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ANNUAL COHO SALMON (*Oncorhynchus kisutch*) AND STEELHEAD (*O. mykiss*) SPAWNING GROUND ESCAPEMENT ESTIMATES 2000 TO 2004 IN SEVERAL COASTAL MENDOCINO COUNTY STREAMS AND RECCOMENDATIONS FOR LONG TERM MONITORING OF COASTAL SALMONIDS

PROJECT 1d2

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Annual coho salmon (*Oncorhynchus kisutch*) and steelhead (*O. mykiss*) spawning ground escapement estimates 2000 to 2004 in several coastal Mendocino County, California streams and recommendations for long term monitoring of coastal salmonids.

By

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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 2003-04 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 carcasses capture-recapture was used to estimate escapement for 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, 2002, and 2003 escapement estimates for these streams, capture-recapture estimates were not different than other methods except assuming one redd per female and redd counts and escapement were correlated. Estimates of the number of coho salmon per redd were different in PC and the SF in 2003-04, but the 2000 to 2004 SF average was not different than the 2003-04 PC estimate and escapement estimated from these values were not significantly different. The 2000 to 2003 average number of steelhead per redd in the Noyo River was not different than the 2003-04 PC estimate and escapement estimated using these values were not significantly different. These results indicate that estimates of the number of fish per redd can be transferred among steams to estimate populations from redd counts. Estimates of *rt* and *e* were variable, depended on estimation method, were not different for coho salmon between PC and the SF, and may be transferable among streams. Coho salmon abundance over four years and for one complete life cycle (2000 to 2004) did not show clear trends. The purpose of this study was to 1) produce annual estimates of coho salmon and steelhead escapement from spawning ground surveys in four coastal Mendocino County streams, 2) continue to evaluate sources of bias in spawning ground escapement estimates (redd based, AUC, and carcass capture-recapture) and compare these to capture-recapture escapement estimates of coho salmon and steelhead in PC and coho salmon releases above the ECS, 3) evaluate trends in adult coho salmon escapement 2000 to 2004, and 4) provide recommendations for long-term regional monitoring of California's coastal salmonids.

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[1] Anadromous Fisheries Research and Monitoring Program Report No. FB05-01. 22 June 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 suggest that the first stage sampling could utilize 1) redd surveys where either the total numbers of redds are a sufficient measure of adult population status or redd counts are 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 using redd areas, 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. 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.

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.

The use of redd counts or escapement estimates based on redd data must 1) represent the actual number of redds present (no over/undercounting errors or redd species misidentification) and 2) reflect population status (Dunham et al. 2001) or be convertible to population estimates for this purpose. Converting redd counts to population estimates requires estimates of the female to male ratio and assumptions about, or empirical estimates of, the number of redds a female salmonid makes or the number of fish per redd (see Gallagher and Gallagher, 2005 for discussion of some of these assumptions). As the product only of reproductive adults, redd counts provide an index of effective population size (Meffe 1986). Maxell (1999) suggests that the sources of counting errors involved in redd counts be identified and reduced before they will be useful for long term monitoring. Dunham et al. (2001) suggest that redd counts are less intrusive and expensive than tagging, trapping, underwater observation, weirs, and genetics for inventorying bull trout populations and that with limited resources more populations can be inventoried over a longer period. However, they conclude that substantial improvements are needed to reduce counting errors before redd counts will be useful for population monitoring. Gallagher and Gallagher (2005) provide techniques to reduce bias in coastal salmonid redd counts and show 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 and that redd counts were significantly correlated with adult escapement. However, they found that escapement estimates assuming one redd per female were significantly different than estimates from other methods.

There has been little or no evaluation of the use of estimates of numbers of fish (or females) per redd to convert redd counts to population estimates. I did not find evidence in the literature supporting the idea that the number of fish or females per redd is constant among streams (e.g. they transferable among streams) or among years, important questions if these estimates are to be used for calibrating first stage sampling (Boydstun and McDonald 2005). 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 (Boydstun and McDonald 2005) to estimate escapement.

The AUC^e (Hilborn et al. 1999) is assumed to produce unbiased estimates of escapement from periodic fish counts and the time (in days) between surveys by converting the trapezoidal approximation (units of fish/days) to fish numbers (AUC) by dividing it by residence time (*rt*: time in days fish are alive on the spawning grounds and subject to being counted), and expanded by an estimate of observer efficiency (*e*: number of fish observed/true number present on each survey) (Korman et al. 2002) to account for fish present but not counted during individual surveys (English et al. 1992, Hilborn et al. 1999). However, 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). 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. Observer efficiency in live fish counts is influenced by habitat and cover complexity, stream flow, water visibility, weather conditions, and the physical and mental state of observers. 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).

Residence time can be estimated in a variety of ways, most of which require capture and tagging of live fish on their way to spawning areas and future detection on the spawning grounds as live fish or carcasses or from fish returning from them (e.g. steelhead). These include the time between capture and recapture of tagged fish (Beidler and Nickelson 1980, English et al. 1992, Irvine et al. 1992, Manske and Schwarz 2000, Gallagher and Gallagher 2005), periodic observation of fish on redds (Neilson and Geen 1981, Gallagher and Gallagher 2005), the proportion of fish observed compared to total counts or estimates calculated from capture-recapture experiments or the AUC (Irvine et al. 1992, Hilborn et al. 1999, Parken et al. 2003, Shardlow 2004), capture-recapture of radio tagged fish (Korman et al. 2002), estimates from the literature (Shardlow 2004, Gallagher and Gallagher 2005), and time laps video (Shardlow 2004). Rarely, if ever, has the reliability of using an estimate of *rt* from one stream in another (i.e. are they transferable among streams?) been evaluated.

Similarly, observer efficiency (*e*) is estimated in a variety of ways, most of which require capture and tagging of live fish on their way to spawning areas and observation of tagged and untagged fish in spawning areas. These include capture-recapture compared to total counts (Jones et al. 1998, Hilborn et al. 1999, Korman et al. 2002), computer simulation (Jones et al. 1998), comparison of counts with electro-fisher counts (Irvine et al. 1992), fence counts or total counts to numbers seen (Shardlow et al. 1987, Korman et al. 2002), total tags to tags observed on each survey (English et al. 1992, Korman et al. 2002), multiple pass of crews (Parken et al. 2003), or predicted from stream flow and visibility (Korman et al. 2002). Given a reliable estimate of *rt* and a total estimate of fish present observer efficiency may also be calculated from the trapezoidal approximation (Korman et al. 2002). Rarely, if ever, has the reliability of using an estimate of *e* from one stream in another (i.e. are they transferable among streams?) been evaluated. Although Irvine et al. (1992) found considerable variation in *e* that depended on the survey methods.

I followed the methods of Gallagher and Gallagher (2005) to estimate escapement from spawning ground surveys in Caspar and Pudding creeks and the South Fork Noyo and Little rivers during 2003-04. Additionally, 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 estimates 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. The use of the variance associated with the estimates of *rt* and *e* to estimate uncertainty associated with the AUC was explored by calculating 95% confidence levels in the AUC estimates from these variables and comparing resulting escapement numbers to capture-recapture and total releases numbers. Capture-recapture estimates were not different than those from other methods except for estimates assuming one redd per female. Redd counts and escapement estimates were significantly correlated. Coho salmon estimates of the number of fish per redd were different in Pudding Creek and the South Fork Noyo River suggesting these variables were not transferable among streams. However, the four year 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. 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. Estimates of *rt* were variable, depended on the method of estimation, were not different for coho salmon between Pudding Creek and the South Fork Noyo River, and appear to be transferable among streams. The *rt* estimates calculated from capture-recapture estimates and the trapezoidal approximation, without estimates of *e*; appear to be the most promising for regional monitoring with the AUC. Estimates of *e* were similarly variable, were not different for coho salmon in Pudding Creek and the South Fork Noyo River, and appear to be transferable among streams. Predictive models were developed to estimate *e* from stream flow and water visibility and were applied to Caspar Creek and Little River. Trends in coho salmon abundance over four years and for one complete life cycle (2000 to 2004) were examined following Gallagher and Knechtle (2004) and did not show significant trends. I discuss the application of these findings to long term regional monitoring and provide recommendations for further study.

The purpose of this study was to 1) produce annual estimates of coho salmon and steelhead escapement from spawning ground surveys in four coastal streams in Mendocino County, California, 2) continue to evaluate sources of bias in spawning ground escapement estimates (redd based, AUC, and carcass capture-recapture) and compare these to capture-recapture of coho salmon and steelhead in Pudding Creek and total releases of coho salmon above the Noyo River ECS, 3) evaluate trends in adult coho salmon escapement 2000 to 2004, and 4) provide recommendations for the 2005-06 Mendocino coast pilot program for the California Plan (Boydstun and McDonald 2005) and long-term regional monitoring of California's coastal salmonids including field methods and analysis procedures.

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 Little River was surveyed approximately bi-weekly from early-December 2003 to mid-April 2004. All available spawning habitat in the South Fork Noyo River above the ECS was surveyed approximately twice per week from early-December 2003 to mid-February 2004 and biweekly from mid-February to mid-April 2004. 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 the size of the redd (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. These estimates were then used to estimate the number of fish by multiplying them by the number of redds counted 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 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 2004 in all streams for which this data was available.

Capture-Recapture

Steelhead escapement in Pudding Creek was estimated using the Petersen capture-recapture method during 2003-04 (Krebs 1989). During 2003-04 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. An attempt was made to use different colored floy tags each week, but logistics and storm events limited this effort. Steelhead capture-recapture estimates were not possible using the Noyo River ECS because steelhead usually bypass this structure.

Coho salmon escapement in Pudding Creek was estimated using the Petersen capture-recapture method during 2003-04 (Krebs 1989). During 2003-04 coho salmon 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 and as carcasses. An attempt was made to use different colored floy tags each week, but logistics and storm events limited this effort.

Coho populations were also estimated by capture and recapture of carcasses during spawning surveys in all streams following the Jolly-Seber method, or the Schnabel method when recaptures were less than seven (Krebs 1989). Known numbers of coho were tagged with colored floy tags released above the Noyo River ECS during 2003-04. An attempt was made to use different colored floy tags each week, but logistics, the need to differentiate between hatchery and wild fish, and storm events limited this effort.

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), and taken from the literature (Gallagher and Gallagher 2005). Because floy tag colors were not routinely changed on a weekly basis and tag numbers could not be determined on live steelhead observed in the stream, the time between capture and recapture on the spawning grounds (*rt*) was estimated in a number of ways. These were: observation day minus the last most likely marking date for each tag color (RDL), observation day minus the median most likely mark date for each tag color (RDM), observation day minus the first likely marking date for each tag color (RDH), observation day minus the last day each color tag was used prior to the observation day for each tagged fish (ODL), observation day minus the median day each color tag was used prior to the observation day for each tagged fish (ODM), and observation day minus the first day each color tag was used prior to the observation day for each tagged fish (ODH). As a potential method to include estimates of uncertainty in the AUC it was calculated with the average and 95% confidence intervals for *rt* from ODL, ODM, and ODH and different estimates of *e* and evaluated by comparison to capture-recapture estimates.

Coho salmon *rt* was estimated from the time between capture and recapture of tagged fish as fresh carcasses and calculated from the trapezoidal approximation and capture-recapture estimate for Pudding Creek and the South Fork Noyo River above the ECS, both with and without estimates of observer efficiency, and taken from the literature (Beidler and Nickelson 1980).

Due to the amount of data from the floy tagging of fish in Pudding Creek and the South Fork Noyo River, observer efficiency (*v*), 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 and estimates of *rt*. Weekly estimates of *e* for each species were used along with weekly estimates of stream flow and water visibility to create predictive regression models to estimate *e* from these variables. 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 visibility.

