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EVALUATION OF COHO SALMON (*Oncorhynchus kisutch*) AND STEELHEAD (*O. mykiss*) SPAWNING GROUND ESCAPEMENT ESTIMATES FOR MONITORING STATUS AND TRENDS OF CALIFORNIA COASTAL SALMONIDS: 2000-2005 ESCAPEMENT ESTIMATES FOR SEVERAL MENDOCINO COUNTY COASTAL STREAMS

PROJECT 1d2

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ABSTRACT

I estimated escapement from spawning ground surveys in Caspar and Pudding (PC) creeks and the South Fork Noyo (SF) and Little rivers during 2004-05 using redd data and the Area-Under-the-Curve. Coho salmon and steelhead were tagged entering PC and recaptured during spawning surveys to estimate abundance. Known numbers of coho salmon were tagged and released above the SF Egg Collecting Station (ECS). Coho salmon escapement was estimated with carcass capture-recapture in all four streams. Recoveries of tagged fish in PC and the SF were used to estimate residence time (*rt*) and observer efficiency (*e*) and compared to other estimates of these values. Including 2001 to 2004 escapement estimates for these streams, capture-recapture estimates and redd counts were significantly correlated and equally reliable for monitoring escapement. Only escapement estimates assuming one redd per female were significantly different than estimates from other methods. Estimates of the number of coho salmon and steelhead per redd were not different among streams and years and escapement estimated using these values were not significantly different. Results indicated that estimates of the number of fish per redd can be transferred among steams to estimate populations from redd counts and that these estimates are equally reliable compared to capture-recapture or total counts. Carcass capture-recapture did not work for steelhead and may not be appropriate for long term regional monitoring. Estimates of *rt* and *e* were variable, depended on estimation method, were not different among streams and years, and may be transferable among streams. Coho salmon abundance over five years and for two complete life cycles did not show clear trends. The purpose of this study was to 1) determine the most reliable method of estimating spawning ground survey based salmonid escapement for status and trend monitoring, 2) produce annual escapement estimates for several coastal Mendocino County streams 2000 to 2005, 3) evaluate trends in abundance, and 4) provide recommendations for monitoring coastal salmon populations.

[1] Anadromous Fisheries Research and Monitoring Program Report No. FB05-02. 30 September 2005. Phillip K. Barrington Senior Biologist Supervisor, California Department of Fish & Game, 50 Ericson Court, Arcata, CA 95521

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INTRODUCTION

Accurate estimates of escapement are essential for effective management and conservation of salmonids (Busby et al. 1996, McElhany et al. 2000). In Northern California coastal coho salmon (*Oncorhynchus kisutch*) and steelhead (*O. mykiss*) are listed as threatened species under the U. S. Endangered Species Act (Federal Register 1997, 2000). Delisting criteria will presumably depend on whether important populations have reached abundance thresholds, one of the four key components of the Viable Salmonid Population concept (Busby et al. 1996). There is a need for reliable, cost effective, and precise techniques for monitoring coastal salmonid escapement in Northern California.

Boydstun and McDonald (2005) propose the use of annual spawning ground surveys for long term regional monitoring of California coastal salmonids where adult population sizes are estimated annually in a rotating panel design that samples 10% of all spawning habitat using one or a combination of commonly used techniques including live fish or redd counts and or salmon carcass counting (first stage sampling). They further propose the use of second stage sampling (life cycle monitoring stations) where known estimates of returning adults from total counts or capture-recapture experiments are used to calibrate spawning ground escapement estimates from the first stage sampling. Boydstun and McDonald (2005) suggest that the first stage sampling could utilize 1) redd surveys where either the total number of redds, redd counts converted to adult numbers using estimates of the number of fish per redd (from second stage sampling or by assigning a constant such as 2.5 fish per redd), or redd areas estimates are a sufficient measure of adult population status 2) repeated live fish counts with the Area Under the Curve (AUC), or 3) salmon carcass capture-recapture techniques (Boydstun 1987). Boydstun and McDonald (2005) state that the California Department of Fish and Game will need to determine which of the above methods should be used after a few years of field experience and data analysis.

Each of the above potential escapement estimation methods is assumed to produce an unbiased estimate of annual coastal salmonid escapement. Escapement estimates from the second stage sampling sites using either capture-recapture or dam counts thus are assumed to be "true" known number for calibration of first stage estimates. Gallagher (2005) discusses the assumptions of these spawning ground escapement estimate methodologies.

Gallagher and Gallagher (2005) provide techniques to reduce bias in coastal salmonid redd counts and show that redd counts were significantly correlated with adult escapement and that escapement estimates based on redd sizes were not significantly different than those from live fish counts (AUC), releases above a counting structure, and capture-recapture experiments. However, they found that escapement estimates assuming one redd per female were significantly different than estimates from other methods. Gallagher (2005) found that coho salmon and steelhead escapement estimates were significantly correlated with redd counts and that redd area, AUC, and coho carcass capture-recapture escapement estimates were not significantly different from "true" escapement estimates.

As proposed by Boydstun and McDonald (2005), estimates of the number of fish per redd for calibrating first stage sampling by converting redd counts to abundance must be transferable among streams and over years. Susac and Jacobs (2002) found considerable variation in the number of female and adult steelhead per redd in coastal Oregon rivers and Dunham et al. (2001) found that bull trout spawner: redd ratios were similarly variable among streams and years. In Oregon steelhead redd counts are significantly correlated with adult escapement and an estimate of 1.54 females per redd was developed (Susac and Jacobs 2002). In Washington redd counts are the principal method for monitoring salmonids and cumulative redd counts are expanded by 2.5 fish per redd to estimate escapement (Boydstun and McDonald 2005). Gallagher (2005) found that the four year (2000 to 2004) average number of coho salmon per redd in the South Fork Noyo River was the same as estimated in Pudding Creek in 2003-04 and escapement estimates using these values were not significantly different than results from other methods suggesting these variables are transferable among streams. The four year average number of steelhead per redd in the Noyo River was not different than estimated in Pudding Creek in 2003-04 and escapement estimates using these values were not significantly different than estimates from other methods suggesting that estimates of the number of fish per redd can be transferred among steams and used to convert redd counts to population estimates (Gallagher 2005).

To use the AUC for estimating escapement from spawning ground surveys, as stated in the California Plan (Boydstun and McDonald 2005), estimates of residence time (*rt*) and observer efficiency (*e*) will need to be transferable from life cycle monitoring stations to streams in which they are not estimated over many years. If a grand mean residence time and the associated statistical uncertainty from observations in many streams over a period of years can be shown not to differ from individual streams over time this estimate could replace yearly stream specific estimates and eliminate the transferability issue. If observer efficiency can be predicted from stream flow or water visibility, stream and year specific estimates will not be needed and the transferability issue would be eliminated.

The AUC method is sensitive to the time between surveys and estimates of *rt* and *e* (English et al. 1992, Hilborn et al. 1999), both of which require independent capture-recapture experiments for their estimation which are usually capable of producing escapement estimates without the AUC (Gallagher and Gallagher 2005). Gallagher (2005) found that biweekly spawning ground surveys were sufficient for use in the AUC in coastal Mendocino County. Because *rt* and *e* change through each spawning season and are different from year to year, English et al. (1992) and Hilborn et al. (1999) suggest that they be estimated annually throughout each season for each stream. However, Gallagher (2005) found that these variables may be transferable among coastal streams. A major short coming of the AUC is that it lacks a rigorous statistical method for calculating confidence bounds and when estimated requires intensive bootstrap computer simulation and independent capture-recapture estimates for their calculation (Korman et al. 2002, Parkin et al. 2003).

Korman et al. (2002) found that observer efficiency for steelhead counts could be predicted from stream flow and water visibility and Gallagher (2005) developed predictive models of *e* for steelhead and coho salmon based on these variables. Gallagher (2005) states that estimates of *rt* and *e* were variable, depended on the method of estimation, were not different for coho salmon between Pudding Creek and the South Fork Noyo River, and may be transferable among streams.

The purpose of this study was to 1) determine the most reliable method of estimating spawning ground survey based salmonid escapement for status and trend monitoring, 2) produce annual escapement estimates for several coastal Mendocino County streams 2000 to 2005, 3) evaluate trends in abundance, and 4) provide recommendations for monitoring coastal salmon populations. I examined and evaluated sources of error and bias in redd counts and escapement estimates based on redd areas, one redd per female, the number of fish per redd from intensively monitored basins, carcass capture-recapture, and live fish observations in the Area-Under-The-Curve (AUC) and investigated the relationship between these escapement estimates and "true" escapement estimated from capture-recapture experiments and releases above a counting structure. Results of these examinations were used to suggest the best methodology for estimating escapement from spawning ground surveys. I also examined trends in abundance over five years for coho salmon and steelhead and for two complete life cycles of coho salmon.

Specific questions important for developing reliable escapement estimation methodologies for long-term large geographic scale monitoring of salmonids addressed were:

1.) Do redd counts reflect population status?
2.) Are redd counts by themselves reliable metrics for long term status and trend monitoring of California's coastal salmonids?
3.) Are escapement estimates based on redd areas reliable and can the assumptions of this approach be justified?
4.) Are escapement estimates assuming one redd per female reliable and can the assumptions of this approach be justified?

5.) Are estimates of the number of fish per redd from intensively monitored basins (e.g. life cycle monitoring stations) reliable for converting redd counts into fish numbers, are these estimates transferable among streams and years, can predictive models be developed and applied to estimate fish numbers from redd counts and do they differ from "true" escapement estimates?

6.) Do carcass capture-recapture estimates differ from true estimates and will they work in the California Plan context?

7.) Can *rt* and *e* be reliably estimated, are these estimates transferable among streams and years, and did the models for predicting *e* from stream flow and water visibility developed in 2004 work in 2005?

8.) Are there trends in escapement over five years for steelhead and coho salmon and over two complete life cycles of coho salmon?

9.) Which if any of the 2004 recommendations worked in 2005 and why?

10.) What recommendations for long term monitoring can be made based on the findings of this study?

I followed the methods of Gallagher and Gallagher (2005) and Gallagher (2005) to estimate escapement from spawning ground surveys in Caspar and Pudding creeks and the South Fork Noyo and Little rivers during 2004-05. Data from Gallagher (2005) was combined with results from 2004-05 for multiyear evaluations. Adult coho salmon and steelhead were captured and tagged at the Pudding Creek weir and recaptured during spawning surveys to estimate capture-recapture population sizes. Adult coho salmon were tagged and released above the Noyo Egg Collecting Station (ECS). Coho salmon carcasses capture-recapture was also used to estimate escapement for all four streams. Tag recoveries of fish tagged at the Pudding Creek weir and the Noyo River ECS were used to estimate *rt* and *e* and these variables were also calculated using the capture-recapture estimates and the trapezoidal approximation.

Redd counts, with bias in counts reduced following Gallagher and Gallagher (2005), and releases above the Noyo River Egg Collecting Station (ECS) were equally reliable measures of coho salmon escapement. Redd counts, with bias in counts reduced following Gallagher and Gallagher (2005), and capture-recapture estimates were equally reliable measures of steelhead escapement. Redd counts and escapement estimates were significantly correlated further substantiating the idea that redd counts are reliable measures of salmonid escapement. Capture-recapture estimates were not different than those from other methods except for estimates assuming one redd per female and reporting results of this approach should be abandoned in the future. Escapement can be estimated from predictive models of the number of fish per redd and redd counts. Redd area escapement estimates were not different than other methods, but the assumptions of this method may be cumbersome for regional monitoring.

Escapement estimates using the average number of fish per redd were not different than capture-recapture estimates or releases above the ECS. The number of fish per redd was not different between Pudding Creek and the South Fork Noyo River above the ECS for both species. The five year average number of coho salmon per redd over predicted coho escapement compared to carcass capture-recapture in Caspar Creek and Little River, but estimates were within the 95% confidence bounds.

Carcass capture-recapture estimates were not different than true estimates but had wide confidence bounds. This method did not work for steelhead and may not work for 3km reaches as suggested in the California Plan (Boydstun and MacDonald 2005) and will require further evaluation in the Mendocino Coast Pilot Program (Gallagher and Collins 2004).

Coho salmon *rt* was not significantly different between Pudding Creek and the South Fork Noyo River nor was it different over two years suggesting these estimates are transferable among streams years. Average *rt* of all year's data and weekly predicted *e* resulted in the best estimate in the AUC for coho salmon. Steelhead *rt* was not significantly different between the Noyo River 2000-03, above the ECS in 2005, and Pudding Creek in 2004 and 2005 suggesting transferability among steams and years. However using average *rt* and weekly *e* overestimated steelhead escapement compared to capture-recapture estimates, but estimates were within the 95% confidence. For steelhead, annual estimates of *rt* without *e* produced the most reasonable escapement estimates in the AUC and should be used in future studies.

