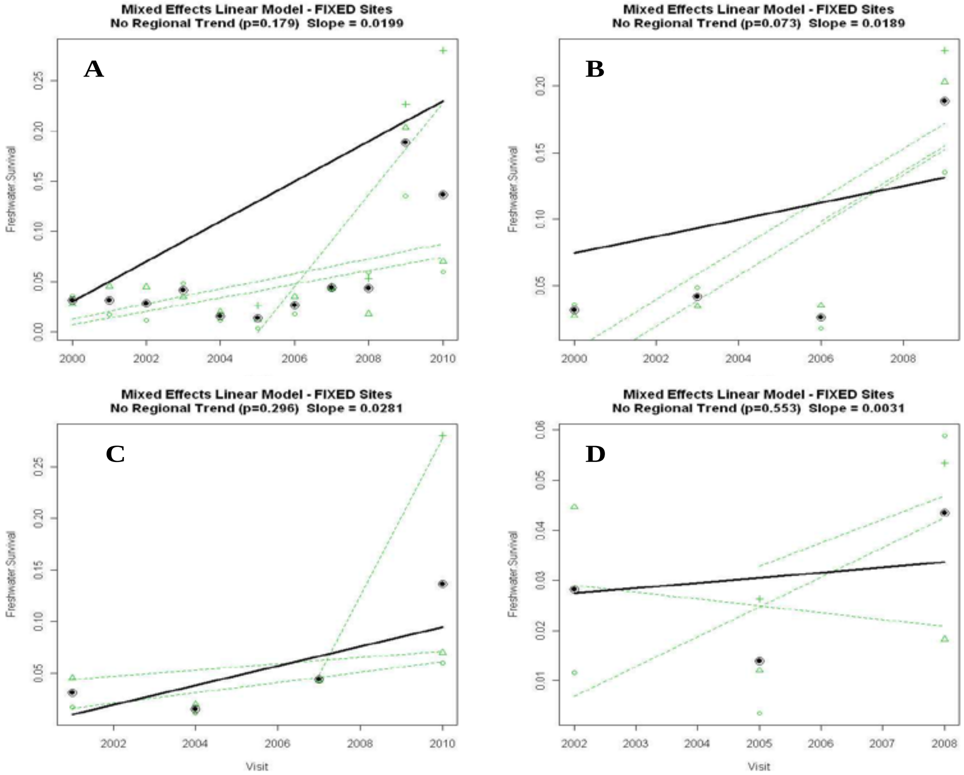

Figure.*8*. Coho salmon egg to smolt survival trends in coastal Mendocino County 2000 to 2011. A. All years. B. Cohort 1. C. Cohort 2. D Cohort 3.

Krebs (1989) states that population estimates for management should be accurate to ± 25% and preliminary surveys should be ± 50%. Jacobs and Nickelson (1998) suggest that ± 30% should be the target precision level for monitoring coho salmon. Jacobs et al. (2001) also defined ± 30% as target precision levels for steelhead redd count estimates in Oregon. Between 2004 and 2008 and in 2011 the precision in the live coho capture-recapture estimates for Pudding Creek was < 30%, in two of these years it was ≤ 25%, and last year it was < 15%. The precision in our steelhead numbers has been > 30% over the past several years. Jacobs and Nickelson (1998) had basin level precision in escapement estimates between 80% and 99%. Korman et al. (2002) suggest that precision in tagging studies can be improved by selecting survey dates with the best possible survey conditions and by increasing the number of tags present (i.e. marking more fish). Despite our continued efforts steelhead prove difficult to capture, tag, and re-observe, primarily due to low abundance. For this species, managers may have to accept larger uncertainties in escapement estimates. This may also hold true for coho salmon in some years (Gallagher et al. 2010b). 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.

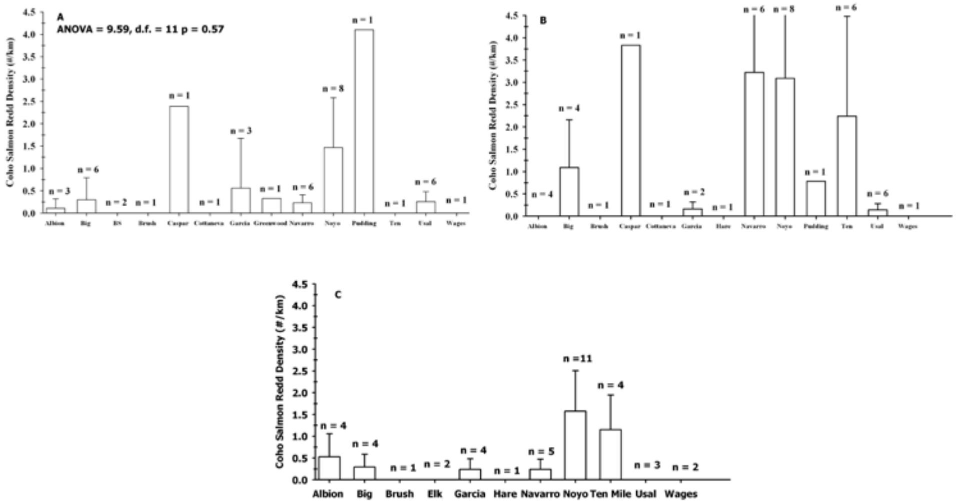

Figure 9. Average coho salmon density by stream for regional surveys in coastal Mendocino County California 2009 to 2011. A. 2009. B. 2010. C. 2011. Numbers above estimates are sample sizes (the number of reaches surveyed). Thin lines are 95% confidence limits.