Trends in Coho Salmon Abundance

Trends in coho salmon abundance over four years and for one complete life cycle (2000 to 2004) were examined following Gallagher and Knechtle (2004). The slopes of adult abundance versus year for all four years were compared with paired t-tests treating each stream as a sample. The slope of adult abundance from 2000 to 2004 for each stream were examined graphically and statistically tested to determine if they differed from zero (i.e. no trend if not different than zero) with t-tests.

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. Liner regression was used to predict *e* from stream flow and water visibility. 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. Statistical significance was accepted at $p < 0.05$.

RESULTS

Redd Counts

Observer efficiency in steelhead redd counts ranged from 0.86 (S.E. = 0.06) to 0.69 (S.E. = 0.14) in the four study streams and was lowest in the South Fork Noyo River (Table 3). The total number of steelhead redds in the four streams ranged from 29 (S.E. = 2) to 238 (S.E. = 15) and was lowest in Little River (Table 3).

Observer efficiency in coho salmon redd counts ranged from 0.83 (S.E. = 0.03) to 0.69 (S.E. = 0.10) 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 44 (S.E. = 2) to 519 (S.E. = 17) and was lowest in Little River (Table 4).

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 2003-04 (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 and Gallagher 2005) steelhead capture-recapture and AUC escapement estimates were significantly different than redd area and one redd per female estimates (ANOVA: $F = 6.16$, $p = 0.06$, $df = 42$). Examined individually, the estimates based on one redd per female were significantly different than all other estimates (Tukey's $q > 3.75$, $p < 0.035$). The AUC and redd area escapement estimates were not significantly different (Tukey's $q = 0.65$, $p = 0.89$). It appears that steelhead escapement has been relatively constant in these four streams over the past three years (Figures 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 and Gallagher (2005) coho salmon AUC estimates in Figures 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 and Gallagher 2005) known numbers of coho salmon released above the ECS were not significantly different than AUC and redd area escapement estimates (ANOVA $f = 1.16$, $p = 0.37$, Figure 3a). Known releases above the ECS and estimates based on assuming one redd per female were not significantly different (ANOVA $f = 4.99$, $p = 0.11$, $df = 7$). Coho salmon carcass based capture-recapture estimate above the ECS were significantly lower than estimates from all other methods (Tukey's $q > 8.95$, $p < 0.001$). It appears that there were more coho salmon returning to spawn above the Noyo River ECS in 2003-04 than in previous years (Figure 3a).

Treating years as samples (previous year's data from Gallagher and 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 ($x^2 = 11.57$, $p = 0.009$, $df = 3$). 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 ($q > 3.74$, $p < 0.05$). Redd area, carcass capture-recapture, and AUC estimates were not significantly different ($q < 3.40$, $p > 0.05$). It appears that there were more coho salmon returning to spawn in Pudding Creek and Little River in 2003-04, whereas fewer returned to Caspar Creek than in 2001-02 but more than in 200-01 and 2002-03.

AUC

Residence Time

Average steelhead residence time based on tag recoveries ranged from 12 to 45 days and was similar to estimates from the literature (Figure 4). Confidence bounds for all estimates, except for those that assumed the longest likely time between tagging and tag recovery, overlapped one another (Figure 4). Residence times calculated from observation day minus the most likely time of tagging and observation day minus the first, median, and last day each tag color was used generally differed by less than one day (Figure 4). Residence time calculated from the trapezoidal approximation and weekly tag based observation efficiency was the longest of all estimated residence times and is likely due to the low estimates of observer efficiency. 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) and overlapped those assuming low and median time between tagging and observation on spawning grounds (Figure 4). Whereas *rt* estimates calculated from weekly observer efficiency and the trapezoidal approximation overlapped main stem residency time from Gallagher and Gallagher (2005) and estimates assuming the longest possible period between tagging and recovery. Residence time assuming the longest period between tagging and recovery and those assuming the shortest time between tagging and recovery were significantly different (ANOVA $F = 9.7$, $p < 0.01$, $df = 29$), but were not significantly different from those assuming the median time between tagging and recovery (Tukey's $q = 3.1$, $p = 0.09$). Steelhead residence time calculated from the trapezoidal approximation and capture-recapture estimates in Pudding Creek without any estimate of observer efficiency was 2.6 days (range 1.48-4.34).

The average coho salmon residence time based on the time between tagging and recovery of tags on carcasses of 32 (S.E. = 1.7) days in Pudding Creek and 28 days (S.E = 1) in the South Fork Noyo River was much longer than that estimated in Oregon (11.5 days) or calculated form the trapezoidal approximation (Figure 5). Residence time for coho salmon that arrived in these streams before 15 December was significantly longer than for fish that arrived later (Figure 5, Pudding Creek $T = 11.5$, $n = 3:16$ $p = 0.04$, South Fork Noyo River $T = 1631.5$, $n = 45:75$, $p < 0.001$). Residence time for early arriving coho salmon was not significantly different between Pudding Creek and the South Fork Noyo River ($q = 0.43$, $p > 0.05$). Residence time for late arriving coho salmon was not significantly different between Pudding Creek and the South Fork Noyo River ($q = 0.36$, $p > 0.05$). Residence time for all tag recoveries in Pudding Creek was not significantly different than for the South Fork Noyo River ($t = 1.63$, $df = 136$, $p = 0.10$). 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 from Oregon. Comparing estimates from all methods, residence time was not significantly different in Pudding Creek and the South Fork Noyo River (ANOVA $F = 1.45$, $p = 0.28$, $df = 12$). But was different depending on how it was estimated (Figure 5).

Observer Efficiency

Steelhead observer efficiency, while variable depending on how I estimated it, was generally lower than estimated for coho salmon and ranged from 0.02 to 0.31 (Figures 6-7). Stream flow was significant for predicting weekly observer efficiency for live steelhead (ANOVA $F = 4.6$, $p = 0.04$) in Pudding Creek and resulted in the following relationship: Observer Efficiency = 0.319 + (0.0231 * stream flow in m^3/s for each survey segment) (Equation 1). Weekly observer efficiency and that predicted from stream flow (Equation 1) in Pudding Creek were not significantly different ($t = 0.15$, $df = 38$, $p = 0.88$) and overlapped with estimates calculated from the total number of steelhead observed divided by the capture-recapture escapement estimate. 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.

Water visibility was significant for predicting weekly observer efficiency for live coho salmon (ANOVA $F = 4.96$, $p = 0.04$) in Pudding Creek and resulted in the following relationship: Observer Efficiency = 0.269 - (0.118 * water visibility in meters) (Equation 2). Weekly coho salmon observer efficiency and estimated from water visibility for each survey segment (Equation 2) in Pudding Creek were not significantly different (T = 930 n = 30:30, p = 0.83) and overlapped with estimates calculated from the total number of coho salmon observed divided by the carcass capture-recapture escapement estimate (Figure 7). These estimates of observer efficiency were lower than those estimated from observations of tagged fish and calculated from trapezoidal area. Although coho salmon observer efficiency differed due to the method of estimation, it was not significantly different between Pudding Creek and the South Fork Noyo River (ANOVA F = 1.23, df = 11, p = 0.32). Observer efficiency estimated from carcass capture-recapture and total fish observed in spawning ground surveys was 1.0 for the South Fork Noyo River because the carcass estimates were significantly lower than the number of fish observed.

Escapement Using Different *rt* and *e* Values

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 8a). 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 1) when using *rt* calculated from the trapezoidal area and stream flow predicted *e*, and 2) when using main stem *rt* (same as high *rt* from likely possible tag time minus observation day) and *e* from total tags observed divided by total tags applied (Figure 8a). 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 8a). These estimates overlapped with the estimate using low *rt* (latest likely tag time minus observation date) and *e* calculated from the capture-recapture estimates and the total live steelhead observed during spawning surveys, the approach of Gallagher and Gallagher (2005). The greatest range in the 95% confidence intervals resulted from using stream flow predicted *e* and *rt* calculated from the trapezoidal approximation and predicted *e*, this estimate did not overlap the capture-recapture estimate (Figure 8a). The two other estimates that showed wide confidence bounds resulted from using low and median *rt* and the associated 95% confidence levels with *e* from the total tags observed divided by the total tags applied (Figure 8a). 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 8b-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 *e* from live fish observations divided by ECS releases (Figure 9a). This pattern is similar in the South Fork Noyo River (Figure 9b) as well as in Caspar Creek and the Little River (Figure 9c-d). Further substantiating the notion that estimates of *rt* and *e* for coho salmon are transferable among nearby streams. The AUC estimates using 11.5 days and stream specific *e* from live fish observations divided by capture-recapture (Pudding Creek) or total releases (South Fork Noyo River) (method of Gallagher and Gallagher 2005) were not different than to “true” number of coho salmon in these streams (Figure 9a-b).

Fish Per Redd

The number of steelhead per redd in Pudding Creek averaged 1.11 (95% ci 0.79-1.79). Estimates of the number of steelhead in Caspar Creek and the Little and South Fork Noyo rivers from multiplying average fish per redd from Pudding Creek by the redd count did not differ from the AUC or redd area escapement estimates (Fig 2, Table 1). Steelhead redd counts and AUC escapement estimates were significantly correlated (Figure 10c, $r^2 = 0.82$, $p = 0.001$, $n = 14$). The average number of steelhead per redd with four streams and three years data was 1.11 (S.E. = 0.18). Adult steelhead escapement estimated using this value and the redd counts for each stream each year were not significantly different from AUC estimates ($t = -0.41$, $df = 13$, $p = 0.69$). However the power of this test was low ($\beta = 0.05$). The data in Figure 10a produced the linear regression model; AUC estimate = -2.13 + (1.064 * redd count) ($r2 = 0.65$, $p < 0.001$, $n = 14$, $b = 0.97$) to predict escapement from redd counts. This model predicts 0.50 fish per redd and 2.002 redds per fish.

The number of coho salmon per redd based on releases above the Noyo River ECS was 1.69 (95% ci = 1.36-1.78) and was lower than the estimate from capture-recapture estimates in Pudding Creek of 2.32 (95% ci = 2.06-3.09) (Table 2). Escapement estimates using these values were higher than AUC, redd area, and known escapement estimates, but the 95% confidence intervals generally overlapped (Figure 3, Table 2). Using the number of fish per redd estimated in the South Fork Noyo River to estimate escapement in Pudding Creek resulted in an estimate lower than those from other methods including the capture-recapture estimate and the 95% confidence intervals did not overlap (Figure 3b, Table 2). Using the number of fish per redd estimated in Pudding Creek to estimate escapement in the South Fork Noyo River resulted in an estimate higher than those of other methods including the capture-recapture estimate and the 95% confidence intervals did not overlap (Figure 3a, Table 2).

The average number of coho salmon per redd in the South Fork Noyo River over four years was 2.3 (S.E. = 0.18). Escapement estimates using this value and the redd counts each year were not significantly different than the known number of coho salmon above the ECS each year ($t = -0.71$, $df = 3$, $p = 0.53$). Without the 2002-03 redd count and release number data (significant influence Cook's DFFITS = -2.78), coho salmon releases and redd counts were significantly related (Figure 10b, $r^2 = 0.99$, $p = 0.04$). The resulting linear regression model: number of coho salmon = -18.48 + (0.945 * redd count) showed a significant relationship (ANOVA $F = 758.6$, $df = 2$, $p = 0.02$). However the power of this test was low ($\beta < 0.001$) and the regression model predicts 19 redds per one fish and thus under predicts the number of coho salmon from redd counts.