Observer efficiencies predicted from stream flow and water visibility were not different from estimates calculated in 2005 nor was it different between Pudding Creek and the South Fork Noyo River suggesting these predictive models can be used to estimate *e* in other streams and subsequent years.

There were no trends in abundance over five years or for two cohorts of coho salmon regardless of escapement estimation method. The slope of the regression lines for steelhead and coho versus year were not significantly different among streams suggesting these streams constitute single populations.

Redd counts are reasonable metrics for long term monitoring of salmonid escapement and avoids problems associated with extrapolating redd counts to fish numbers as well as those associated with the AUC and should be primary metric for long term monitoring of California's Coastal Salmonids. If conversion of redd counts to fish numbers is necessary, then using either the average number of fish per redd or predictive regression equations presented herein should suffice.

MATERIALS AND METHODS

Study Area and Data Collection

The streams studied were Caspar and Pudding creeks and the Little and South Fork Noyo rivers (Figure 1). These streams range in drainage area from 13-62 km^2, flow directly into the ocean, are unregulated, and are surface and groundwater fed with peak flows occurring in winter following heavy rains.

All available spawning habitat in Caspar and Pudding creeks and the South Fork Noyo and Little rivers was surveyed approximately bi-weekly from early-December 2004 to mid-April 2005. Field methods, reduction of bias in redd counts, escapement estimation from redd data, and examination of the relationship between redd counts and capture-recapture escapement estimates followed Gallagher and Gallagher (2005). Redd density was calculated from the observer efficiency corrected redd counts divided by the reach length (km) for each survey segment.

Escapement Estimates

Redd Area and One Redd/Female

Escapement estimates based on redd data followed Gallagher and Gallagher (2005) and were made by expanding total redd counts by the male to female ratio (Tables 1 and 2) and by a method which assumes the number of redds a female makes is related to redd size (redd area method). Escapement estimates assuming one redd per female were made by multiplying the observer efficiency corrected number of redds by the male to female ratio observed in each river and summing this with the number of redds. The number of fish and females per redd were calculated from the total observer efficiency corrected redd counts and estimates of the number of fish and females from the redd area method. Redd area fish density (number per km) was calculated from the observer efficiency corrected redd estimates divided by the reach length (km) for each survey segment.

Number of Fish Per Redd

The number of fish per redd was calculated by dividing the capture-recapture estimates for coho salmon and steelhead (Pudding Creek only) by the observer efficiency corrected estimate of the number of redds of each species in Pudding Creek and in the South Fork Noyo River for all years this data was available. These estimates were then used to convert redds counts to fish numbers in each stream such that fish per redd in Pudding Creek was used to estimate fish in the South Fork Noyo River and visa versa. The average number of coho salmon per redd from 2001-2005 above the ECS and Pudding

Creek 2004 and 2005 were used to convert redd counts to fish numbers and these data compared to capture-recapture estimates.

The average number of steelhead per redd from the Noyo River 2000-2003 and Pudding Creek 2004 and 2005 used to convert redd counts to fish numbers and these data compared to capture-recapture estimates. The numbers of fish per redd were similarly estimated using AUC and carcass capture-recapture estimates and estimated from linear regression of the total redd counts and the AUC and capture-recapture estimates using data from 2000 to 2005 in all streams for which this data was available. Redd counts were also converted to fish numbers using equations from Gallagher (2005) and compared to capture-recapture estimates and releases above the ECS for all streams and years this data was available. When standard kurtosis p-values were < 0.05 data were log transformed for regression analysis. Escapement predicted from these equations was compared to capture-recapture and releases above the ECS for all streams and years this data was available.

Capture-Recapture

Steelhead escapement in Pudding Creek was estimated using the Schnabel capture-recapture method during 2004-05 (Krebs 1989). During 2004-05 steelhead were captured and marked with brightly colored floy tags at a weir located 0.25 km from the Pacific Ocean and recaptured visually during spawning surveys. Following the recommendation of Gallagher (2005) floy tag colors were changed weekly. Steelhead capture-recapture estimates were not possible using the Noyo River ECS because steelhead usually bypass this structure and too few fish were marked and recovered.

Coho salmon escapement in Pudding Creek was estimated using the Jolly-Seber and Schnabel capture-recapture methods during 2004-05 (Krebs 1989). During 2004-05 coho salmon were captured and marked with brightly colored floy tags and with weekly specific operculum punches at a weir located 0.25 km from the Pacific Ocean and sightings of live marked and unmarked fish in spawning surveys were used to estimate escapement. Following the recommendation of Gallagher (2005) floy tag colors were changed weekly. Floy tags on carcasses were recovered and all carcasses inspected for operculum punches to estimate tag loss and *rt*. Less than 1% of coho salmon marked at the weir were recaptured at the weir having been washed below the dam by high flows after being marked and released. Data from these recaptures was used to estimate tag loss.

Known numbers of coho were marked with colored floy tags and released above the Noyo River ECS during 2004-05. Floy tag colors at the ECS were not changed weekly, but hatchery and wild fish were given different colored tags (Mike Morrison Personal Communication). The proportion of tagged fish observed below the ECS was used to correct total release count above the ECS for fish that passed back downstream of, and spawned below, the ECS.

Coho populations were also estimated by capture and recapture of carcasses during spawning surveys in all streams following Gallagher and Gallagher (2005) with Jolly-Seber method, or the Schnabel or Petersen method when recaptures were less than seven (Krebs 1989). Carcass mark-recapture data for 2004-05 was examined by survey reach to determine the appropriateness of the data for producing reach specific capture-recapture estimates.

AUC

Spawning population estimates were derived from live fish observations using the AUC (English et al. 1992, Hilborn et al. 1999). Steelhead *rt* was estimated from the time between capture and recapture of tagged fish and calculated from the trapezoidal approximation and capture-recapture estimate for Pudding Creek, both with and without estimates of observer efficiency (note that *rt* is also called survey life, Korman et al. 2002). Steelhead *rt* was also estimated from observation in Pudding Creek during 2003-04, observations in the Noyo River 2000 though 2003, observations in the South Fork Noyo River during 2005, and taken from the literature (Gallagher and Gallagher 2005).

To evaluate if estimates of *rt* and associated statistical uncertainty could be used to provide some measure of uncertainty in the AUC average and S.E.'s were calculated and combined with various estimates of *e* to calculate AUC escapement estimates. Residence times were compared among steams and over years using paired t-tests and ANOVA. The AUC escapement estimates were calculated with various combinations of *rt* and *e* and compared to capture-recapture escapement estimates.

Coho salmon *rt* was estimated from the time between the initial capture of live fish and recapture of tagged fresh (clear eyes and no fungus assumed recently deceased) carcasses in Pudding Creek 2003-04 and 2004-05 and in the South Fork Noyo River above the ECS 2001 through 2005, calculated from the trapezoidal approximation and capture-recapture both with and without estimates of observer efficiency for 2004-05, and taken from the literature (Beidler and Nickelson 1980). To evaluate if estimates of *rt* and associated statistical uncertainty could be used to provide some measure of uncertainty in the AUC average and S.E.'s were calculated and combined with various estimates of *e* to calculate AUC escapement estimates. Residence times were compared among steams and over years using paired t-tests and ANOVA. The AUC escapement estimates were calculated with various combinations of *rt* and *e* and compared to capture-recapture escapement estimates and releases above the ECS.

Due to the amount of data from the floy tagging of fish in Pudding Creek and the South Fork Noyo River, observer efficiency (*e*), the ratio of total fish seen to the total present (Korman et al. 2002), was estimated a number of different ways. Following Gallagher and Gallagher (2005) the total number of fish of each species observed during spawning surveys was divided by the capture recapture estimates for each season. Thus confidence intervals for AUC and capture-recapture estimates were interrelated for estimates calculated in this manner. Observer efficiency was also estimated from the total marked and the total observed marked during spawning surveys for the entire season and weekly, and calculated from the trapezoidal approximation with different estimates of *rt*. Weekly estimates of *e* for each species were predicted from weekly estimates of stream flow and water visibility using regression models from Gallagher (2005). A typographic error was discovered in the equation for predicting steelhead observer efficiency from stream flow data presented in Gallagher (2005). The correct equation is Observer Efficiency = 0.0319 + (0.0231 * stream flow m^3/s). These models were applied to Caspar Creek and Little River where tag based estimates of *e* were not available to predict it from flow and water visibility. Predicted and calculated weekly *e* for the South Fork Noyo River and Pudding Creek in 2005 were compared using paired *t*-tests.

Trends in Coho Salmon Abundance

Trends in coho salmon and steelhead abundance over five years and for two complete life cycles of coho salmon (2000 to 2004 and 2001 to 2005) were examined following Gallagher and Knechtle (2004) and Gallagher (2005). The slopes of adult abundance versus year for all five years were compared with paired t-tests treating each stream as a sample. The slope of adult abundance versus year from 2000 to 2005 for each stream were examined graphically and statistically tested to determine if they differed from zero or from one another. Redd counts and redd densities versus year were similarly examined for trends.

Data Analysis

Population estimates were compared with ANOVA or the Kruskal-Wallis ANOVA on ranks when Standard Kurtosis p-values were < 0.05. Correlation was used to determine if redd counts or redd area escapement estimates were related to capture-recapture or AUC escapement estimates by treating year and river specific data for each species as samples. An ANOVA or the Kruskal-Wallis ANOVA on ranks when Standard Kurtosis p-values were < 0.05, were used to test if estimates of coho salmon *rt* and *e* were different between Pudding Creek and the South Fork Noyo River. Relationships between capture-recapture, releases above the Noyo River ECS, and AUC escapement estimates and redd counts were examined with correlation and fish per redd numbers estimated with linear regression models. The Bland-Altman method (Glantz 1997) was used to determine if redd counts and capture-recapture escapement estimates or releases above the ECS (coho salmon only) were equally reliable metrics for monitoring escapement. This technique was also employed to examine the reliability of escapement estimates based on redd areas, AUC, predicted from relationships between capture-recapture estimates or releases above the ECS and redd counts relative to "true" escapement estimates as well as examining *rt* estimates. The Bland-Altman method is used to compare two different measures of the same thing. If two measures are significantly correlated (suggesting reasonable agreement between the two), the mean difference between two measures (MD) is small (indicating no systematic bias), the standard deviation of MD is small relative to observations (SDL), the difference between the two measures and the mean are not significantly related (rDM), and the differences and means are within two standard deviations of the mean then the two techniques give measures which are equally reliable (Glantz 1997). Statistical significance was accepted at $p < 0.05$.

RESULTS

Redd Counts

Observer efficiency in steelhead redd counts ranged from 0.95 (S.E. = 0.05) to 0.42 (S.E. = 0.10) in the four study streams and was lowest in Caspar Creek (Table 3). The total number of steelhead redds in the four streams ranged from 22 (S.E. = 6) to 131 (S.E. = 9) and was lowest in Little River (Table 3).

Observer efficiency in coho salmon redd counts ranged from 0.96 (S.E. = 0.02) to 0.57 (S.E. = 0.15) in the four study streams and was lowest in Caspar Creek (Table 4). The total number of coho salmon redds in the four streams ranged form 76 (S.E. = 15) to 436 (S.E. = 24) and was lowest in Little River (Table 4).

Steelhead redd counts and capture-recapture were equally good measures of escapement. Steelhead redd counts and capture-recapture escapement estimates for the Noyo River 2000 to 2003 and Pudding Creek in 2004 and 2005 were significantly correlated ($r = 0.83$, $p = 0.04$, $n = 6$), the MD of -71.7 was low, SDL = 100.1 was fairly small compared to the range of the data, the rDM was not significant ($r^2 = 0.03$), and all data were within two standard deviations of the mean. Likewise, coho salmon redd counts and releases above the ECS were equally good measures of escapement. These two variables were significantly related ($r^2 = 0.80$), the MD of -5.4 indicated no systematic bias, the SDL = 99.9 was fairly small compared to the range of the data, the rDM was not significant ($r^2 = 0.26$), and all data were within two standard deviations of the mean.

Escapement Estimates

The uncertainty associated with estimating steelhead escapement by capture-recapture and the AUC was large and overlaps that of other methods suggesting all methods gave similar results for 2004-05 (Figure 2a-d, Table 3). For consistency with Gallagher and Gallagher (2005) steelhead AUC estimates in Figures 2a-d and Table 3 were made with *rt* of 12.6 days and *e* from the Pudding Creek capture-recapture estimates divided by the total number of steelhead observed during spawning ground surveys (see discussion of *rt* and *e* in the following section). Treating years as samples (previous year's data from Gallagher 2005) Noyo River 2000-03 and Pudding Creek 2004 and 2005 steelhead capture-recapture, AUC, and redd area escapement estimates were significantly different (ANOVA: $F = 5.22$, $p = 0.03$, df = 43, $\beta = 0.60$). Examined individually, the redd area and AUC estimates were significantly different (Tukey's $q = 4.57$, $p = 0.02$). The capture-recapture estimates were not significantly different than redd area or AUC escapement estimates (Tukey's $q > 2.15$, $p > 0.25$). Treating years as samples and including data from all streams and years, redd area and AUC escapement estimates were not significantly different (Tukey's $q = 1.25$, $p = 0.65$, $b = 0.89$). It appears that steelhead escapement has been relatively constant in four streams over the past five years (Figure 2a-d). It was not possible to make carcass based capture-recapture population estimates for steelhead because very few carcasses were observed during spawning ground surveys.