Smolt Abundance

PIT tags allowed us to mark individual fish and collect fish specific data during multiple recaptures in Pudding Creek. We found that only a small proportion of fish were captured multiple times or showed delayed migration. Because the PIT tags provide unique individual marks, we were able to account for multiple recaptures when developing input matrices for Darr and thus reduced this potential source of error. In 2012-13, pit tagged smolts returning as adults should provide useful information on ocean survival.

Bell and Duffy (2007) document a two-year freshwater life history of coho salmon for the first time in California. Bell (2001) states that 28% of coho captured during the second year of his study were age two. We documented two-year old coho salmon smolts in coastal Mendocino County, California by using PIT tags to mark fish during spring downstream trapping and fall electro-fishing - beginning in 2006. We have observed this life history each year since we initiated PIT tag operations. Our estimates of two-year-old coho salmon smolts in coastal Mendocino streams were less than observed by Bell (2001). Our 2006 over-summer data for Pudding Creek 2006 to smolts 2007 and our 2008 smolts marked at Caspar Creek caught again in 2009 (19% ± 2) suggested that about 20% of the year old coho tagged in spring 2006 remained in these streams for an additional year (Gallagher and Wright 2007). According to ODFW (1996) coho smolts remain in streams for two or three years in British Columbia, the coldest part of their range. Water temperatures in our LCS are similar to those of the other coastal California streams where this life history has not been observed. Based on our recapture of adults with PIT tags first marked as smolts, the average size at smolting was about 98 mm, suggesting there is a threshold size necessary for coho migration to the ocean (Gallagher and Wright 2009). Fish that fail to meet this size by the end of spring may remain in the stream a second year. At the time of migration to the ocean in their second spring these fish are generally larger than this minimum size. In fact most two year rearing coho salmon are much larger than the one year-old fish (Wright et al. 2012). This suggests fish marked later in the spring are likely to hold a second year, probably because they had yet reached a sufficient size for migrating to the ocean.

Survival

Coho smolt to adult survival over nine smolt-to-adult return cycles was similar to that reported by Bradford (1999), Logerwell et al. (2003), and Shapovolov and Taft (1954) between 2002 and 2005, was considerably lower from 2006 to 2010, and appears to have rebounded some in 2011 (*Fig.* 7). Both smolt to adult and recruits per spawner show a similar drop in mid to late-2000 and a possible rebound in 2011 (Table 6). Coho smolt to adult (and adult-to-adult) survival is influenced by ocean conditions at the time of ocean entry. Gallagher and Wright (2011) found that ocean survival was more influential in driving population production than was freshwater survival, furthering the notion that ocean conditions at the time coho salmon smolts immigrate to the sea is important to survival (Spence and Hall 2010).

Trends in Coho Abundance, Productivity, and Survival

We did not find significant trends in coho escapement over 11 years in our LCS streams. This may be a result of the length of the time series or due to the three-year coho salmon life cycle. However, all populations showed moderate to high extinction risk and population sizes < 500 (Tables 7-8) and there was a negative trend in the geometric mean escapement for all LCS coho populations. When we examined escapement trends by cohort none showed a significant negative trend at $p < 0.05$. If we increased the p-value for accepting statistical significance to $p \leq 0.10$, two of three cohorts showed significant negative escapement trend over 11 years. Both of these approaches to evaluate escapement trends are designed to incorporate the three-year life history of coho salmon. Thus the difference between the regional model results by cohort and methods suggested by Spence et al. (2008) may be a result of small sample size in the latter or because of cohort overlap that is not accounted for in our mixed model analysis but is using the geometric mean approach. Trend detection may be more appropriate over a longer time series (Spence and Williams