Coho salmon redd counts and carcass capture-recapture estimates were significantly correlated (Figure 10a, $r = 0.86$, $p = 0.0004$, $n = 14$, $\beta = 0.99$). The resulting linear regression model [carcass escapement estimate = -98.335 + (1.717 * redd count)] predicted 37 redds per fish and thus underestimates escapement. The AUC escapement estimates and redd counts were significantly correlated ($r^2 = 0.81$, $p < 0.001$, $n = 14$, $b = 0.99$). The resulting linear regression model [AUC escapement = -2.345 + (1.542 * redd count)] estimates 1.52 redds per fish and 0.66 fish per redd. The data in Figure 10b result in an average of 0.83 (S.E. = 0.19) fish per redd. The predicted escapement for each stream each year from this relationship were not significantly different than the carcass capture-recapture estimates ($W = 10.00$, $p = 0.80$). However, escapement estimates from redd counts using the estimate of 2.3 fish per redd from the South Fork Noyo River were significantly different from carcass capture-recapture and AUC estimates ($t = 4.18$, $df = 14$, $p < 0.001$, $\beta = 0.97$). The estimate of 2.31 fish per redd (95% ci 2.12-2.91) from Pudding Creek in 2003-04 was similar to the four year average number of fish per redd (2.3, S.E. = 0.19) for releases above the ECS.

Trends in Coho Salmon Abundance

The trend in coho salmon abundance over four years in the four study streams shows a slight increase over time (Figure 11a). However, the slope of abundance versus year was not significantly different than zero ($W = 10$, $p = 0.12$). The trend in coho salmon abundance for one complete life cycle (2001 to 2004 adults) appears to show an increase in adults in Pudding Creek and the South Fork Noyo River (Figure 11b). However the slopes of these trend lines were not significantly different than zero ($t = 1.72$, $df = 3$, $p = 0.18$). The power of this test was low ($\beta = 0.21$).

DISCUSSION

Redd Counts

Observer efficiency in redd counts was similar to previous years (Gallagher and Gallagher 2005). Steelhead redd counts were highest in Pudding Creek and lowest in Little River during 2003-04 (Figure 12, Table 1) and were similar to counts in these streams over the past four years (Gallagher 2003). Steelhead redd counts were slightly, but not significantly, higher in 2003-04 than during 2000-2003 (Figure 12). The reason the 2000 steelhead redd counts are lower than other years is likely due to the fact that surveys were not initiated in this stream until late-January and some spawning may have been missed (Gallagher 2000).

Coho salmon redd counts were highest in Pudding Creek followed by the South Fork Noyo River, both of which showed an increase in redd counts over the past four years (Figure 12b-c, Table 2). The redd counts in these two streams are higher than reported over the last four years (Gallagher 2003). Redd counts in Caspar Creek and Little River appear to have remained relatively consistent over the past four years (Figure 12), but show a slight increase over 2002-03. The increase in redd counts observed in 2003-04 likely indicate higher escapement levels than in previous years (Figures 2-3). The effort in the South Fork Noyo River was doubled (crews attempted to survey twice per week), but effort in Pudding Creek was similar to previous years suggesting that increase in effort was not the cause of the observed higher redd count in 2003-04. A large portion of the spawning coho salmon in the South Fork Noyo River were of hatchery origin (Figure 3a), yet no hatchery fish were observed in Pudding Creek. Thus it is unlikely the increase in redd counts was due to artificial propagation. It is interesting that both coho salmon and steelhead redd counts were highest in Pudding Creek of all streams examined in 2003-04. Ocean smolt survival conditions were good in 2001 (http://jisao.washington.edu/pdo/PDO.latest) and it is likely that increased ocean survival and adequate stream flows in 2003-04 contributed to the increase in coho salmon spawning observed in these streams this year.

Similar to the redd counts, both steelhead and coho salmon redd densities (redds/km) during 2003-04 were highest in Pudding Creek followed by the South Fork Noyo River (Figure 13) and were higher than reported for Mendocino coast streams since 1989

(Gallagher 2003). Although the South Fork Noyo River above the ECS has more km's of stream with spawning habitat, redd densities were higher in Pudding Creek suggesting this stream, though shorter, has more spawning habitat or better smolt production. However, escapement and redd counts were higher in Pudding Creek during 2003-04 than previously reported such that less suitable spawning habitat may have been used. Steelhead redd densities appear to have increased in 2002-03 and 2003-04 compared to previous years (Figure 13c, Gallagher 2003).

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). 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 number of redds per fish (and per female) was different for coho salmon in Pudding Creek and the South Fork Noyo River and the 2003-04 estimates appeared unreliable for converting redd counts to fish numbers in different streams (Figure 3, Table 2). Although I was only able to estimate the number of steelhead per redd in Pudding Creek, this estimate appears to produce reasonable escapement estimates in other streams (Figure 2, Table 1). Further evaluation of the number of fish per redd should be conducted (see discussion in the following section). 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) and could be used for long term monitoring of coastal salmonids in the California Plan (Boydstun and McDonald 2005).

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 with a somewhat shorter interval between surveys in the South Fork Noyo River. 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 known numbers for 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-b). 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).

Residence Time

The purpose of this exercise was to determine, from the data collected in Pudding Creek and the South Fork Noyo River during 2003-04, the most reliable estimate of *rt* for coho salmon and steelhead, examine transferability between streams, and make recommendations for future monitoring. Interestingly the *rt* estimates in Pudding Creek and the South Fork Noyo River were similar (Figures 8-9) even though in Pudding Creek fish were tagged about 0.25 km from the ocean, where as the Noyo River ECS is > 12 km from the ocean. Because *rt* and *e* can 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. Coho salmon residence time differed between early and late arriving fish (Figure 5) similar to results of English et al. (1992) and was higher than the estimate of 11.5 days from Oregon (Biedler and Nickelson 1980). About 76% of the coho salmon tagged at the Pudding Creek weir were captured on or before 15 December 2003, but only 5% of the total number of fish observed on the spawning grounds were observed prior to this date and it was not possible to tell which fish observed in the stream after this date had arrived early and which had arrived later. Using early and late estimated *rt* in both Pudding Creek and the South Fork Noyo River greatly overestimated escapement (data not shown) with weekly estimates of *e* and under estimated escapement with capture-recapture based estimates of *e*. This result was similar using the average *rt* from all tag recoveries and was not different than using early and late *rt* separately, similar to findings of English et al. (1992). Surveys in Pudding Creek were generally conducted an average of 10.5 days apart. Assuming two days travel time from the weir to the spawning grounds *rt* estimates from fresh coho salmon carcasses could have been off by about 8 days. I estimated an *rt* of 25.6 (S.E. = 1.7, range = 13 - 38) by assuming each recovered tag carcass was actually 7.5 days old when recovered. The AUC estimates from this *rt* value were higher than the capture-recapture estimate with weekly *e* and lower using capture-recapture *e*. The *rt* estimates using capture-recapture and total tags observed and total tagged were similar to Oregon's 11.5 day estimate (Figure 5) and produced reasonable escapement estimates with the AUC and capture-recapture based *e* (Figure 9).

In this study estimates of coho salmon residence time calculated from the trapezoidal approximation (10.7 S.E. = 1.2 and 10.8 S.E. = 1.6 days, Figure 5) were not different than 11.5 from Oregon and also produced reasonable AUC estimates compared to capture-recapture estimates (Figure 9a-b). English et al. (1992) and Irvine et al. (1992) found coho salmon residence time to range on average between 13 and 17 days (total range 8 - 20.3 days) over three years in two creeks in British Columbia. The *rt* from tag recoveries, not accounting for time between surveys, in both Pudding Creek and the South Fork Noyo River were much higher, and *rt* estimated by other means were similar, to these estimates. Accounting for time between surveys *rt* from tag recoveries, while still higher than estimated in British Columbia, were within the range reported by Irvine et al. (1992). There may be latitudinal differences in *rt* for coho salmon. Peak arrival times and duration of the spawning run in the two creeks studied by Irvine et al. (1992) appear to be similar to that observed in coastal Mendocino County streams.

Steelhead residence time calculated from the trapezoidal approximation and estimated from tag recoveries in Pudding Creek (Figure 5) were not different from estimates for tributary (12.6 days) and main stem (41.3 days) estimates from the Noyo River and taken from the literature (Gallagher and Gallagher 2005). This suggests the average time steelhead spend in smaller coastal streams is about 12 days and the use of 12.6 days for *rt* is recommended. In larger rivers residence time may be up to 55 days (Kormen et al. 2002) and the value of 41.3 days steelhead residence time is recommended in these areas. There was a large range in the possible values of steelhead *rt* and seasonal shifts in *rt* could not be examined because tag colors were not changed frequently, the same color was used weeks apart because there was no set tag schedule, and in some cases no steelhead were tagged for a period of weeks and tag colors were not changed when next fish were captured and tagged.

Future capture-recapture efforts for both steelhead and coho salmon should change tag colors every week so that weekly bounds around residence time can be estimated and potential differences in *rt* due to arrival time can be examined. In streams where weirs are used to capture and tag adult steelhead going upstream, downstream migrant traps could be set up to capture tagged fish and get individual based estimates of *rt*. Steelhead and coho salmon captured going upstream at weirs could also be tagged with pit tags and recaptured with a series of directional antenna arrays set at tributary junctions to better estimate *rt*. To estimate observer efficiency on each survey it will be necessary to know how many tagged versus untagged fish are observed and pit tags are not visible such that the use of both pit tags and floy tags on each fish might be required. If so, the stress and mortality associated with applying both colored floy tags and pit tags to each adult captured should be evaluated.

Coho salmon residence times were not significantly different between Pudding Creek and the South Fork Noyo River suggesting these values were transferable to streams in which they were not estimated. Irvine et al. (1992) and English et al. (1992) found *rt* estimates for coho salmon to be similar between two creeks in one of the three years of their study in British Columbia, but did not evaluate if estimates in one stream could be used in the other. Although steelhead *rt* was only estimated in Pudding Creek during 2003-04 several factors suggest that it is transferable among streams: 1) the Noyo River tributary and main stem estimates of Gallagher and Gallagher (2005) were not different than estimated in Pudding Creek, 2) steelhead redd area and AUC escapement estimates were not significantly different, and 3) the steelhead AUC estimates for the South Fork Noyo and Little rivers and Caspar Creek using different *rt*'s were not different (Figure 8). Further evaluation of the transferability of steelhead and coho salmon *rt* estimates among rivers should be done. In 2005-06 I plan to capture, tag, and release coho salmon and steelhead using the weir on Pudding Creek and a portable weir on Caspar Creek such that *rt* may be estimated and compared among these streams. Coho salmon will also be tagged and released above the Noyo River ECS so there will be three streams data on *rt* in 2005-06 and two years data for the South Fork Noyo River and Pudding Creek for further evaluating transferability. A similar approach may be employed on Freshwater Creek in 2005-06 (Seth Ricker, Perrs. Comm.) such that examining the transferability of *rt* values at a larger geographic scale may be possible. This type of analysis will be necessary to determine if it is reasonable to employ one value of *rt* for each species for all of coastal California as indicated in the California Plan (Boydstun and McDonald 2005).

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. 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, 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).