The uncertainty associated with each method of estimating coho salmon escapement, while generally higher for capture-recapture and AUC estimates overlap the point estimates, suggesting all methods were reasonable (Figure 3a-d, Table 2). For consistency with Gallagher (2005) coho salmon AUC estimates in Figure 3a-d and Table 2 were made with *rt* of 11.5 days (Biedler and Nickelson 1980) and *e* from the Pudding Creek capture-recapture estimates divided by the total number of coho salmon observed during spawning ground surveys (see discussion of *rt* and *e* in the following section). Treating years as samples (previous year's data from Gallagher 2005) known numbers of coho salmon released above the ECS, AUC, redd area, one redd per female, and carcass capture recapture escapement estimates were significantly different (ANOVA $f = 10.14$, $p < 0.001$, $df = 22$, $\beta = 0.99$, Figure 3a). Examined individually, known releases above the ECS and estimates based on redd areas, one redd per female, and AUC were not significantly different (Tukeys $q < 2.66$, $p > 0.37$). Coho salmon carcass based capture-recapture estimate above the ECS were significantly lower than estimates from all other methods (Tukey's $q > 5.71$, $p < 0.003$).

Bland-Altman analyses (Glantz 1997) suggest ECS release counts and AUC and redd area estimates were equally reliable estimates of coho salmon escapement. Applying this analysis to escapement estimates assuming one redd per female and carcass capture-recapture suggests these measures were not reliable compared to ECS releases for monitoring escapement. Releases above the ECS and AUC escapement estimates were significantly related ($r^2 = 0.80$) suggesting reasonable agreement between the two, the MD was low (-5.4) suggesting no systematic bias, the SDL of 100 was relatively low compared to the range of the data, the rDM was not significant ($r^2 = 0.26$), and the data were within two standard deviations. Releases above the ECS and redd area escapement estimates were significantly related ($r^2 = 0.94$) suggesting reasonable agreement between the two, the MD was low (57.4) suggesting no systematic bias, the SDL of 39.6 was relatively low compared to the range of the data, the rDM was not significant ($r^2 = 0.01$), and the data were within two standard deviations. Releases above the ECS and escapement estimates assuming one redd per female were significantly correlated ($r = 0.98$, $p = 0.003$, $n = 5$) suggesting reasonable agreement between the two, the MD was high (97.8) suggesting some systematic bias, the SDL of 99.5 was relatively high compared to the range of the data, the rDM was significant ($r = 0.92$, $p = 0.049$, $n = 5$), and the data were within two standard deviations. Releases above the ECS and carcass capture-recapture escapement estimates were not significantly correlated ($r = 0.14$, $p = 0.91$, $n = 3$) suggesting lack of agreement between the two, the MD was high (-302.3) suggesting some systematic bias, the SDL of 123.9 was relatively high compared to the range of the data, rDM was not significant ($r = -0.77$, $p = 0.44$, $n = 3$), and the data were within two standard deviations.

Treating years as samples (previous year's data Gallagher 2005) and including data from all streams, coho salmon carcass capture-recapture, AUC, redd area, and assuming one redd per female population estimates were significantly different ($x^2 = 14.22$, $p = 0.003$, $df = 3$). Results of Student-Newman-Kuels pair wise comparisons showed that estimates based on one redd per female were significantly different than carcass capture-recapture, AUC, and redd area estimates ($q > 4.37$, $p < 0.05$). Redd area, carcass capture-recapture, and AUC estimates were not significantly different ($q < 3.34$, $p > 0.05$).

The probability of a live coho salmon losing a floy tag calculated from recaptures at the Pudding Creek weir during 2004-05 was 0.075 and no salmon lost their operculum punches. The probability of losing a floy tag was 0.57 and the probability of losing a operculum punch was 0.212 from observations of tagged carcasses during spawning ground surveys.

Number of Fish Per Redd

The number of steelhead per redd in Pudding Creek in 2005 was 1.62 (95% CI 1.04-2.15). The average number of steelhead per redd in Pudding Creek 2004 and 2005 of 1.36 ((%% CI 0.91-1.97) was not significantly different than estimated in the Noyo River (average 1.07, S.E. = 0.13) 2000 to 2003 ($t = -1.13$, $p = 0.30$, $n = 5$, $\beta = 0.07$). Steelhead capture-recapture escapement estimates and redd counts were significantly correlated ($r = 0.83$, $p = 0.04$, $n = 5$, Figure 4a). Escapement estimated by multiplying the five year average number of fish per redd by redd counts each year were not significantly different than capture-recapture estimates ($t = 0.88$, $df = 5$, $p = 0.42$, $\beta = 0.05$). Bland-Altman analysis suggests both methods were equally reliable for estimating escapement (MD = -

32.2, SDL = 89.5, rDM = -0.76 p = 0.0805, < 2SDs'). Taking the log of these data resulted in the following predictive model; Log capture-recapture estimate = 1.351 + (0.458 * log redd count) ($r^2 = 0.81$, p = 0.01, β = 0.72). Escapement estimated using redd counts in this equation were not significantly different from capture-recapture estimates (W = 9.0, p = 0.44). Bland-Altman analysis suggests both methods were equally reliable for estimating escapement (MD = -1.83, SDL = 32.4, rDM = 0.005, < 2SDs'). Steelhead redd counts and AUC escapement estimates were significantly correlated (r = 0.77, p = 0.003, n = 17, β = 0.97, Figure 4b). Escapement estimated from redd counts using the predictive model from Gallagher (2005) where AUC estimate = -2.13 + (1.064 * redd count) was not significantly different from capture-recapture estimates in the Noyo River 2000-03 and Pudding Creek 2004 and 2005 (t = -0.191, df = 5, p = 0.86, β = 0.05). Bland-Altman analysis suggests both methods were equally reliable for estimating escapement (MD = 5.53, SDL = 70.97, rDM = -0.75 p = 0.08, < 2SDs'). Estimates of the number of steelhead in Caspar Creek and the Little and South Fork Noyo rivers from multiplying average fish per redd by the redd count did not differ from the AUC or redd area escapement estimates (Fig 2, Table 1).

The number of coho salmon per redd in Pudding Creek in 2005 was 2.67 (95% CI 2.20-3.89). The number of coho salmon per redd above the ECS in 2005 was 1.74 (95% CI 1.70-1.79). The 2004 and 2005 average number of coho salmon per redd in Pudding Creek was 2.50 (S.E. = 0.14). The five year (2001-05) average number of coho salmon per redd above the ECS was 2.06 (S.E. = 0.37). The grand mean of all observations was 2.19 (S.E. = 0.27) fish per redd. Treating years as samples the number of coho salmon per redd was not significantly different between Pudding Creek and above the ECS (t = -0.68, df = 6, p = 0.52, β = 0.05). Treating years as samples the number of coho salmon per redd was not different between the ECS and Pudding Creek in 2004 and 2005 (t = 3.0, p = 0.33, n = 2). Escapement estimates using the five year average fish per redd times redd counts were not significantly different from capture-recapture in Pudding Creek 2004 and 2005 or releases above the ECS 2001-05 (t = -0.47, df = 6, p = 0.47, β = 0.05). Escapement estimates using the five year average fish per redd times redd counts in Caspar Creek and Little River were within the 95% confidence bounds of the carcass capture-recapture estimates (Table 2). Coho salmon redd counts and releases above the ECS were not significantly correlated ($r = 0.86$, $p = 0.06$, $n = 5$, Figure 5a). However, redd counts and female coho salmon releases were significantly correlated ($r = 0.99$, $p = 0.002$, $n = 5$). Bland-Altman analysis suggests both measures were equally reliable for monitoring coho salmon escapement (see redd counts above). This data produced the following relationship: Log Females above ECS = 0.214 + (0.862 * log redd count) ($r^2 = 0.90$, $p = 0.003$, $\beta = 0.56$). Escapement estimated using this model were not significantly different than ECS releases 2001-05 or capture-recapture estimates in Pudding Creek 2004 and 2005 ($t = 0.42$, $df = 4$, $p = 0.70$, $\beta = 0.05$). Carcass capture-recapture estimates and redd counts were significantly correlated ($r = 0.87$, $p < 0.001$, $n = 18$, Figure 5b) as were redd counts and AUC escapement estimates ($r = 0.91$, $p < 0.001$, $n = 18$). Escapement estimated from redd counts using the predictive model from Gallagher (2005) where AUC estimate = -2.345 + (1.542 * redd count) were not significantly different from capture-recapture estimates in Pudding Creek 2004 and 2005 and releases above the ECS 2001-05 ($t = -2.00$, $df = 6$, $p = 0.09$, $\beta = 0.30$). Bland-Altman analysis suggests both methods were equally reliable for estimating coho salmon escapement (MD = 164.27, SDL = 217.01, rDM = 0.76 $p = 0.05$, < 2SDs').

AUC

Residence Time

The 2005 Pudding Creek steelhead residence time based on tag recoveries averaged 28.3 (S.E. = 1.8, $n = 3$, range 26-32, Figure 6). Steelhead residence time was not different between Noyo River 2000 to 2003, Pudding Creek 2004 and 2005, and in the South Fork Noyo River during 2005, nor was it different among years (ANOVA $H = 7.99$, $df = 5$, $p = 0.16$, Figure 6). The average residence time from all observations of steelhead was 16.8 (S.E. 1.98, $n = 37$). Residence time calculated from the trapezoidal approximation and weekly tag based observation efficiency was the longest of all estimated residence times for both streams and did not overlap other estimates (Figure 6). Residence time calculated from the trapezoidal approximation and observer efficiency from the total number of steelhead observed in spawning surveys divided by capture-recapture estimates were similar to the tributary estimate of Gallagher and Gallagher (2005) in the South Fork Noyo River and overlapped the Pudding Creek estimate (Figure 6). The results using Pudding Creek capture-recapture observer efficiency were slightly less than using total tag observer efficiency. Whereas *rt* estimates calculated from weekly observer efficiency and the trapezoidal approximation in Pudding Creek overlapped main stem residency time from Gallagher and Gallagher (2005) and estimates assuming the longest possible period between tagging and recovery. Steelhead residence time calculated from the trapezoidal approximation and capture-recapture estimates without estimates of observer efficiency were similar in Pudding Creek (1.33-3.10 days) and the South Fork Noyo River (1.48-4.34 days) (Figure 6). Average residence time calculated with the trapezoidal approximation without estimates of *e* for Pudding Creek 2004 and 2005 was 2.22 days (range 2.29-2.83 days).

The 2004-05 average coho salmon residence time based on the time between tagging and recovery of tags on carcasses of 21.1 (S.E. = 4.32, range 4-44, n = 10) days in Pudding Creek and 26.8 days (S.E = 2.73, range 5-48, n = 21) in the South Fork Noyo River was much longer than that estimated in Oregon (11.5 days) or calculated form the trapezoidal approximation (Figure 7). Pudding Creek and South Fork Noyo River residence times for all tag recoveries in 2004 and 2005 were not significantly different (ANOVA F = 1.69, df = 339, p = 0.15, $\beta = 0.22$). Bland-Altman analysis suggests average residence times estimated in either stream or year were equally reliable. Pudding Creek and South Fork Noyo River residence times were significantly correlated ($r > 0.81$, $p < 0.004$), the MD was -0.43 indicating no systematic bias, the SDL of 6.73 and was low compared the data ranges, the RDM was not significant (r = 0.74, p = 0.26, n = 4), and all data were within two standard deviations. Residence time calculated from the trapezoidal approximation was less than that from tag recoveries, except when using predicted weekly observer efficiency and was similar to estimates of 11.5 days from Oregon (Figure 7). Estimates of residence time calculated from the trapezoidal approximation without estimates of *e* were not different between the two streams over two years (Figure 7). But *rt* was different depending on how it was estimated (Figure 7).