2011, Spence et al. 2008), with additional covariates such as mean December to January stream flow, an index of the Pacific decadal oscillation or ocean survival, annual precipitation, March to June stream flow two years previous, and perhaps other values. Larsen et al. (2004) found that trend detection increased markedly with increased time series and Shea and Mangel (2001) state that statistical uncertainty in trend detection for modeled coho populations increased with shorter time series. There is increasing evidence that Pacific salmonid populations follow a decadal cycle in abundance that is related to large-scale climate cycles (Smith and Ward 2000, Smith et al. 2000). If salmonid population abundance fluctuates on decadal or longer periods, our 11 year dataset could be too short to detect these long-term trends. However, Bradford et al. (2000) suggest their results, and others they cite, argue against the idea that regional climate variation affects coho freshwater survival. When we examined adult coho salmon trends by cohort we found that two cohort showed a significant negative trend (at $p < 0.10$) whereas their smolt progeny did not, furthering the notion that poor ocean conditions was the cause. In addition, we saw no trends in smolt abundance and a positive trend freshwater survival for one cohort (at $p < 0.10$), whereas productivity (recruits per spawner) and smolt to adult survival showed significant negative trends. Similar to Moore et al. (2011) low adult returns did not result in low smolt abundance. Gallagher and Wright (2011) showed that marine survival drives populations in our LCS which suggests that ocean rather than freshwater conditions may be responsible for the negative trends we observed.

We did not examine steelhead trends due to the short time series in the data. Steelhead can live up to seven years and spawn as many as four times (Shapovolov and Taft 1954). Thus we only have data for one generation. Continued monitoring of these streams is necessary to provide this type of data as well as information needed for population viability assessments as recommended by Spence et al. (2008).

Regional Spawning Survey Abundance Estimation

For the third consecutive year we produced Chinook and coho salmon and steelhead 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% confidence half widths) was lower than expected, we now have estimates, with statistical certainty, of how many salmonids 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.

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% 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*. 10) peaked out at n = 41 and did not substantially decrease after about 58 reaches (~15%). 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. 2010 b) 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% to 35% 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.

Table 10. Estimated sample sizes (number of reaches) for five desired levels of precision (width of the 95% 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

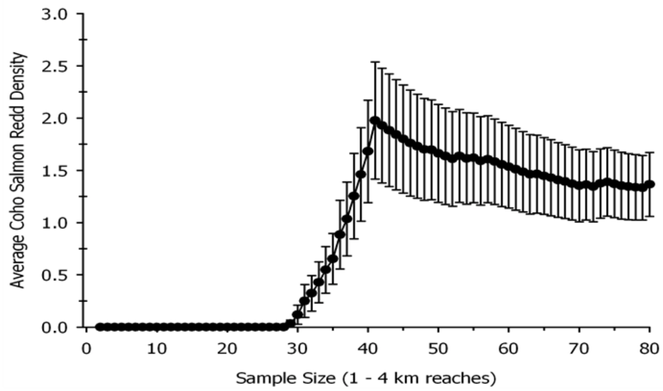

Figure 10. Cumulative mean coho salmon redd density (±SE) plotted against the number of sample reaches surveyed in coastal Mendocino County, California during 2010.

Crawford and Rumsey (2009) suggest that salmon monitoring programs strive for estimates that have a coefficient of variation (CV) of ± 15%. Our regional CV's for coho salmon averaged 221% (n = 41) to 220% (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% 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.

Additional Accomplishments

Three primary literature publications were produced as a result of FRGP Grant P0810312. In addition the California Coastal Monitoring Plan (Adams et al. 2011) was published. This document, which forms the foundation of salmon monitoring in coastal California, benefited a great deal due to work funded by this grant. Sean Gallagher presented preliminary findings from this study at the 2011 Salmonid Restoration Federation conference and participated in a workshop on monitoring salmon in California. Dave Wright and Sean Gallagher gave papers at the Redwood Science symposium in June 2011. Other accomplishments: Campbell received a Mendocino County Fish and Game Commission grant to fund improvements in their PIT tag arrays at the Pudding Creek dam. As a result of analysis conducted under this grant (Gallagher and Wright 2011) we have started to evaluate methods for regionally monitoring fish habitat. In summer 2011 we participated in training and conducted habitat surveys following the CHaMP protocols (wwww.Champmonitoring.org).

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RECOMMENDATIONS

The life cycle monitoring portion of this study should be continued into perpetuity to gather data on multiple generations of salmonids and increase the data set for trend detection. After 2009, these streams should be included in a larger coast-wide monitoring effort. Increase capture and marking of steelhead by better operation of the Pudding Creek flashboard dam and the Noyo ECS. Bootstrap simulations should be used to calculate 95% confidence bounds for regional population estimates. Coordination with others collecting this type of data should continue and a standardized database should be constructed for use at the regional level for both LCS streams and regional GRTS sampling. Access agreements with landowners should be established prior to November 1st each season.

Capture-recapture at LCS streams should use weekly specific colored floy tags and operculum punches with recaptures made during spawning ground surveys. Smolt abundance should be estimated annually at LCS streams using downstream migrant traps and PIT tag capture-recapture. The effect of using the neighborhood variance estimator (Stevens 2002) to estimate confidence bounds on sample size should be evaluated. All coastal salmon monitoring should be included in a master sample and use of standardized data collection procedures and well trained staff (Gallagher et al. 2007).

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