In this study *e* was estimated by the proportion of tagged fish observed compared to total number of tagged fish present both weekly and for the season total, the total number of fish observed divided by the capture-recapture or total release estimates, predicted from water visibility or stream flow using linear regression of these variable versus weekly estimated observer efficiency, and calculated from the trapezoidal approximation. In addition, on three occasions groups of more than 100 coho salmon were tagged and released above the Noyo River ECS and surveys conducted as soon after releases as possible with observer efficiency estimated as the total tagged seen to total released (M. Knechtle Perrs. Comm.). For coho salmon the proportion of tagged fish observed for each group release trial (average 0.22, range 0.20 – 0.24) was the same as the proportion of tags observed to total tagged present by week in both creeks (Figure 7). The method of using the total marked observed and the total number of fish observed divided by the capture-recapture or release numbers yielded higher estimates of *e* than the weekly estimates. These higher values of *e* likely result from double counting the same fish numerous times because, while the trapezoidal approximation controls double counts by including the time between surveys, the sum of all live fish observed during all surveys does not account for double counts. Thus the total of live fish counts for all surveys may overestimate observer efficiency. However, using these values and 11.5 days *rt* resulted in AUC estimates that were not different from the "true" escapement estimates for coho salmon. The observer efficiency estimate for the South Fork Noyo River using the carcass capture-recapture estimate and total live fish observed was 1.0 because the carcass capture-recapture estimate significantly under estimated the number of fish present.

The estimates of *e* predicted using equations 1 and 2 were generally lower than estimates from other estimates but produced AUC estimates that were not different than those from other approaches (Figures 8-9) depending on which values of *rt* were employed. Water visibility and stream flow was not consistently collected during field surveys and improving consistency in collection of these data may improve predictive models. Kormen et al. (2002) found that stream flow and water visibility were significantly associated with observer efficiency for steelhead and were able to predict *e* from these variables. This approach holds promise for regional spawning ground surveys in the California Plan (Boydstun and McDonald 2005) because if reliable predictive models of *e* based on physical stream data can be developed it will not be necessary to estimate observer efficiency for each stream and survey period. Continued evaluation of this approach is recommended.

The *e* values from different methods of estimation were not different between Pudding Creek and the South Fork Noyo River (Figure 7). Also predictions of *e* from equations 1 and 2 were not different among streams. These results suggest that estimates of *e* in any one stream can be applied to other streams (e.g. they are transferable among streams).

Estimates of *e* calculated from the trapezoidal approximation and capture-recapture or total releases (the "true" escapement estimates) differ depending on the estimate of *rt* used. In Figures 6 and 7, I used residence times of 11.5 for coho salmon and 12.6 for steelhead (Gallagher and Gallagher 2005) to calculate *e* from the trapezoidal approximation and the "true" escapement values for coho salmon and steelhead. Because of the interrelatedness of the data these estimates of *e* were similar to those derived from the total number of live fish observed during spawning ground surveys divided by the "true" estimates (Figures 6-7). When I used coho salmon *rt* from Pudding Creek of 32.6

days (average of all tag recovery on fresh carcasses minus first tag day) to calculate *e* with the trapezoidal approximation and "true" escapement the estimate (0.17-0.26) was similar to the weekly estimates. These AUC estimates were exactly the same as the "true" estimate due to the interrelatedness of the data (data not presented) and this was the same for steelhead (data not presented). This result was the same as using estimates of *rt* calculated from the trapezoidal approximation without estimates of *e* for both species for the same reason (Figures 8-9). Because it appears that estimates of *e* and *rt* are transferable among nearby streams, it may be reasonable to estimate *rt* and capture-recapture escapement estimates using tagging studies in streams with counting structures coupled with spawning ground surveys to estimate the trapezoidal approximations, calculate observer efficiency from these data, and apply the resulting estimates of *rt* and *e* to other nearby streams. This approach should receive further evaluation, especially on a broader geographic scale. But this would be the same as using *rt* calculated without estimates of *e* from the data.

Estimates of *e* may be improved by changing tag colors weekly and conducting surveys after releasing known numbers of tagged fish. However, the most precise AUC escapement estimates were made with *rt* calculated from the trapezoidal approximation and the capture-recapture estimates without estimates of *e*. 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.

Escapement with Different *rt* and *e* Values

The most precise estimates from the AUC resulted from using *rt* calculated from the capture-recapture estimates and the trapezoidal approximation without estimates of *e*. However, estimates using *rt* from Gallagher and Gallagher (2005) and *e* from the total live fish observed divided by capture-recapture estimates also produced AUC escapement estimates that were not different from redd area and capture-recapture estimates. Using *e* predicted from equations 1 and 2 gave the most unreliable AUC estimates and, although these models appear promising, they need improvement before widespread application. It may be that estimates of *rt* and *e* will need to be calculated from the trapezoidal approximation in streams where independent capture-recapture programs are employed each year and applied to other nearby streams. This needs further evaluation, especially on a broader geographic scale.

Fish Per Redd

The number of coho salmon per redd differed slightly among streams and years and 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. (2000) 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. In this study the number of coho salmon per redd was different between the South Fork Noyo River and Pudding Creek and escapement estimates using values from one stream in the other were different from "true" numbers in 2003-04. The three year average number of coho salmon per redd above the Noyo River ECS, was 2.50 (S.E. = 0.46, range = 1.82 – 3.40) and was higher than the 2003-04 estimate of 1.69 (Table 2) fish per redd. However, including the 2003-04 data the four year average number of coho salmon per redd above the Noyo River ECS was 2.30 (S.E. = 0.18) which was the same as the Pudding Creek estimate in 2003-04. These numbers are similar to the estimate of 2.5 fish per redd used to convert redd counts to fish numbers in Washington (Boydstun and McDonald 2005). The low number of coho salmon per redd in the South Fork Noyo River during 2003-04 may be a result of the large number of hatchery fish (Figure 3) or because the estimate of the number of fish released above the ECS that moved back down of 18% (M. Knechtle Perrs. Comm.) was low. However, using an estimate of 2.5 fish per redd overestimated the number of coho salmon in the

South Fork Noyo River during 2003-04, but was not significantly different over four years. 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 coho salmon escapement from redd counts. Improvements to field and laboratory methods listed above for redd counts, capture-recapture, and AUC will also likely improve these estimates.

Similar to the results for coho salmon the number of steelhead per redd differed slightly among streams and years and the use of one value for all streams to convert redd counts to fish numbers for regional spawning ground surveys appears reliable. The average number of steelhead per redd in the Noyo River over four years (2000 to 2003) of 1.39 (S.E. = 0.32, rang 0.60 to 2.09) overlapped the Pudding Creek capture-recapture based estimate for 2003-04 of 1.11 (95% ci = 0.79 - 1.79). The average number of steelhead per redd from AUC estimates and redd counts using all years data was the same as the estimate of the number of fish per redd in Pudding Creek during 2003-04. The AUC and redd area escapement estimates were not significantly different from estimates using 1.11 fish per redd to convert redd counts to fish numbers over four years. This estimate is slightly lower than the estimate of 0.64 steelhead per redd (range 0.32 – 1.03) in Oregon (Susac and Jacobs 2002) suggesting that the number of fish per redd may vary over the range of these fish. Susac and Jacobs (2002) found variation in the number of steelhead per redd among streams and years in Oregon. With a few years data on a number of streams it may be possible to develop a standard conversion factor with the associated uncertainty to estimate steelhead escapement from redd counts. Improvements to field and laboratory methods listed above for redd counts, capture-recapture, and AUC will also likely improve these estimates.

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. In 2001-02 Gallagher (2003) estimated using the AUC that there were 381 (range 305-565) coho salmon in Caspar Creek.

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 two 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 addition 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 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? This column will help remind field personal to examine all redds and flags 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. 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 calculated from Pudding Creek data in 2003-04 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 converted to population estimates using the estimate of fish/redd for coho salmon and steelhead resulting from this study. This approach needs further evaluation, especially considering if these values are consistent among streams and years over a large geographic area. If these values continue to remain similar among streams and years as shown here, this should be the primary approach for long term regional monitoring of California's coastal salmonids as described in the California Plan (Boydstun and McDonald 2005). The method of estimating escapement from 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 these should be changed weekly. 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. George Neillands and Mike Morrison provided useful comments on earlier drafts of this report.

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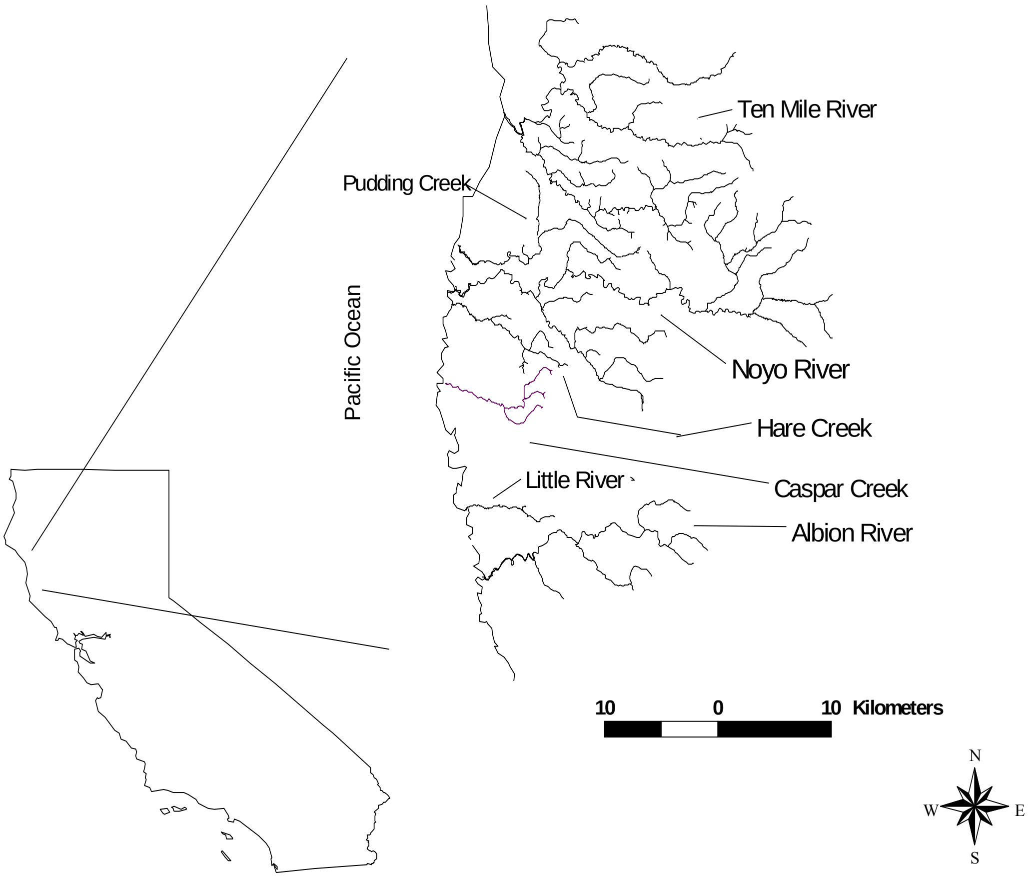


Figure 1. Location of study stream in Mendocino County, California.