Observer Efficiency

Steelhead observer efficiency, while variable depending on how I estimated it, was generally lower than estimated for coho salmon, ranged from 0.045 to 0.25, and was not significant between the South Fork Noyo River and Pudding Creek in 2005 ($t = 1.53$, $df = 3$, $p = 0.22$, $\beta = 0.13$, Figures 8-9). Observer efficiency for steelhead was not significantly different between Pudding Creek in 2004 and 2005 and in the South Fork Noyo River in 2005 (ANOVA $F = 2.66$, $df = 13$, $p = 0.11$, $\beta = 0.27$). Steelhead observer efficiency predicted from 2004-05 stream flow using the regression developed by Gallagher (2005) was not significantly different than weekly estimates ($t = 1.96$, $df = 14$, $p = 0.07$, $\beta = 0.34$). Observer efficiency estimated from the total number of marked steelhead observed divided by the total number marked, from capture-recapture and total observed on spawning grounds, and predicted from the trapezoidal area overlapped, but were higher than weekly and predicted estimates (Figure 8).

Coho salmon observer efficiency was not significantly different between Pudding Creek and the South Fork Noyo River in 2003-04 or 2004-05 ($t = -1.87$, $df = 6$, $p = 0.11$, $\beta = 0.26$, Figure 9). Observer efficiency was different based on method of estimation, however it was not different by method over two years between the two streams (ANOVA $H = 8.63$, $df = 6$, $p = 0.20$). In 2005 weekly coho salmon observer efficiency and that predicted from water visibility (Equation 2, Gallagher 2005) in Pudding Creek were not significantly different ($t = 1.96$, $df =14$, $p = 0.07$, $\beta = 0.34$) and overlapped with estimates calculated from the total number of coho salmon observed divided by the carcass capture-recapture escapement estimate (Figure 9). These estimates of observer efficiency were lower than those estimated from observations of tagged fish in 2003-04 and calculated from trapezoidal area (Figure 9). Observer efficiency estimated from carcass capture-recapture and total fish observed in spawning ground surveys (Pudding Creek 0.46-0.69, ECS 0.12-1.0) was similar to total tags observed divided tags applied and live observations divided by capture-recapture or total releases above the ECS (Figure 9).

Escapement Using Different Values of *rt* and *e*

Area under the curve escapement estimates for steelhead in Pudding Creek, although variable depending on which combinations of *rt* and *e* were used, generally overlap and were within the range of the capture-recapture estimate (Figure 10a). The Pudding Creek steelhead AUC estimate using *rt* derived from the trapezoidal approximation divided by the capture-recapture estimate without estimates of *e* were exactly the same as the capture-recapture estimates due to the interrelatedness of the data. All AUC escapement estimates using different combinations of *rt* and *e* overlapped with the capture-recapture estimate except using average of all streams and years *rt* (Figure 6 AVG) and Pudding Creek 2005 weekly *e* (Figure 10a). The most precise estimate resulted from using *rt* calculated from the trapezoidal area with *e* from total tags observed divided by total tags applied which was the same as that resulting from using *rt* derived from the trapezoidal approximation divided by the capture-recapture estimate without estimates of *e* (Figure 10a). The 2004 Pudding Creek *rt* estimated without *e* and the average of the 2004 and 2005 estimates produced escapement estimates within the capture-recapture 95% confidence bounds. The 2005 observed *rt* and calculated *e* also overlapped the capture-recapture estimate. The most reasonable estimates of *rt* and *e*, based on comparison of the resulting AUC estimates to the capture-recapture estimates in Pudding Creek, produced overlapping AUC escapement estimates in Caspar Creek, and the Little and South Fork Noyo rivers (Figure 10b-d).

All Pudding Creek coho salmon AUC estimates using estimates of *rt* from Pudding Creek, the South Fork Noyo River, and 11.5 days from Oregon (Biedler and Nickelson 1980) and *e* from either the South Fork Noyo River or Pudding creek overlapped the capture-recapture estimates except using 2005 Pudding Creek *rt* and *e* calculated from live fish observed divided by 2005 capture-recapture estimate (Figure 11a). This pattern is similar in the South Fork Noyo River (Figure 11a), except *rt* of 11.5 days and the *e* from live fish observed divided by ECS releases and Pudding Creek *rt* estimated without *e* AUC estimates do not overlap the ECS release. Only AUC estimates using Pudding Creek and ECS 2005 *rt* and capture-recapture based *e* fall outside the 95% confidence bounds of the coho salmon carcass capture-recapture estimates in Caspar Creek (Figure 11b). All AUC estimates for Little River overlap the coho salmon carcass capture-recapture 95% confidence bounds (Figure 11c). The AUC estimated with average all years and streams *rt* and *e* predicted from weekly stream flow (Gallagher 2005, equation 2) produced the most reliable coho salmon escapement estimates (Figure 11).

Abundance Trends

There were no significant trends in steelhead redd area abundance over four years in Pudding and Caspar creeks and the Little and South Fork Noyo rivers ($r^2 < 0.41$, $p > 0.29$, Figure 2) and the slopes of these lines were not significantly different than zero ($p > 0.05$). There were no significant trends in steelhead AUC abundance over four years in Pudding and Caspar creeks and Little River ($r^2 < 0.55$, $p > 0.26$, Figure 2) and the slopes of these lines were not significantly different than zero ($p > 0.05$). There was no trend in steelhead redd counts over four years ($r^2 < 0.46$, $p > 0.32$, Figure 12). There was no trend in steelhead redd densities over four years in these streams ($r^2 < 0.56$, $p > 0.33$, Figure 13).

There was no trend in coho salmon abundance based on ECS releases, redd areas, AUC, or redd counts over five years ($r^2 < 0.71$, $p > 0.07$, $\beta < 0.42$, Figures 3a and 14a) and the slopes were not significantly different from zero ($p > 0.05$). There was no trend in coho salmon redd densities above the ECS over five years ($r^2 = 0.13$, $p = 0.64$, $\beta = 0.20$, Figure 15a) and the slope of this line was not significantly different than zero ($p > 0.05$). There was no trend in redd area coho salmon abundance over four years on Caspar and Pudding creeks and Little River ($r^2 < 0.73$ $p > 0.06$, $\beta < 0.43$, Figure 3b-d) and the slopes of these lines were not significantly different than zero ($p > 0.05$). There were no significant trends in coho salmon AUC abundance over four years in Pudding and Caspar creeks and Little River ($r^2 < 0.77$, $p > 0.05$, Figure 3) and the slopes of these lines were not significantly different than zero ($p > 0.05$). There were no significant trends in coho salmon carcass capture-recapture abundance over four years in Pudding and Caspar creeks and Little River ($r^2 < 0.66$, $p > 0.18$, Figure 3) and the slopes of these lines were not significantly different than zero ($p > 0.05$). There was no trend in coho salmon redd counts over four years ($r^2 < 0.46$, $p > 0.32$, Figure 14) and the slopes of these lines were not significantly different than zero ($p > 0.05$). There was no trend in coho salmon redd densities over four years above the ECS and in Caspar and Pudding creeks ($r^2 < 0.75$, $p > 0.6$, Figure 15) and the slopes of these lines were not significantly different than zero ($p > 0.05$). However, redd densities in Little River showed a significant linear relationship over four years ($r^2 = 0.81$, $p = 0.04$, $\beta = 0.56$, Figure 15b), but the slope of this line was not significantly different than zero ($p > 0.05$). The regression lines for coho salmon redd density versus year were not significantly different among these four streams ($t < 1.50$, $p > 0.10$).

The trends in coho salmon abundance for two complete life cycles (2001 to 2004 and 2002 to 2005 adults) appear to show an increase in adults in Pudding Creek and the Little and South Fork Noyo rivers (Figure 16). There appears to be no trend in coho salmon abundance over two life cycles in Caspar Creek (Figure 16). With only two data points for each stream it was not possible to statistically examine these apparent trends.

DISCUSSION

Redd Counts

Redd counts, with bias in counts reduced following Gallagher and Gallagher (2005), and releases above the Noyo River Egg Collecting Station (ECS) were equally reliable measures of coho salmon escapement. Redd counts, with bias in counts reduced following Gallagher and Gallagher (2005), and capture-recapture estimates were equally reliable measures of steelhead escapement. Redd counts and escapement estimates were significantly correlated further substantiating the idea that redd counts are reliable measures of salmonid escapement. Escapements were reliably estimated from predictive models of the number of fish per redd and redd counts. Spawning ground surveys have been the primary method for monitoring status and trends of coastal salmonids in Oregon since 1948 and redd counts are the primary method used in Washington (Boydstun and

MacDonald 2005). Redd counts have been used to monitor bull trout populations in Idaho for over 20 years (Dunham et al. 2001). As the product only of reproductive adults, redd counts provide an index of effective population size (Meffe 1986). Redd counts are reasonable metrics for long term monitoring of salmonid escapement and avoid problems associated with extrapolating redd counts to fish numbers as well as those associated with the AUC and should be primary metric for long term monitoring of California's Coastal Salmonids. If conversion of redd counts to fish numbers is necessary, then using either average number of fish per redd or predictive regression equations presented herein should suffice.

Escapement Estimates

One Redd Per Female

With another year's data only escapement estimates assuming one redd per female were significantly different than other estimation methods strengthening the findings of Gallagher and Gallagher (2005) and Gallagher (2005). Estimates of the number of fish per redd from Pudding Creek capture-recapture and releases above the Noyo River ECS indicate both steelhead and coho salmon females make more than one redd (Tables 1-2). Escapement based on the assumption that female steelhead and coho salmon only make one redd clearly over estimate the number of returning salmonids in coastal Mendocino County. In Oregon coastal streams steelhead females were found to make more than one redd (Susac and Jacobs 2002). Thus it appears that this approach is not useful for long term monitoring of salmonid escapement. Especially considering the fact that these species are listed as threatened, overestimation of their numbers when populations are actually low could have serious consequences for fishery managers.

Redd Area

The redd area method appears to be reasonable for estimating escapement from spawning ground surveys and avoids many problems associated with other estimation methods.

Similar to Gallagher and Gallagher (2005) escapement estimates based on the assumption that redd size is related to the number of redds a female salmonid creates (redd area method) were not significantly different than AUC and capture-recapture escapement estimates, further supporting the notion that this assumption was valid. This method accounts for multiple redds per female (Tables 2-3) and smaller redds have lower importance in escapement estimates. However, this method requires that the female to male ratio be estimated for each stream or assumed to be one to one. Withler (1966) found steelhead sex ratios to be nearly one to one along the Pacific Coast from California to British Columbia. The female to male ratio in coastal Mendocino County streams has similarly been nearly one to one over the past few years (Gallagher 2003). So it does not seam unreasonable to apply the assumption of a one to one sex ratio for coastal salmonids when it can not be readily estimated during spawning ground surveys. The redd area method avoids problems associated with the estimation and transferability among streams of estimates of the number of redds per fish (and per female) for converting redd counts to fish numbers. The redd area method was shown to work for a variety of water years and streams, is not susceptible to mechanical failure, and fish are not handled, tagged, or their movements impeded. This approach may be useful and applicable to examine and monitor metapopulation dynamics (Rieman and Mcintyre 1996) important for recovery of these threatened species (Isaak et al. 2003).

Number of Fish per Redd

Estimates of the number of fish per redd can be used to convert redd counts to population estimates and are transferable among streams. Escapement estimates using the average number of fish per redd and predicted with log regressions and the predictive models from Gallagher (2005) and estimated from capture-recapture experiments or releases above the ECS were equally reliable. The number of fish per redd was not different between Pudding Creek and the South Fork Noyo River above the ECS for both species over two years. Estimates of the number of steelhead per redd were not different between the Noyo River 2000-03 and Pudding Creek 2004 and 2005. Gallagher (2005) found that the four year (2000 to 2004) average number of coho salmon per redd in the South Fork

Noyo River was the same as estimated in Pudding Creek in 2003-04 and escapement estimates using these values were not significantly different than results from other methods suggesting these variables are transferable among streams. The four year average number of steelhead per redd in the Noyo River was not different than estimated in Pudding Creek in 2003-04 and escapement estimates using these values were not significantly different than estimates from other methods suggesting that estimates of the number of fish per redd can be transferred among steams and used to convert redd counts to population estimates (Gallagher 2005).

In Oregon steelhead redd counts are significantly correlated with adult escapement and an estimate of 1.54 females per redd was developed (Susac and Jacobs 2002). In Washington redd counts are the principal method for monitoring salmonids and cumulative redd counts are expanded by 2.5 fish per redd to estimate escapement (Boydstun and McDonald 2005). In this study the number of steelhead and coho salmon per redd differed slightly among streams and years but the use of one value for all streams to convert redd counts to fish numbers for regional spawning ground surveys appears reliable. Dunham et al. (2001) found considerable spatial and interannual variation in bull trout spawner: redd ratios and attributed it to either strong life history variation among populations or bias and imprecision in redd counts. Gallagher and Gallagher (2005) showed that bias in steelhead and coho salmon redd counts can be reduced and that spawner abundance and redd counts were significantly correlated. With a few years data on a number of streams it may be possible to develop a standard conversion factor with associated uncertainty to estimate steelhead and coho salmon escapement from redd counts. Improvements to field and laboratory methods listed below will also likely improve these estimates.

Capture-Recapture

Carcass capture-recapture estimates were not different than "true" numbers or other methods of estimating escapement, except assuming one redd per female, but had wide confidence bounds. This method underestimated coho salmon escapement above the

ECS in three of five years and the data were appropriate for capture-recapture estimates in only ten of 17 (59%) reaches in Pudding Creek and above the ECS during 2004-05. This method did not work for steelhead and may not work for 3km reaches as suggested in the California Plan (Boydstun and MacDonald 2005). This methodology will require further evaluation in the Mendocino Coast Pilot Program (Gallagher and Collins 2004).

Escapement was estimated from live fish capture-recapture following the Jolly-Seber (Krebs 1989) method for Pudding Creek and data were pooled by weekly surveys. Floy tag loss from live coho salmon was low and capture-recapture estimates were not affected by tag loss. During 2004-05 smaller floy tags were used than during 2003-04 and this may have affected tag loss. These smaller tags seemed more difficult to differentiate tag colors during field surveys. Future capture-recapture experiments should use larger floy tags and further evaluate tag loss and other assumptions of this methodology. Floy tag loss on carcasses was high thus the recapture-capture portion of this technique should not rely on floy tag recoveries from carcasses during spawning ground surveys. Carcass capture-recapture methods followed Gallagher and Gallagher (2005) where carcasses were tagged with individually numbered metal disks attached with hog rings to the lower jaw (Gallagher and Knechtle 2003). Therefore estimates from this experiment were independent of floy tags and operculum punches applied to live fish on their way to the spawning grounds. However, carcass tag loss and other assumptions of the capture-recapture methodologies were not evaluated in this study, but their evaluation should be part of future monitoring efforts.

AUC

The AUC method is sensitive to the time between surveys and estimates of *rt* and *e* (English et al. 1992, Hilborn et al. 1999), both of which require independent capture-recapture experiments for their estimation which are usually capable of producing escapement estimates without the AUC (Gallagher and Gallagher 2005). The streams in this study were surveyed approximately every nine days. Storms and high flow/high turbidity limited surveys during some periods, however the AUC estimates, depending on how *rt* and *e* were estimated were not significantly different than “true” escapement estimates of steelhead and coho salmon. This suggests that biweekly surveys were reasonable. The steelhead AUC escapement estimate in Pudding Creek following Gallagher and Gallagher (2005) with *rt* of 12.6 days and *e* estimated from capture-recapture and total live fish observed during surveys was higher than the capture-recapture estimate, but the 95% confidence bounds overlapped (Figure 8a). Coho salmon AUC estimates with *rt* of 11.5 days and *e* from capture-recapture in Pudding Creek were not different from the capture-recapture estimates (Figure 9a). This suggests the use of these values was reasonable. However, the most precise estimates, when compared to know numbers, resulted from using *rt* estimated from the trapezoidal approximation without estimates of *e* (Figures 8a, 9a) or using field estimated *rt* and *e* calculated from the trapezoidal area. This is due to the interrelatedness of the data (see discussion of *rt* and *e* in the following sections).

Steelhead escapement was best estimated using the AUC with the 2004 and 2005 average *rt* without estimates of *e* followed by annual 2005 estimates of *rt* and weekly predicted *e*. These values should continue to be evaluated for applicability for long term monitoring of California’s coastal salmonids. Coho salmon escapement was best estimated in the AUC using weekly predicted *e* and the average of all *rt* observations. These values should be used to estimate escapement with the AUC and continue to be evaluated for applicability for long term monitoring of California’s coastal salmonids.

Residence Time

The purpose of this exercise was to determine, from the data collected in the Noyo River 2000-03 and in Pudding Creek and the South Fork Noyo River during 2003-04 and 2004-05, the most reliable estimate of *rt* for coho salmon and steelhead, examine transferability between streams, and make recommendations for future monitoring. Steelhead residence time was not significantly different among streams or over years, but was much longer in Pudding Creek than in the South Fork Noyo River during 2004-05 (Figure 4). The overall average estimate of steelhead *rt* was slightly longer than Gallagher and Gallagher

(2005) and did not produce reasonable AUC escapement estimates when combined with weekly *e*. English et al. (1992) and Hilborn et al. (1999) suggest that *rt* be estimated annually throughout each season for each stream. Based on the results of this study steelhead *rt* should be estimated annually but can be transferred among nearby streams. Steelhead *rt* will need further evaluation prior to application to the California Plan, especially transferability over larger geographic area. Estimation of steelhead *rt* was improved by weekly application of different colored floy tags. Changing floy tag color weekly should be continued in future monitoring evaluations.

Coho salmon *rt* was not significantly different between Pudding Creek and the South Fork Noyo River nor was it different over two years suggesting these estimates are transferable among streams and years. Average *rt* of all year's data and weekly predicted *e* resulted in the best estimate in the AUC for coho salmon.

I found using average *rt* and the associated 95% confidence values to estimate escapement with the AUC, as a potential technique to include statistical estimates of uncertainty in its calculation, for steelhead was not reliable with data from Pudding Creek in 2003-04 and 2004-05. However, it should be possible with data from numerous streams and a period of years to develop a distribution of species specific residence times. This distribution then could be used to estimate escapement and associated statistical uncertainty with the AUC. This approach may hold promise but will require more years' information from different streams that are coupled with capture-recapture estimates for further evaluation.

Observer Efficiency

The purpose of this exercise was to determine, from the data collected in Pudding Creek and the South Fork Noyo River during 2003-04 and 2004-05, the most reliable estimates of *e* for coho salmon and steelhead, examine transferability, and make recommendations for future monitoring. Observer efficiency in live fish counts for use in estimating escapement with the AUC is used to account for fish present but not observed during periodic counts of fish on spawning grounds (Korman et al. 2002). There is a rather large body of literature concerning the estimation of *e* for use in the AUC and most researchers use capture-recapture methods, which are capable of estimating escapement without the AUC, to estimate it (Parken et al. 2003, Korman et al. 2002, Hilborn et al. 1999).

Observer efficiency predicted from stream flow and water visibility were not different from estimates calculated in 2005 nor was it different between Pudding Creek and the South Fork Noyo River suggesting these predictive models can be used to estimate *e* from these variables in other streams. Since *e* was not different between the South Fork Noyo River and Pudding Creek nor when predicted from water visibility and stream flow among the four study streams it seams reasonable to use the *rt* estimates calculated from the trapezoidal approximation without estimates of *e* as it is included in the capture-recapture estimates in this manner, thus avoiding the expense and difficulty in estimating *e* independently for each stream.

Trends in Coho Salmon Abundance

The number of coho salmon and steelhead currently returning to Caspar Creek to spawn is not different than it was during the early 1960's. During the 1960-61 season Kabel and German (1967) counted coho salmon and steelhead entering Caspar Creek at a mill pond fish ladder which was removed in late-1961. Although not clearly stated in their report, assuming that all fish entering the stream were counted at this ladder, there were a total of 322 coho salmon and 92 steelhead in Caspar Creek in 1960-61. Following a strict three year life cycle the offspring of the 1961 coho salmon reproduction would be encountered 13 generations later in 2001-02 and 14 generations later in 2004-05. In 2001-02 Gallagher (2003) estimated using the AUC that there were 381 (range 305-565) coho salmon in Caspar Creek and in 2004-05 the carcass based escapement estimate was 197 (95% CI = 129-411). Steelhead AUC escapement estimate for 2004-05 was 50 (95% CI = 30-76) using *rt* 12.6 and Pudding Creek capture-recapture based *e*.

Similar to the findings of Gallagher and Knechtle (2004) I found no significant trends in coho salmon escapement over five years in four streams. The lack of trends in the coho salmon escapement estimates may be a result of the length of the time series, only five years. Because coho salmon generally have a rigid three year life cycle we might not observe trends with only five years data. I suspect that trend detection would be more appropriate with more year's data and annual estimates examined by three-year cohorts which include potential 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 others. 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 salmon populations increased with shorter time series. There is increasing evidence that Pacific salmonid populations follow a decadal cycle in abundance which is related to large scale climate (Smith and Ward 2000, Smith et al. 2000). If salmonid population abundance fluctuates on decadal or longer time frames, the five years data examined could be too short to detect these long term trends. However, Bradford et al. (2000) suggest their results and results of other works they refer to argue against the idea that regional effects of climate affect freshwater survival in coho salmon. Nonetheless, I suggest the merit of this exercise was the exploration of potential methods using annual escapement estimates for trend detection. These data may also prove useful for population viability analyses (Legault 2005) such as done by Chilcote (2001) for steelhead in Oregon.

RECOMMENDATIONS

Estimation of coho salmon and steelhead escapement from spawning ground surveys in these streams should continue, with one more year of monitoring we will have data on three complete life cycles of coho salmon and nearly one for steelhead. This data will be valuable for trend detection, restoration evaluation, and status evaluations.
Improvements in methods and effort proposed by Gallagher and Collins (2004) including capture-recapture estimates in an additional stream (Caspar Creek), better rotation of colored floy tags, potential use of pit tags, and better training and coordination of crews

will improve escapement estimates. The results from the tagging studies should continue to be examined to determine if *rt* and *e* differ among streams and if any combination of these values can be used reliably and cost effectively for long term regional monitoring.

Field methods should follow Gallagher and Knechtle (2003) and Gallagher and Gallagher (2005) but include the following changes. The field data form should include a column with yes or no box asking, was each redd re-measured? A data field for floy tag yes or no should be added. A data field for denoting the side of the fish the floy tag was located should be added. These columns will help remind field personal to examine all redds, redd flags, and floy tags carefully during each survey. The distance and compass direction from where the flag for each redd is tied (must be on the nearest solid object and securely attached) and the middle of the tail spill will be written on each flag and in the notes. Remeasure and the total redd length and maximum width must be written on all flags for which fish were observed on redds. These must be remeasured on subsequent surveys and crossed out if no change or new measurements written on the flags. Stream flow and water visibility will be determined and recorded for every survey. The field data form should also have a column for fish condition, both live and dead, which may add precision to *rt* estimates.

Reduction of bias in redd counts and estimation of escapement using redd area, capture-recapture, and the AUC should follow Gallagher and Gallagher (2005). In addition AUC escapement estimates should use *rt*'s for each species from this report without estimates of *e*. And these evaluated by comparison to capture-recapture estimates. The transferability of estimates of *e* and *rt* should be further examined and predictive models of *e* tested and improved. The AUC gave vastly different results depending on the estimates of *rt* and *e* employed, and since these variables are difficult and perhaps expensive to generate this method of estimating escapement may prove too cumbersome for long term regional monitoring of coastal salmonids.

Redd counts should be the primary metric for long term monitoring and these converted to population estimates using the estimate of fish/redd for coho salmon and steelhead resulting from this study. Monitoring populations using redd counts and estimates of the number of fish per redd is computationally and practically the easiest of the methods evaluated in this study and likely the most reliable given that bias in redd counts are reduced following Gallagher and Gallagher (2005). This method is also the least intrusive on the fish as they do not need to be handled, tagged, or their movements impeded. Given the apparent transferability and consistency of estimates of the number of fish per redd, this approach appears more suitably than the AUC for regional long term monitoring. The use of redd areas for estimating escapement, while apparently reliable and the least intrusive to the fish, is computationally and perhaps conceptually slightly more cumbersome than using estimates of the number of fish per redd. Clearly assuming one redd per female is not reliable and it should no longer be used to estimate escapement in this fashion.

Capture-recapture experiments at weirs or counting structures should use brightly colored floy tags to mark fish and denote species and week of tagging. The possibility of using pit tags and directional antenna arrays should be explored and the potential cost benefit in terms of mortality from double tagging adult fish evaluated. If the potential mortality is high, then colored floy tags or a similar marking technique which is easy to detect during spawning ground surveys should be used. Tag loss and evaluation of the assumptions of the capture-recapture methods should be further evaluated. Because carcass capture-recapture in the South Fork Noyo River drastically underestimates escapement, assumed to result from the smaller area of stream surveyed, it should not be used in a regional context for monitoring coho salmon abundance.

ACKNOWLEDGEMENTS

Personnel from the California Department of Fish and Game's Anadromous Fisheries Resource Assessment and Monitoring Program and the Central Coast Salmon and Steelhead Resource Assessment Program, Campbell Timberlands Management, and NOAA Fisheries Santa Cruz helped with collecting the data for this study. Special thanks to volunteers Scott Lemon and John Henderson for helping for many long cold

hours at the Pudding Creek weir. George Neillands and Mike Morrison provided useful comments on earlier drafts of this report.