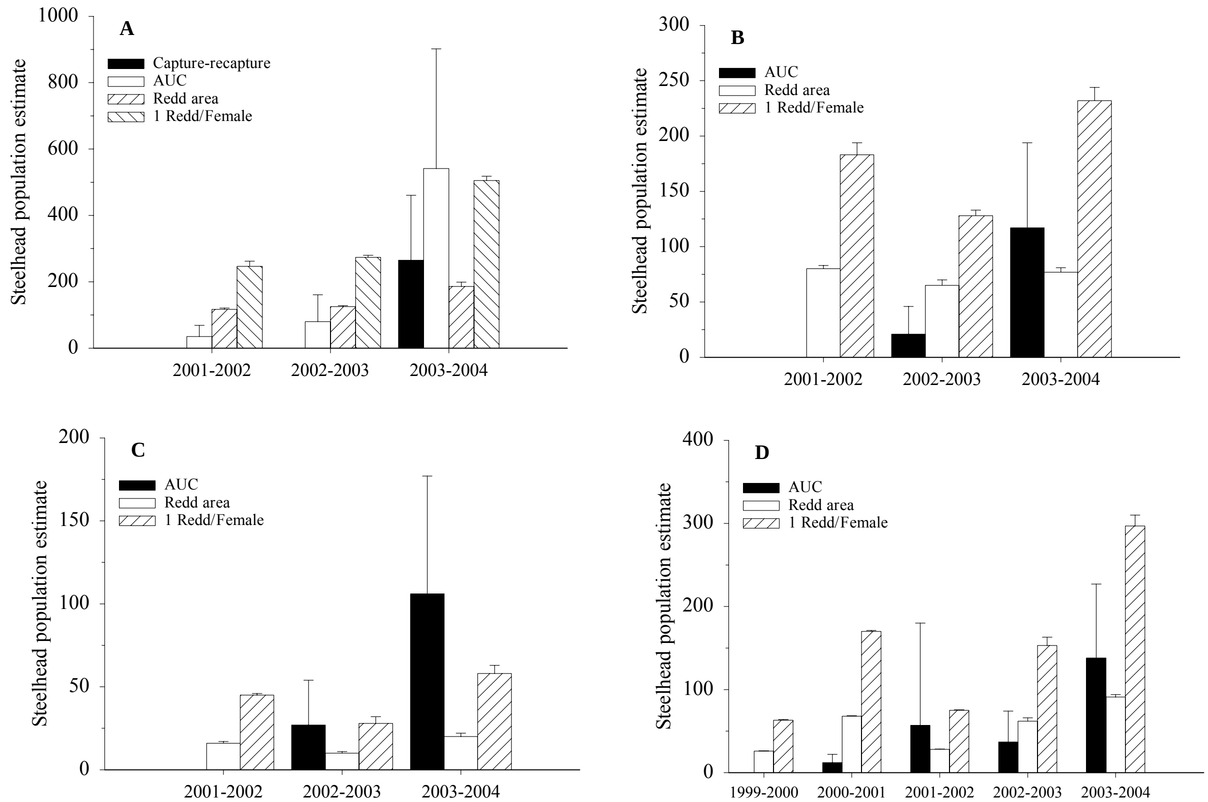


Figure 2. Steelhead population estimates in four coastal Mendocino County streams. a). Pudding Creek 2002-2004. b). Caspar Creek 2002-2004. c). Little River 2002-2004. d). South Fork Noyo River above the ECS 2000 to 2004. Thin lines are 95% confidence bounds for capture-recapture and AUC and S.E. of observer error for redd data.

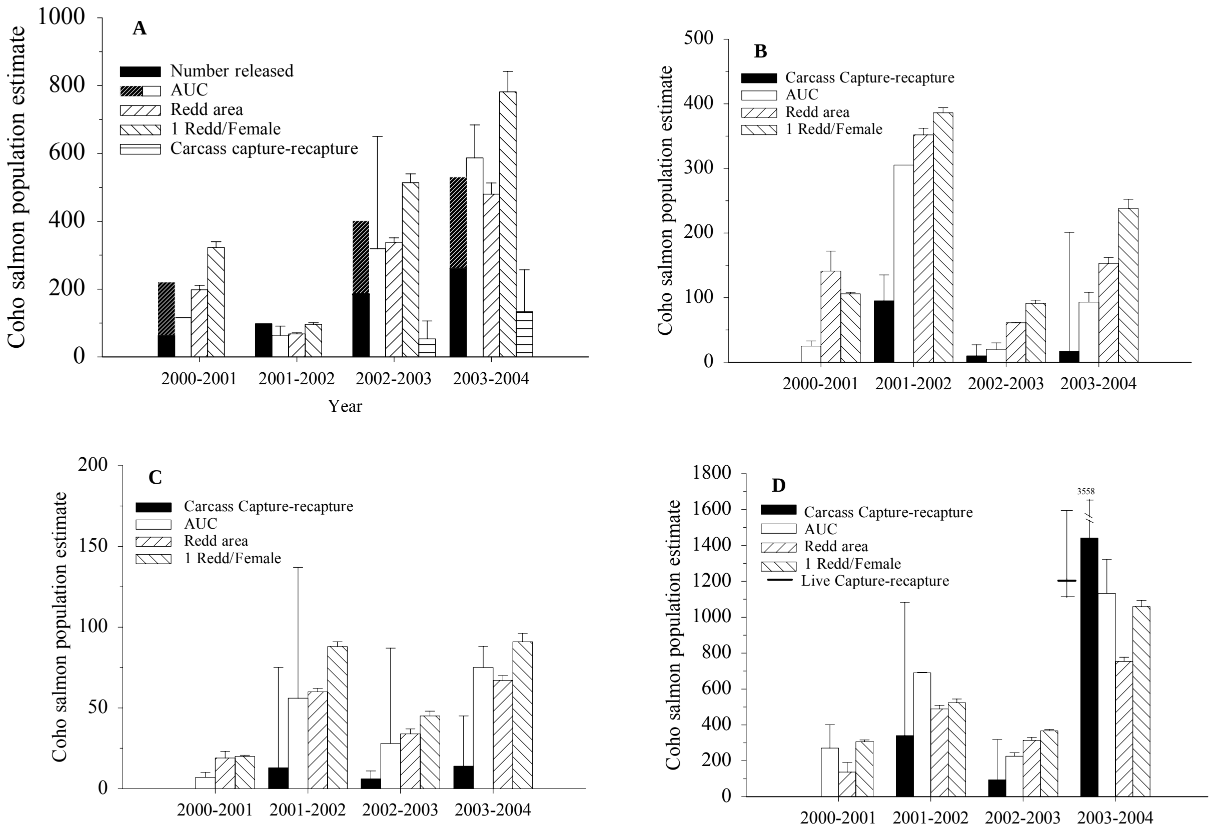


Figure 3. Coho salmon population estimates for four streams in coastal Mendocino County, California 2001-2004. a). South Fork Noyo River above the ECS. b). Caspar Creek. c). Little River. d). Pudding Creek. Shaded area indicates hatchery fish in panel a. Thin lines are 95% confidence bounds for capture-recapture and AUC and S.E. of observer error for redd data.

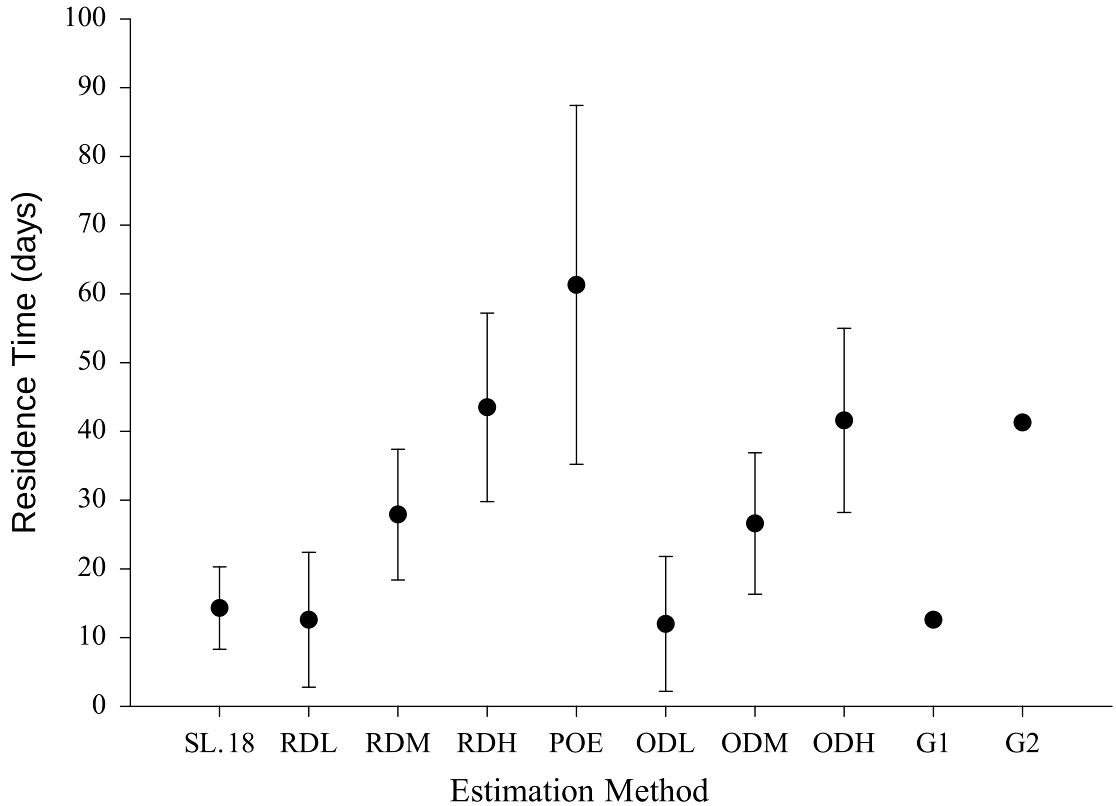


Figure 4. Various estimates of steelhead residence time for Pudding Creek 2003-04. SL .18 is *rt* calculated from the trapezoidal approximation with *e* = 0.18. G1 and G2 are estimates from Gallagher and Gallagher (2005). See methods section for definitions of other abbreviations.

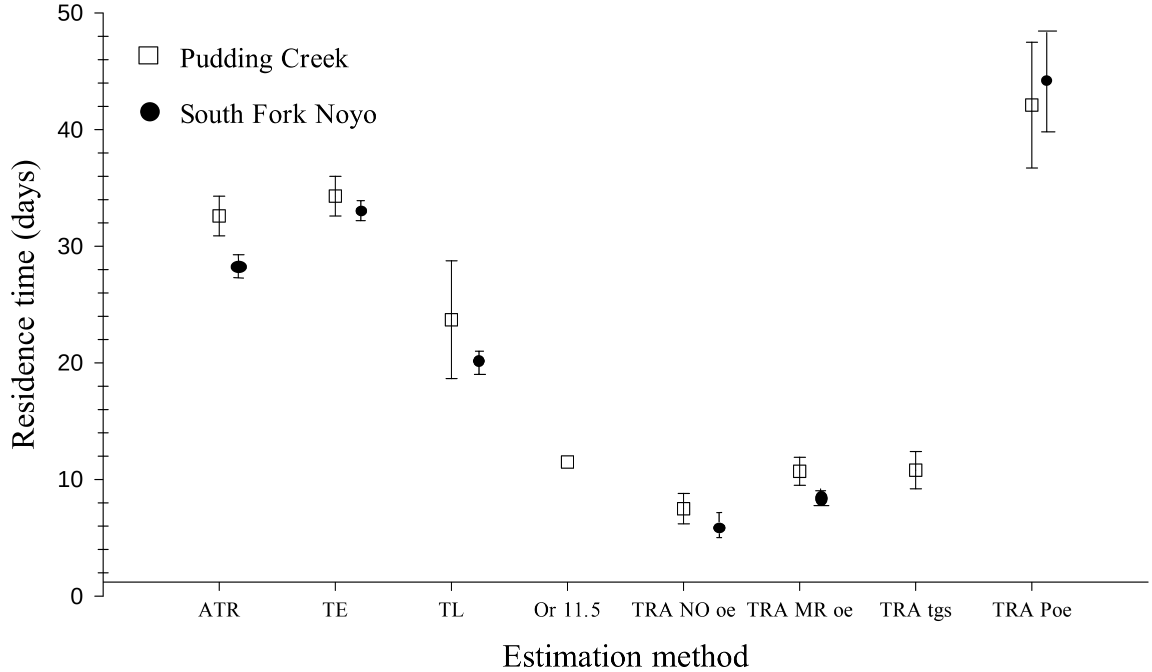


Figure 5. Various estimates of coho salmon residence time for Pudding Creek and the South Fork Noyo River 2003-04. ATR is all tag recoveries. TE is tag recoveries of fish entering before 12/15/03. TL is tag recoveries of fish entering after 12/15/03. Or 11.5 means 11.5 days from Oregon. TRA Nooe is *rt* 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. TRA tags is estimated *rt* from trapezoidal approximation and *e* from the total number of tags applied to total observed during spawning surveys. TRA Poe is *rt* calculated from the trapezoidal approximations and *e* predicted from equation 2.