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PERSONAL COMMUNICATIONS

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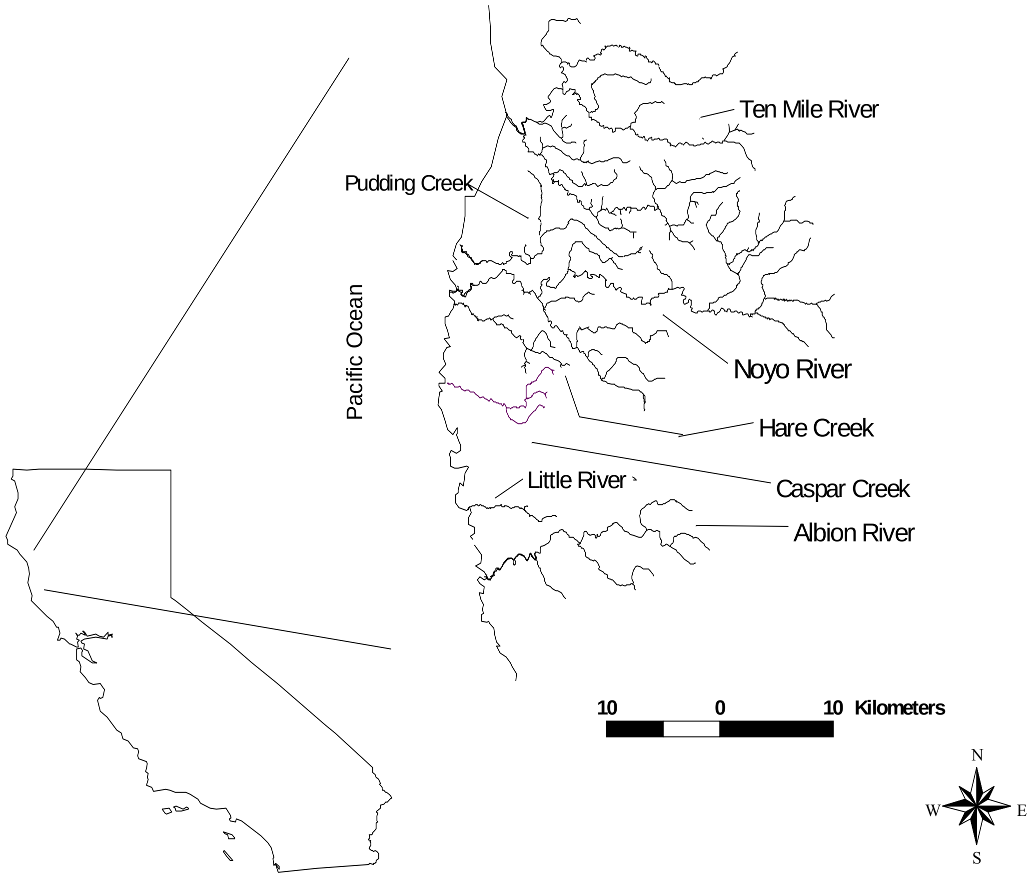


Figure 1. Location of study streams in Mendocino County, California.

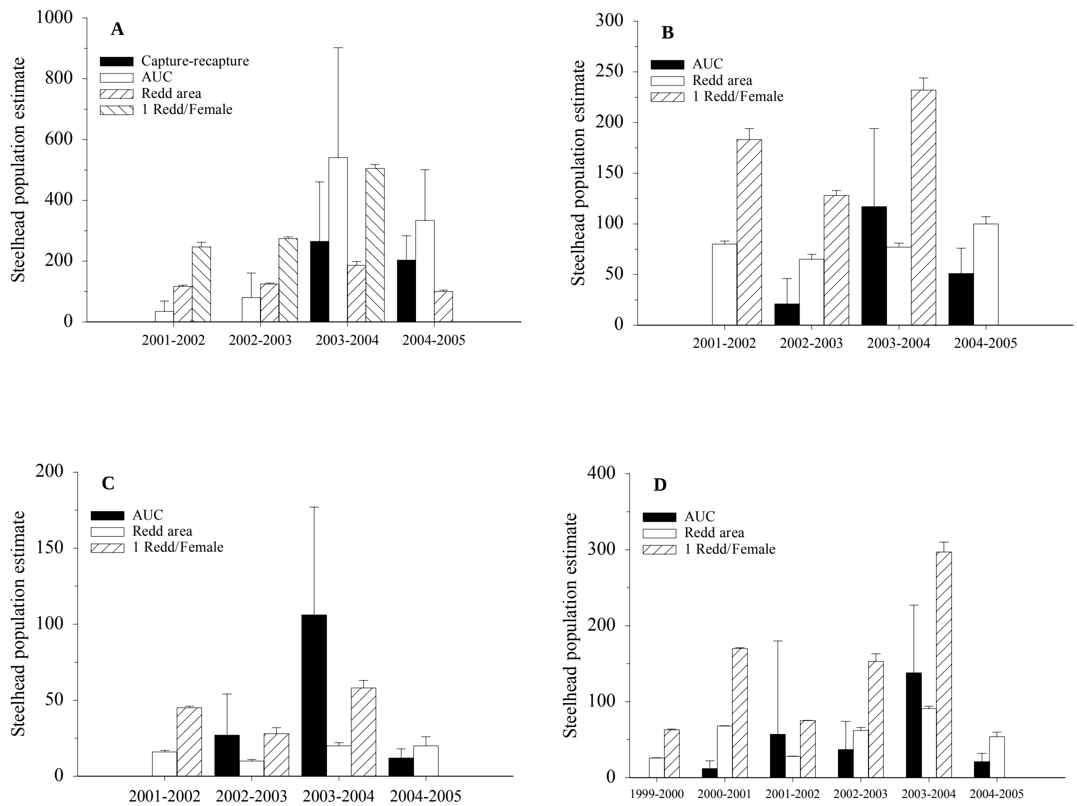


Figure 2. Steelhead population estimates in four coastal Mendocino County streams. a). Pudding Creek 2002-2005. b). Caspar Creek 2002-2005. c). Little River 2002-2005. d). South Fork Noyo River above the ECS 2000 to 2005. Thin lines are 95% confidence bounds for capture-recapture and AUC and S.E. of observer error for redd data.

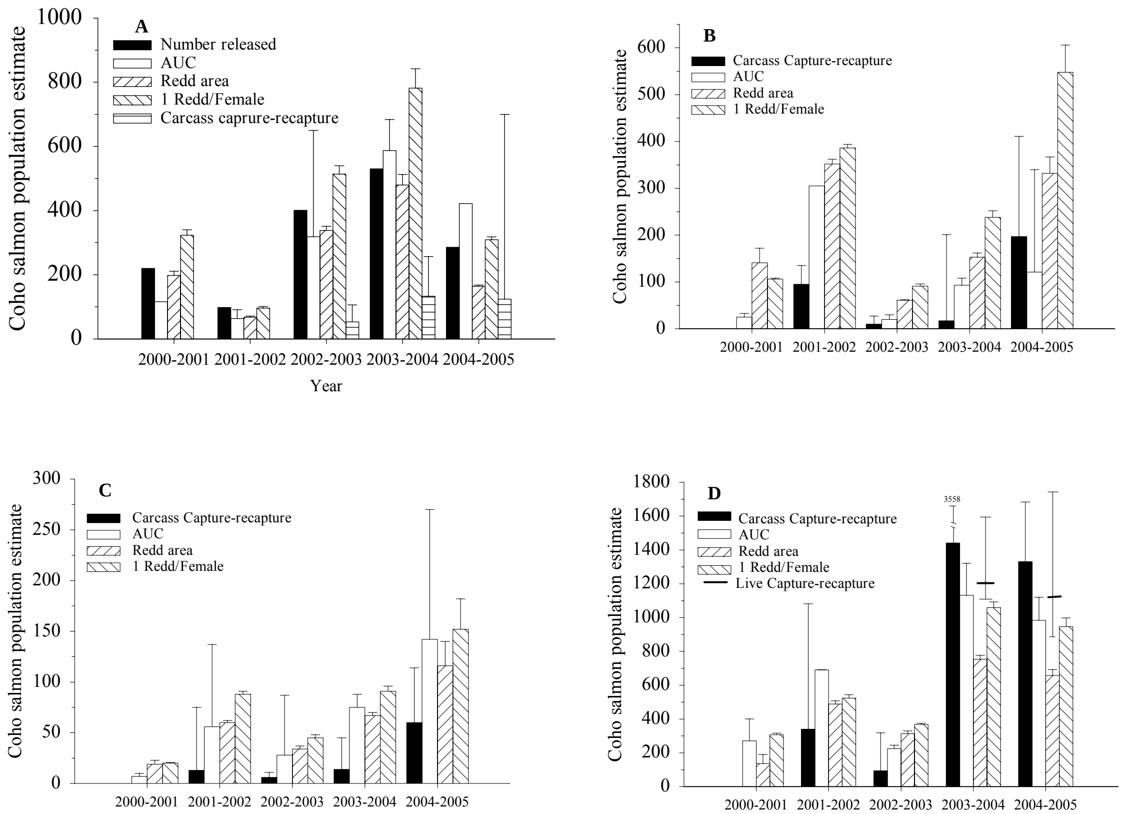


Figure 3. Coho salmon population estimates for four streams in coastal Mendocino County, California 2001-2005. a). South Fork Noyo River above the ECS. b). Caspar Creek. c). Little River. d). Pudding Creek. Thin lines are 95% confidence bounds for capture-recapture and AUC and S.E. of observer error for redd data.

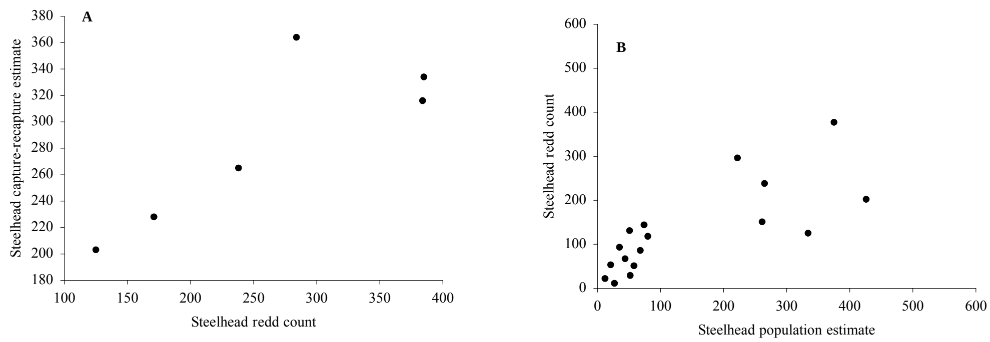


Figure 4. Relationship between redd counts and steelhead population estimates in several Mendocino County streams 2000-2001, 2002-2003, 2003-2004, and 2004-2005. a). Redd counts relative to the capture recapture estimates. b). Redd counts relative to AUC estimates for steelhead in four streams.

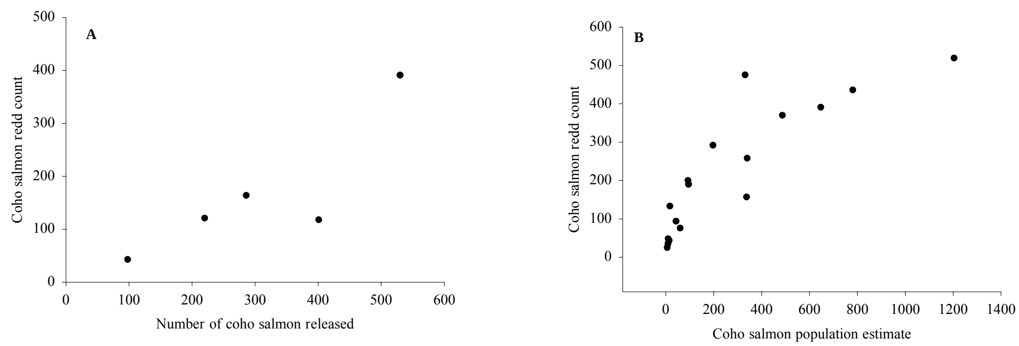


Figure 5 Relationship between redd counts and coho salmon population estimates in several Mendocino County streams 2000-2001, 2002-2003, 2003-2004, and 2004-2005. a). Redd counts relative to the number of coho salmon released above the Noyo River ECS. b). Redd counts relative to capture-recapture estimates for coho salmon in four streams.