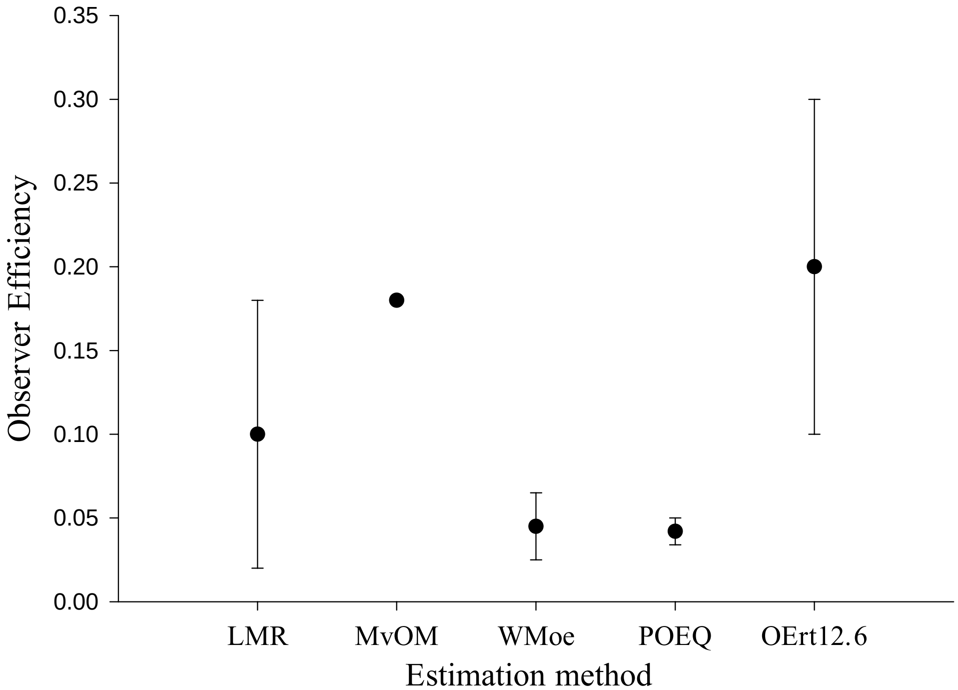


Figure 6. Various estimates of steelhead observer efficiency in Pudding Creek during 2003-04. LMR is total number of live fish observed during spawning ground surveys divided by the capture recapture estimate. MvOM is the total number of marked steelhead observed during spawning ground surveys divided by the total marked at the weir. WMoe is the weekly number of marked steelhead observed divided by the number of marked steelhead present each week. POEQ is observer efficiency predicted from equation 1. OErt12.6 is observer efficiency calculated from the trapezoidal approximation and *rt* of 12.6 days.

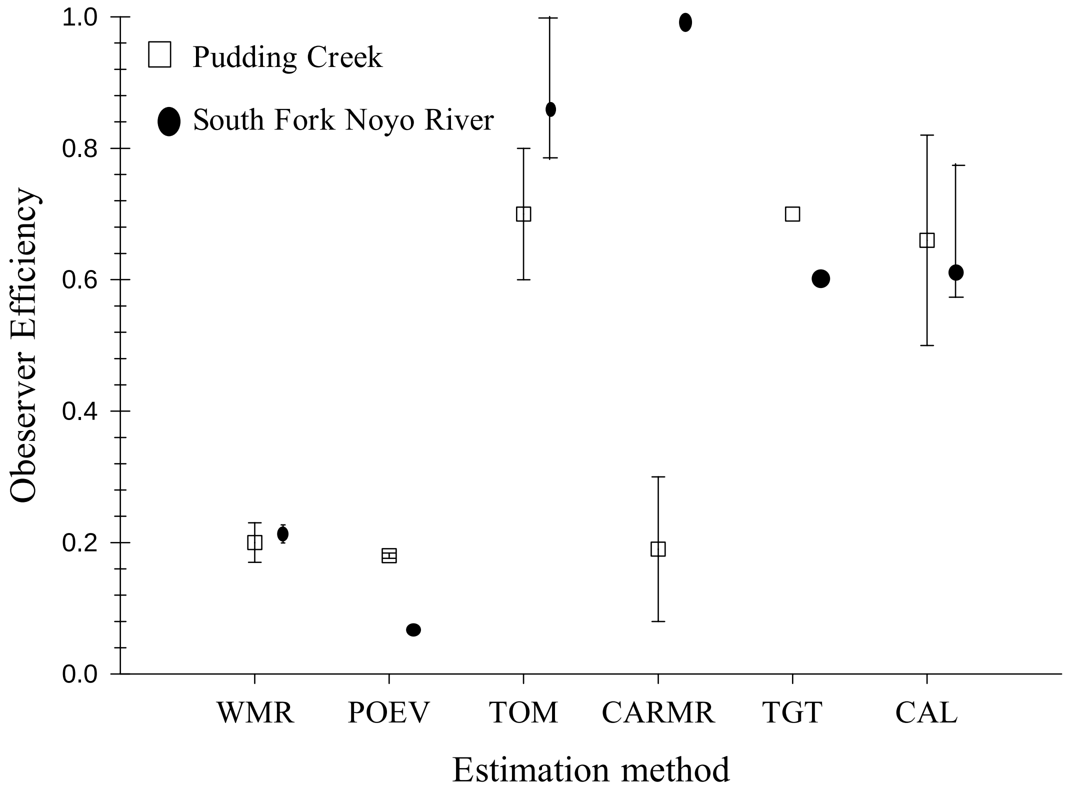


Figure 7. Various estimates of observer efficiency for coho salmon in Pudding Creek and the South Fork Noyo River during 2003-04. WMR is observer efficiency from the weekly number of tagged fish observed divided by the weekly number of tagged fish present. POEV is observer efficiency predicted from equation 2. TOM is the total number of marked fish observed during spawning ground surveys divided by the capture-recapture estimates. CARMR is the total number of life fish observed during spawning ground surveys divided by the carcass capture-recapture estimates. TGT is observer efficiency estimated from the total number of tagged fish observed divided by the total number of fish tagged and released. CAL is observer efficiency calculated from the trapezoidal approximation and *rt* of 11.5 days.

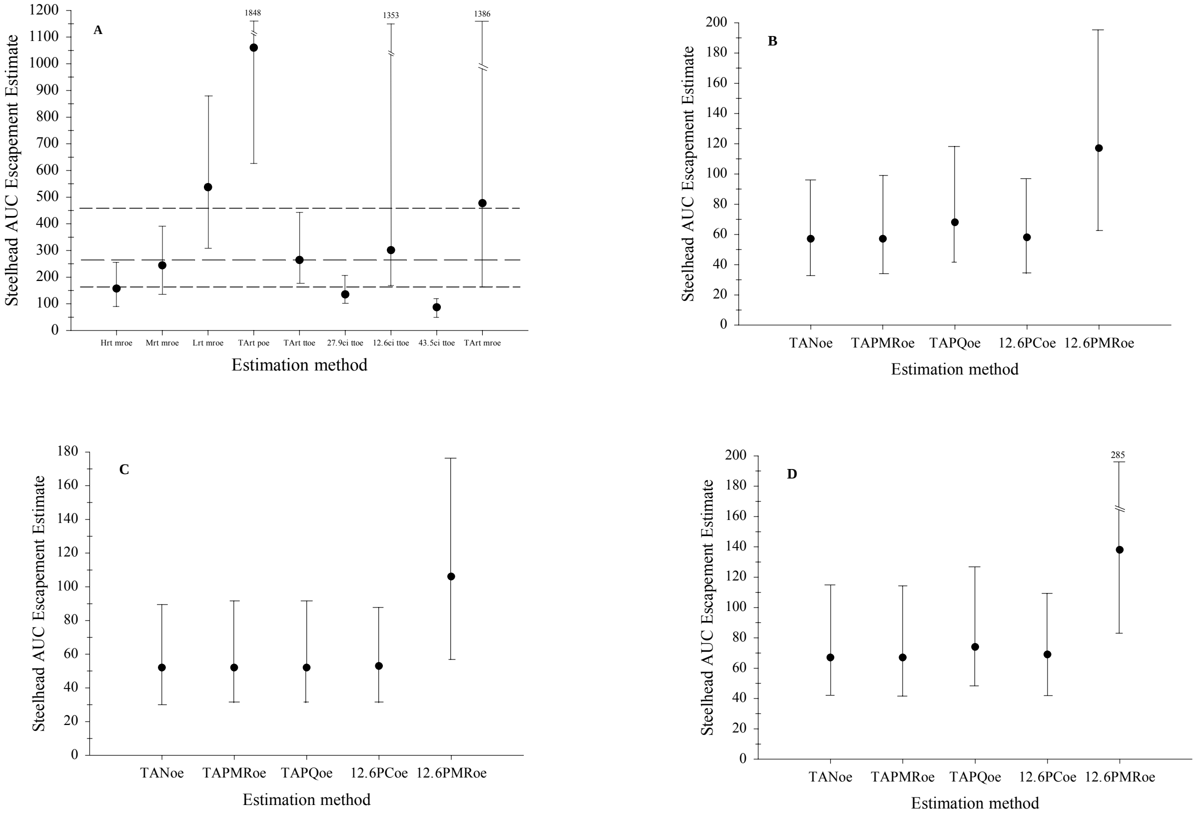


Figure 8. Steelhead AUC escapement estimates for various combinations of *rt* and *e* for four streams in Mendocino County, California during 2003-04. a). Pudding Creek. b). Caspar Creek. c). Little River. d). South Fork Noyo River above the ECS. Thin lines are 95% confidence bounds. Dashed horizontal line in panel a is the capture-recapture estimates and the short dashed lines are the 95% confidence bounds on this estimate. Rt is residence time. H. M, L are RDL, RDM, and RDH (see text for explanation). M ore is observer efficiency from the total number of live fish observed divided by the capture-recapture estimate. Poe (and PQoe) is observer efficiency predicted from equation 1. Ttoe is observer efficiency from the total tags observed divided by total tags present. Noe means *rt* calculated from the trapezoidal approximation without estimates of observer efficiency and the capture-recapture estimates. 12.6, 27.9, and 43.5 are residence times ODL, ODM, and ODH. TA means these values were calculated from the trapezoidal approximation.