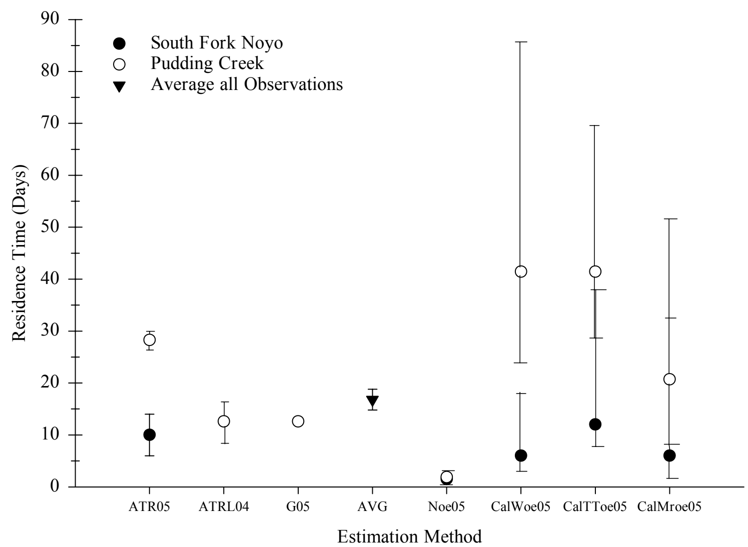


Figure 6. Various estimates of steelhead residence time for Pudding Creek 2003-04 and 2004-05 and the South Fork Noyo River in 2004-05. ATRo5 is all tag recoveries in 2004-05. ATR04 is all tag recoveries in 2003-04. G05 is from Gallagher and Gallagher (2005). AVG is the average of all observation in the Noyo River 2000-03, Pudding Creek 2004 and 2005, and the South Fork Noyo River 2005. Nooe05 is calculated from the trapezoidal area without estimates of *e*. Cal is calculated from the trapezoidal area. Weo5 is weekly e from 2005. Toe05 is e from total observed divided by capture-recapture estimates. Mre05 is total observed marked divided by the total marked.

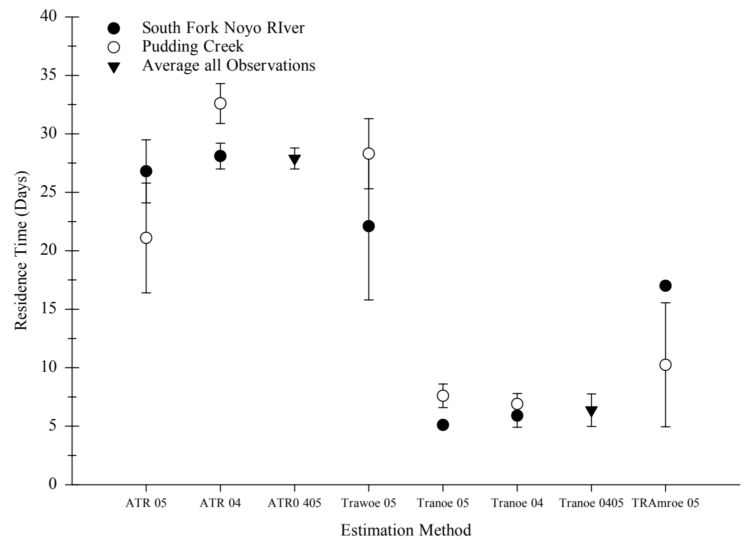


Figure 7 Various estimates of coho salmon residence time for Pudding Creek and the South Fork Noyo River 2003-04. ATR is all tag recoveries. Tranoe is *rt* estimated from the trapezoidal approximation without estimates of observer efficiency. TRAmroe is *rt* estimated from the trapezoidal approximation with capture-recapture estimates of observer efficiency. Trawoe is *rt* estimated from the trapezoidal approximation with weekly estimates of observer efficiency.

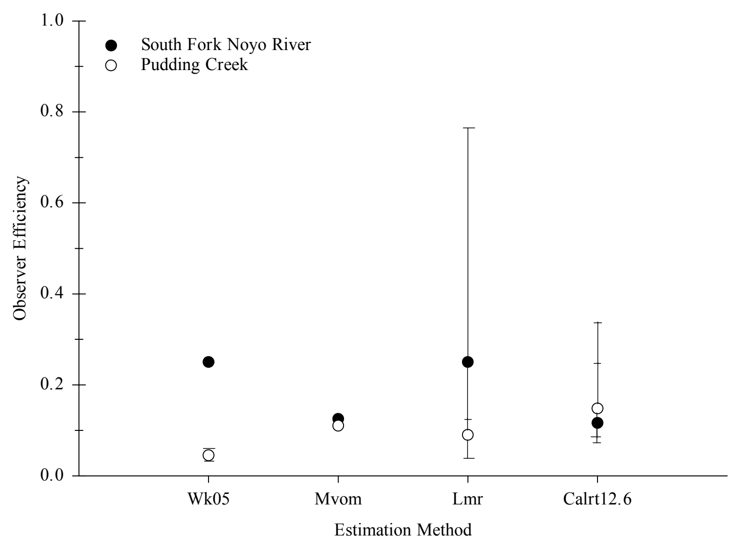


Figure 8. Various estimates of steelhead observer efficiency in Pudding Creek and the South Fork Noyo River during 2004-05. Wk05 is the weekly number of marked steelhead observed divided by the number of marked steelhead present each week. Mvom is the total number of marked steelhead observed during spawning ground surveys divided by the total marked. LMR is total number of live fish observed during spawning ground surveys divided by the capture recapture estimate. Calrt12.6 is observer efficiency calculated from the trapezoidal approximation and *rt* of 12.6 days.

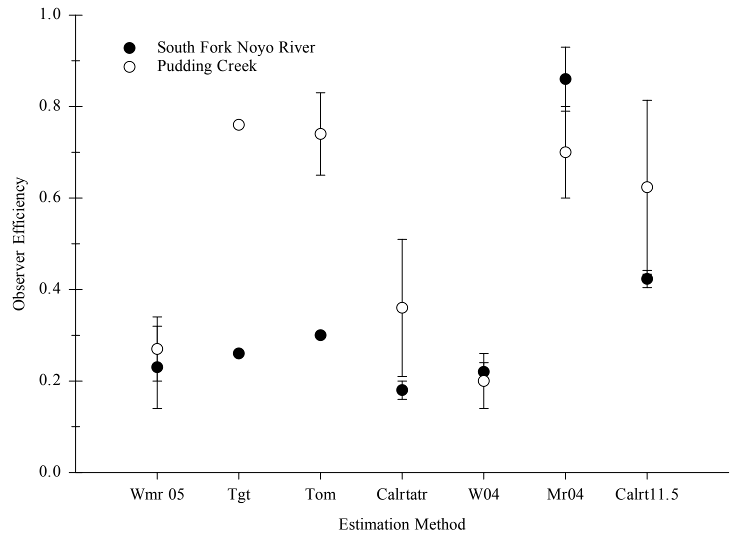


Figure 9. Various estimates of observer efficiency for coho salmon in Pudding Creek and the South Fork Noyo River during 2003-04 and 2004-05. Wmr is observer efficiency from the weekly number of tagged fish observed divided by the weekly number of tagged fish present. Tgt is observer efficiency estimated from the total number of tagged fish observed divided by the total number of fish tagged and released. Tom is the total number of marked fish observed during spawning ground surveys divided by the capture-recapture estimates. Calrtatr is *e* calculated from the trapezoidal approximation with <u>rt</u> from all tag recoveries in 2004-05. W04 is weekly *e* from 2003-04. Mr04 is total live observed divided by the capture-recapture estimates in 2004-05. Calrt11.5 is observer efficiency calculated from the trapezoidal approximation and *rt* of 11.5 days.

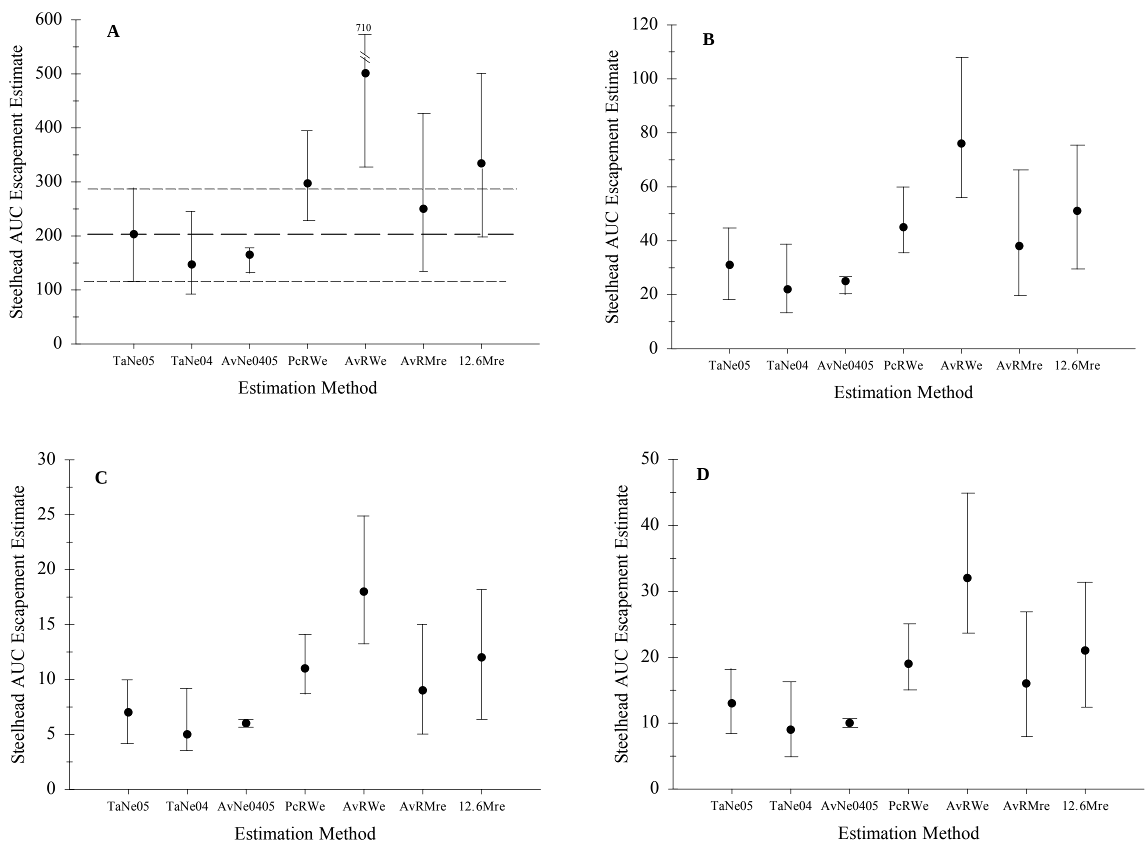


Figure 10. Steelhead AUC escapement estimates for various combinations of *rt* and *e* for four streams in Mendocino County, California during 2004-05. a). Pudding Creek. b). Caspar Creek. c). Little River. d). South Fork Noyo River above the ECS. Thin lines are 95% confidence bounds. Dashed horizontal line in panel a is the capture-recapture estimates and the short dashed lines are the 95% confidence bounds on this estimate. TaNe is using *rt* without estimates of *e*. AvNe is the average of TaNe 2004 and 2005. PcrRWe is with *rt* from Pudding Creek 2004-05 and weekly *e*. AvRWe is with the average of all observations *rt* and weekly *e*. AvRMre is with the average of all observations *rt* and *e* from the total number of live fish observed divided by the capture-recapture estimate. 12.6Mre is with *rt* of 12.6 days and *e* from total live observed divided by the 2004-05 Pudding Creek capture-recapture estimate.