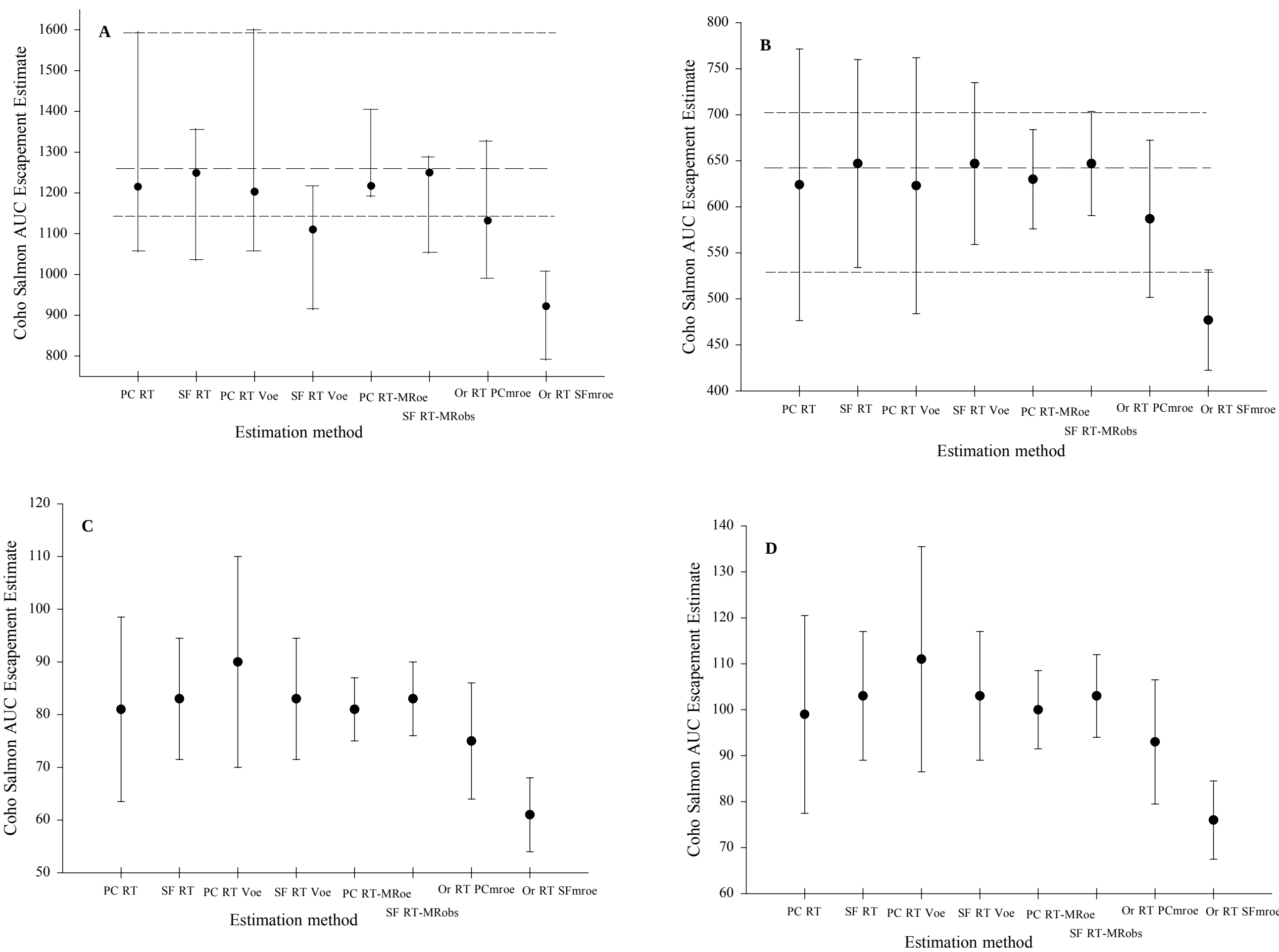


Figure 9. Coho salmon AUC escapement estimates for various combinations of rt and e for four streams in Mendocino County, California during 2003-04. a). Pudding Creek. b). South Fork Noyo River above the ECS. c). Little River. d). Caspar Creek. Thin lines are 95% confidence bounds. Dashed horizontal line in panel a is the capture-recapture estimates and the short dashed lines are the 95% confidence bounds on this estimate. PC RT and SF RT is residence time estimated from the trapezoidal approximation without estimates of observer efficiency and the capture-recapture estimate in Pudding Creek (PC) and total releases above the ECS for the South Fork Noyo River (SF). RT Voe means that residence time was estimated with the trapezoidal area with observer efficiency from equation 2 and the capture-recapture and total release estimates for Pudding Creek and the South Fork Noyo River above the ECS. M ore and MR obs means capture-recapture based observer efficiency was used. Or Rt is 11.5 days from Oregon’s estimate.

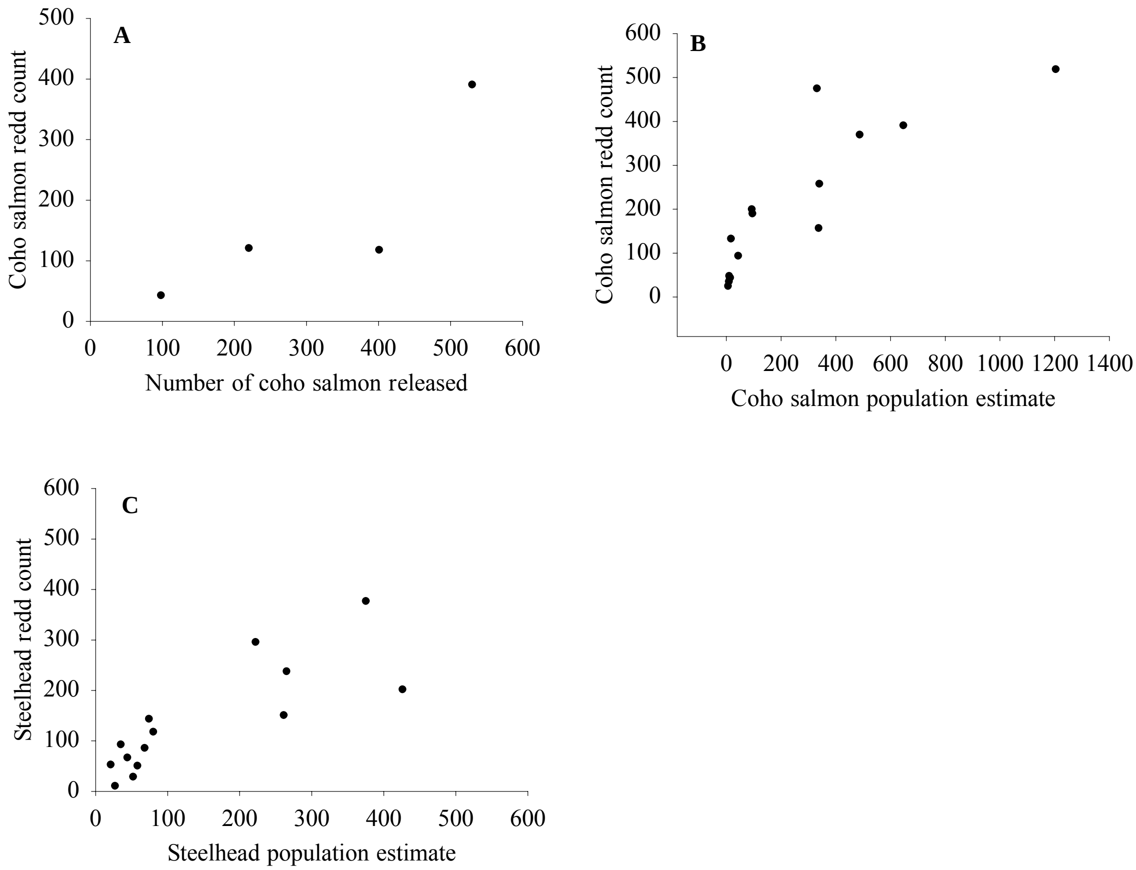
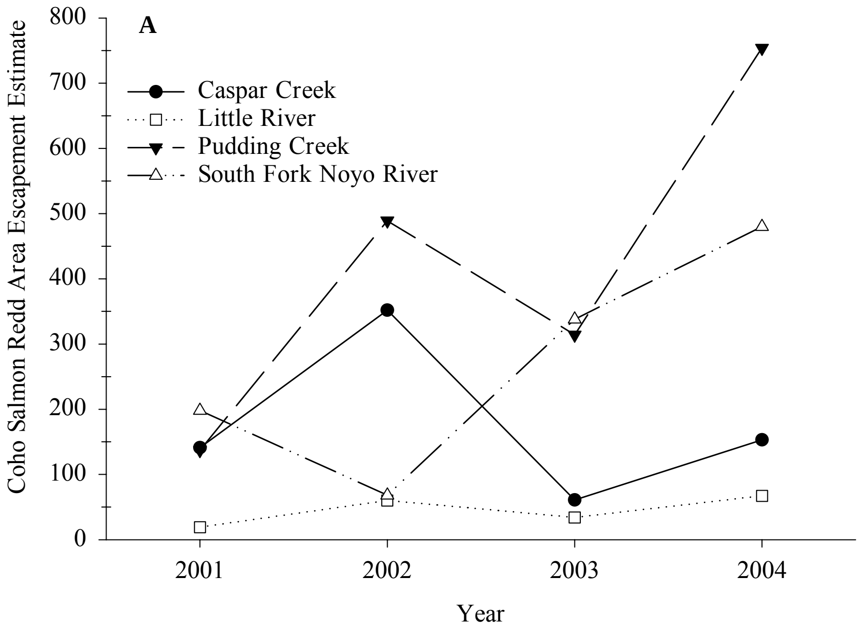


Figure 10. Relationship between redd counts and salmonid population estimates in several Mendocino County streams 2000-2001, 2002-2003, and 2003-2004. a). Redd counts relative to the number of coho salmon released above the Noyo River ECS. b). Redd counts relative to capture-recapture estimates for coho salmon in four streams. c). Redd counts relative to AUC estimates for steelhead in four streams.



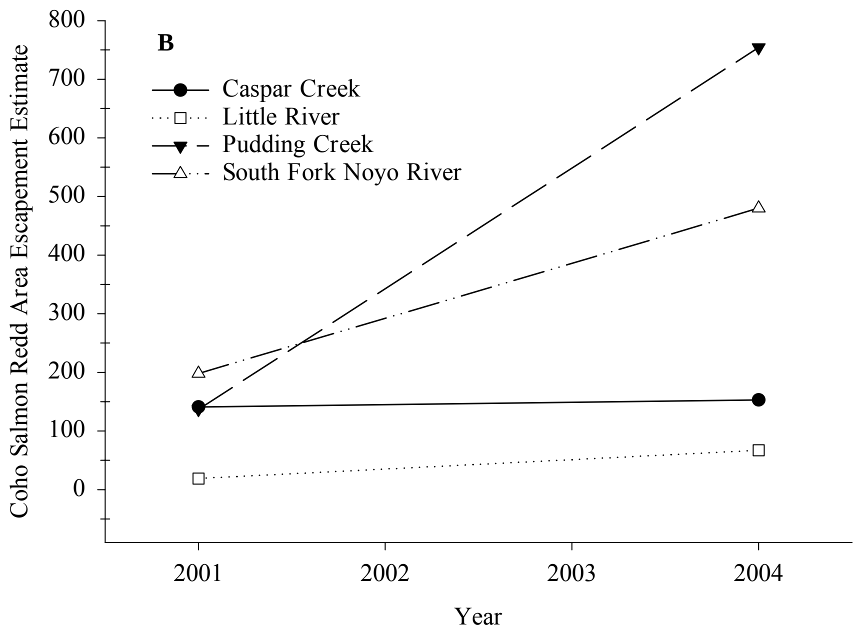


Figure 11. Trends in coho salmon abundance in four streams in coastal Mendocino County 2001 to 2004. a). Redd area escapement versus year 2001 to 2004. b). Redd area escapement estimates for one complete life cycle 2001 adults to 2004 adults.