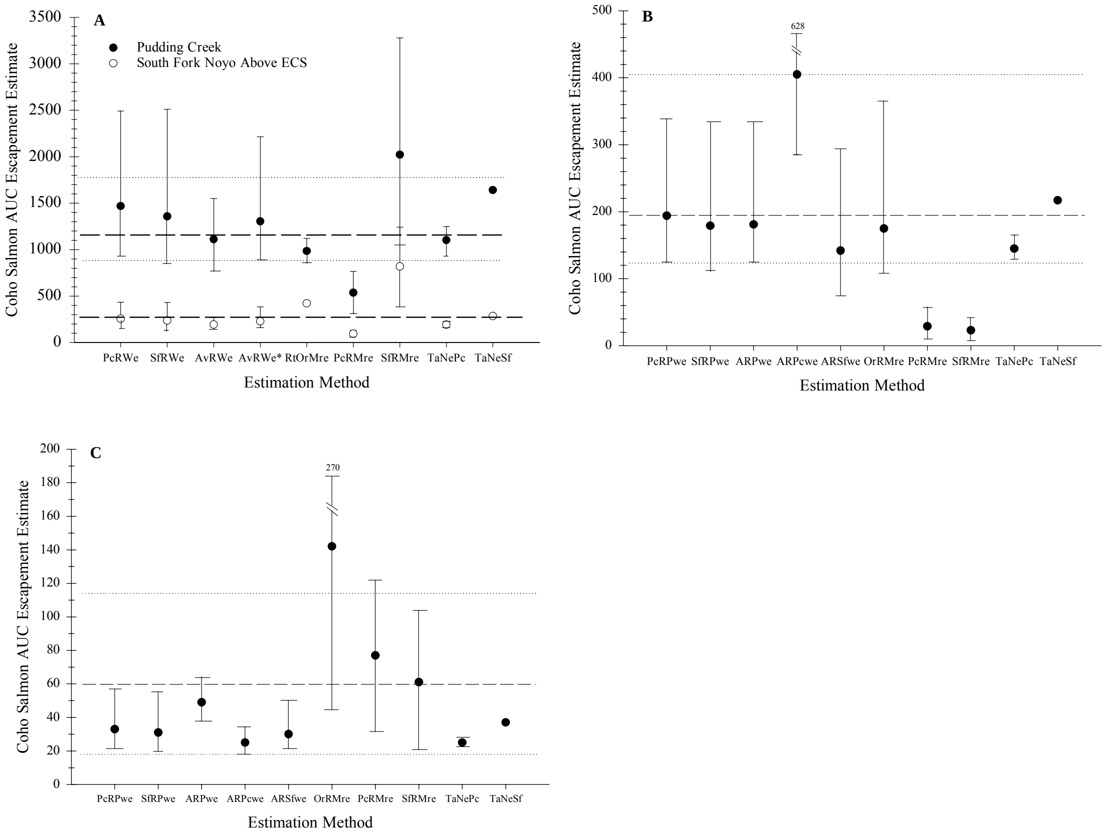


Figure 11. Coho salmon AUC escapement estimates for various combinations of *rt* and *e* for four streams in Mendocino County, California during 2004-05. a). Pudding Creek. and the South Fork Noyo River above the ECS. b). Caspar Creek. c). Little River. Thin lines are 95% confidence bounds. Dashed horizontal lines in panel a is the live fish capture-recapture estimate for Pudding Creek and the total release above the ECS and the short dashed lines are the 95% confidence bounds on this estimate. Horizontal dashed lines in panels b and c are the carcass capture-recapture estimates and the dotted lines are the 95% confidence bounds. PCR and SFR is residence time estimated from tag recoveries in 2004-05. AvR is the average residence time from all observations. RtOr is 11.5 days. TaNe is with *rt* calculated from the trapezoidal approximation without estimates of e. We is weekly *e* for 2004-05. Mre is *e* from the total live fish observed divided by the capture-recapture estimates.

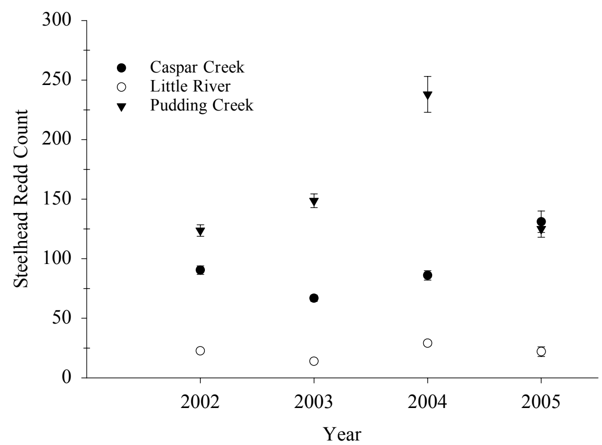


Figure 12. Steelhead redd counts versus year.

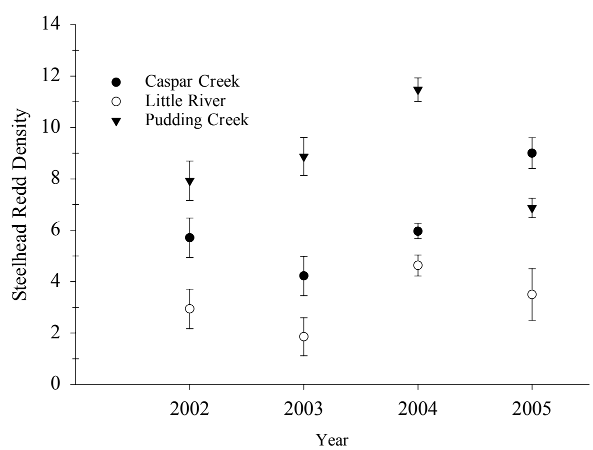


Figure 13. Steelhead redd density versus year.

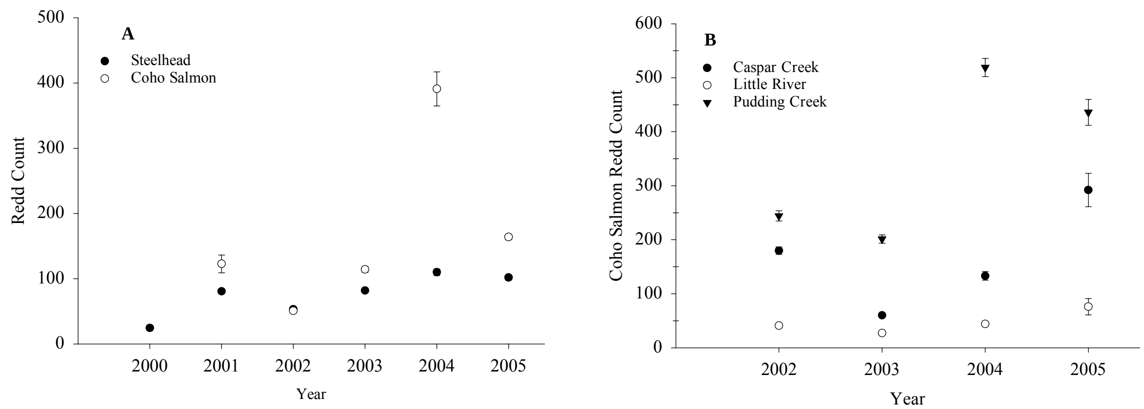
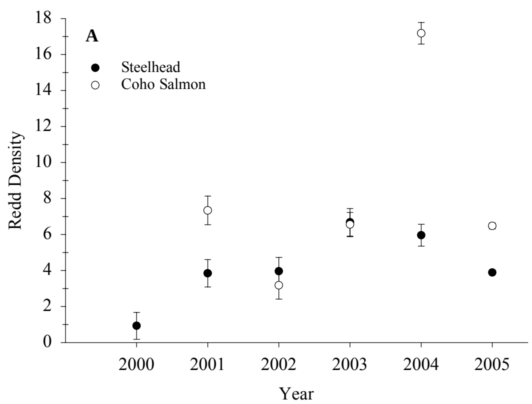


Figure 14. Redd counts versus year. a). Steelhead and coho salmon redd counts versus year above the ECS. b). Coho salmon redd counts versus year in Caspar and Pudding Creeks and Little River.



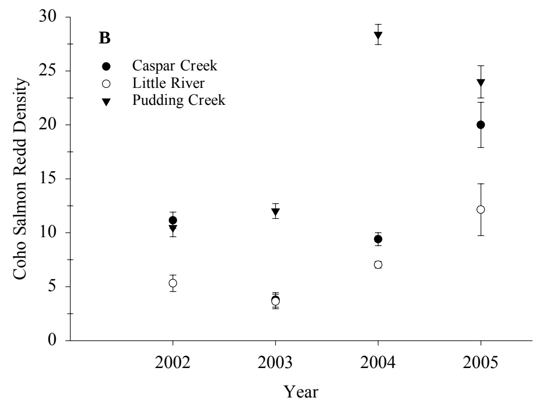


Figure 15. Redd density versus year. a). Steelhead and coho salmon redd density versus year above the ECS. b). Coho salmon redd density versus year in Caspar and Pudding creeks and Little River.

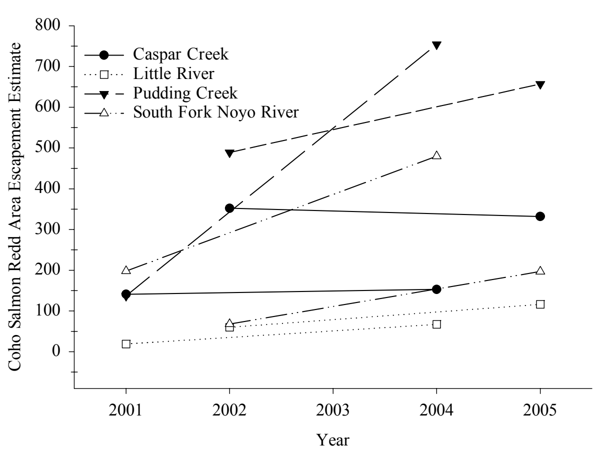


Figure 16. Coho salmon abundance over two life cycles 2001 to 2004 and 2002 to 2005.

Table 1. Steelhead escapement estimates, female to male ratios, live fish observer efficiency, and associated information from spawning ground surveys in four coastal Mendocino County streams during 2004-05.

Stream Name	Number Live	Female:Male	Trapezoidal Area	Predicted Observer Efficiency	Escapement Fish/Redd	Redds/Female		Fish/km
						AUC*	Redd Area	
Caspar Creek	6	1.00:1.00	58	-	154 ± 11	3.2-5.2-9.2	2.6 ± 0.01	2.1-3.5-5.2
Little River	1	1.00:1.00**	13.5	-	26 ± 5	2.0-3.7-7.8	2.2 ± 0.37	1.1-1.9-2.8
Pudding Creek	20	2.25:1.00^	387.5	0.04 ± 0.005	0.91-1.37-1.97^	0.93-1.23-1.93^	2.5 ± 0.02	6.7-11.1-15.6^
South Fork Noyo	4	1.40:1.00	24	-	120 ± 5	5.4-8.4-14.5	2.27 ± 0.10	0.4-0.6-1.0

* AUC is tra*pcmr0e/rt 12.6 from gandg
^ Data from capture-recapture estimates
** Assumed 1.00:1.00

Table 2. Coho salmon escapement estimates, female to male ratios, live fish observer efficiency, and associated information from spawning ground surveys in four coastal Mendocino County streams during 2004-05.

Stream Name	Number Live	Escapement Carcass	Escapement Mark-Recapture	Female:Male	Trapezoidal Area	Predicted Observer Efficiency	Escapement Fish/Redd PC*	Escapement Fish/Redd SF*	Redds/Female AUC**	Redds/Female Redd Area	Fish/km
Caspar Creek	108	123-197-411	-	1.14:1.00	1105	0.18 ± 0.01	729 ± 77	603 ± 64	3.95 ± 0.95	1.46 ± 0.01	7.5-12-25.1
Little River	7	19-60-114	-	1.00:1.00	190.5	0.14 ± 0.03	157 ± 31	157 ± 31	2.89-5.03-6.47	1.31 ± 0.01	7.2-22.7-43.1
Pudding Creek	779	250-781-4388	899-1167-1773	0.85:1.00	8370.5	0.27 ± 0.07^	2.68 ± 0.03^	901 ± 10	1.04 ± 0.18	1.56 ± 0.02	49.5-64.3-97.7^
South Fork Noyo	87	48-124-710	272-536-854 (286)	1.13:1.00	1455	0.23 ± 0.09^	410 ± 50	1.74 ± 0.04^	0.69 ± 0.01 (1.50 ± 0.14)	1.47 ± 0.01	16.7^

* average fish per redd aboce ecs 01-05 and pc 04/05
^ data from total released above ecs or mr live est in pc
** auc rt 11.5 car mr/live obs oe
Data in brackets are from total counts above the ECS

Table 3. Steelhead redd data and redd based escapement estimates in four coastal Mendocino County streams during 2004-05. The O.E. column is the observer efficiency adjusted redd count.

Stream Name	Redd Observer Efficiency	Number of Redds		Escapement Estimate	Redds/km
		Raw	O. E.	Redd Area	
Caspar Creek	0.44 ± 0.10	79	131 ± 9	100 ± 7	9.0 ± 0.60
Little River	0.44 ± 0.43	15	22 ± 6	20 ± 6	3.5 ± 0.60
Pudding Creek	0.82 ± 0.04	102	125 ± 7	100 ± 5	6.78 ± 0.38
South Fork Noyo	0.95 ± 0.05	119	125 ± 4	55 ± 4	3.89 ± 0.12

Table 4. Coho salmon redd data and redd based escapement estimates in four coastal Mendocino County streams during 2004-05. The O.E. column is the observer efficiency adjusted redd count.

Stream Name	Redd Observer Efficiency	Number of Redds		Escapement Estimate		Redds/km
		Raw	O. E.	Redd Area	1 Redd/Female	
Caspar Creek	0.57 ± 0.15	167	292 ± 31	200 ± 35	548 ± 58	19.99 ± 2.12
Little River	0.66 ± 0.29	50	76 ± 15	116 ± 24	152 ± 30	12.14 ± 2.40
Pudding Creek	0.85 ± 0.07	371	436 ± 24	657 ± 35	949 ± 43	24.0 ± 1.54
South Fork Noyo	0.96 ± 0.02	157	164 ± 4	197 ± 4	309 ± 6	6.48 ± 0.16