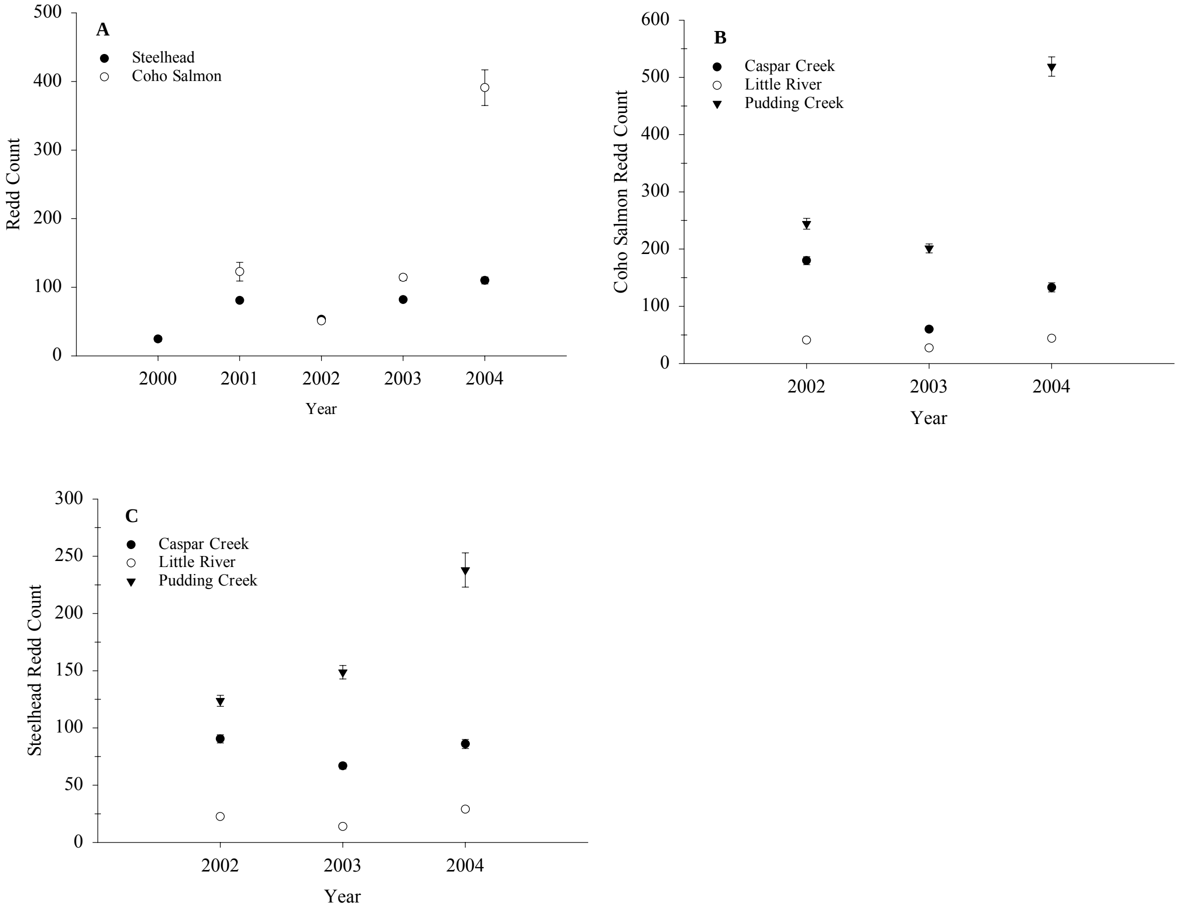


Figure 12. Coho salmon and steelhead redd counts in four steams in coastal Mendocino County. a). Coho and steelhead redd counts above the Noyo River ECS 2000 to 2004. b). Coho salmon redd counts in Caspar and Pudding creeks and Little River 2002, 2003, and 2004. c). Steelhead redd counts in Caspar and Pudding creeks and Little River 2002, 2003, and 2004. Thin lines are SE's from observer efficiency in redd counts.

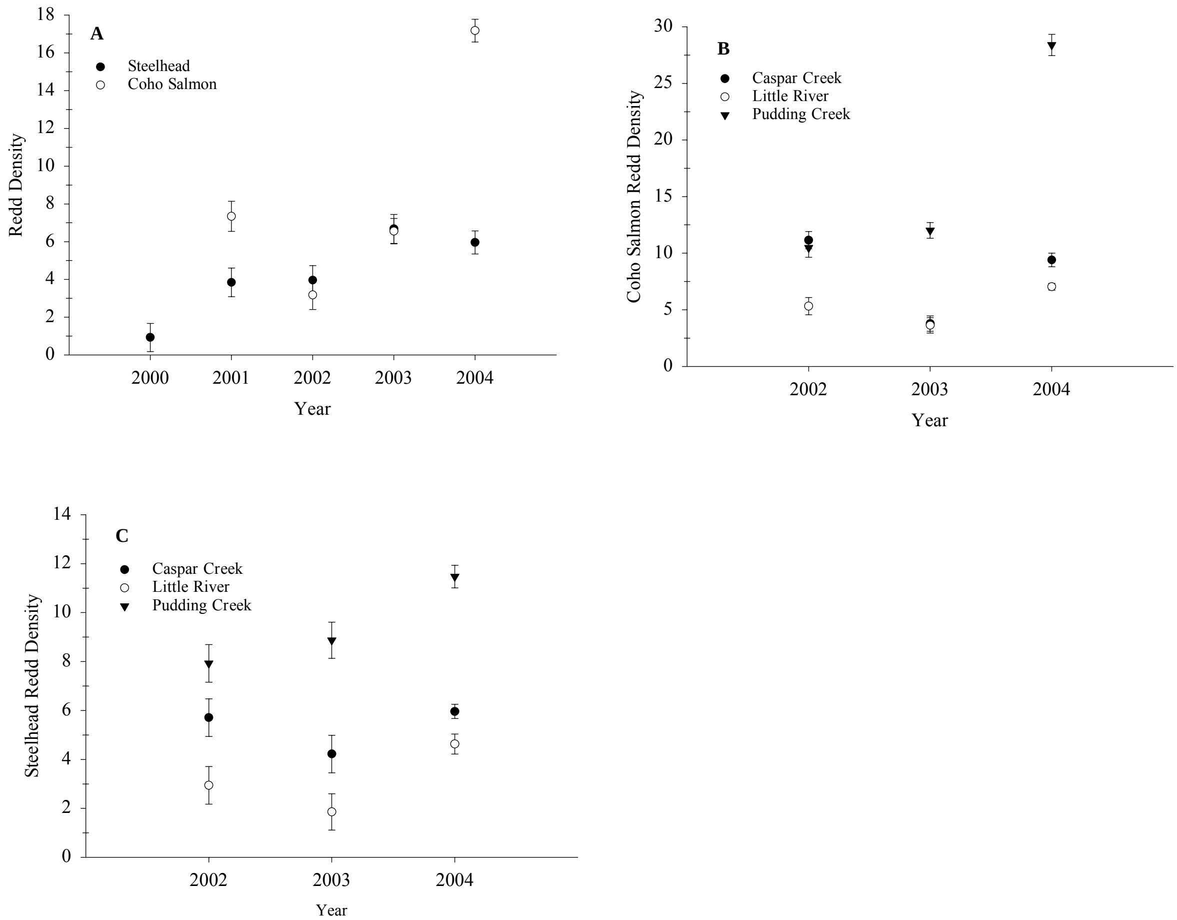


Figure 13. Coho salmon and steelhead redd densities (number per km) in four steams in coastal Mendocino County. a). Coho and steelhead redd densities above the Noyo River ECS 2000 to 2004. b). Coho salmon redd densities in Caspar and Pudding creeks and Little River 2002, 2003, and 2004. c). Steelhead redd densities in Caspar and Pudding creeks and Little River 2002, 2003, and 2004. Thin lines are SE's.

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 2003-04.

Stream Name	Number Live	Female:Male	Trapezoidal Area	Predicted Observer Efficiency	Escapement Fish/Redd	Redds/Female		Fish/km
						AUC*	Redd Area	
Caspar Creek	8	0.60:1.00	147	0.035 ± 0.001	59-96-161	1.13-1.78-3.06	2.70-2.71-2.72	4.99-5.28-5.56
Little River	4	1.00:1.00**	134	0.042	19-32-57	0.38-0.55-0.91	2.80-2.90-3.00	4.95-8.31-14.53
Pudding Creek	27	0.89:1.00	682	0.042 ± 0.008	0.79-1.11-1.79 ^	1.25-2.01-3.12 ^	2.69-2.70-2.84	8.65-14.6-25.4 ^
South Fork Noyo	12	0.71:1.00	173.5	0.038 ± 0.001	83-122-218	0.98-1.46-5.90	1.53-1.54-3.86	2.42-4.40-7.31

* AUC estimates based on capture-recapture observer efficiency and residence time of 12.6 days.

** Assumed one to one ratio of females to males

^ Fish per redd from capture-recapture estimate.

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 2003-04.

Stream Name	Number	Escapement		Female:Male	Trapezoidal	Predicted Observer	Escapement		Redds/Female		Fish/km
	Live	Carcass	Mark-Recapture		Area	Efficiency	Fish/Redd PC	Fish/Redd SF	AUC*	Redd Area	
Caspar Creek	106	6-17-201	-	1.30:1.00	749	0.16 ± 0.02	257-309-436	170-225-251	2.00-2.20-2.37	1.56-1.57-1.58	5.72-6.57-7.63
Little River	51	9/14/1945	-	0.92:1.00	607	0.16 ± 0.02	86-102-142	54-71-78	1.04-1.17-1.28	1.35-1.36-1.40	10.54-11.98-14.06
Pudding Creek	901	819-1441-3558	1067-1204-1600	1.00:1.04	9115	0.18 ± 0.01	2.06-2.32-3.09 ^	682-877-954	0.70-0.90-0.99 ^	1.40-1.41	58.79-66.34-88.15 ^
South Fork Noyo	558	91-133-257	530-647-706 *	1.06:1.00	4722	0.14 ± 0.02	752-907-1288	1.36-1.69-1.78 ^	1.14-1.26-1.40	1.50-1.54-1.55	21.95-26.80-29.25 ^

* AUC estimates based on capture-recapture observer efficiency and residence time of 11.5 days.

* South Fork Noyo mark-recapture is total released minus fraction assumed to fall back downstream below the ECS, the total released, and a capture-recapture estimate from G. Szerlong (Perrs. Comm.).

^ Fish per redd from capture-recapture estimate.

Table 3. Steelhead redd data and redd based escapement estimates in four coastal Mendocino County streams during 2003-04.

Stream Name	Redd Observer Efficiency	Number of Redds		Escapement Estimate		Redds/km
		Raw	O. E.	Redd Area	1 Redd/Female	
Caspar Creek	0.86 ± 0.06	75	86 ± 4	77 ± 4	232 ± 11	5.96 ± 0.29
Little River	0.69 ± 0.12	22	29 ± 2	20 ± 2	58 ± 5	4.63 ± 0.41
Pudding Creek	0.80 ± 0.06	190	238 ± 15	186 ± 13	505 ± 32	11.47 ± 0.46
South Fork Noyo	0.69 ± 0.14	78	110 ± 5	91 ± 3	264 ± 12	5.69 ± 0.61

Table 4. Coho salmon redd data and redd based escapement estimates in four coastal Mendocino County streams during 2003-04.

Stream Name	Redd Observer Efficiency	Number of Redds		Escapement Estimate		Redds/km
		Raw	O. E.	Redd Area	1 Redd/Female	
Caspar Creek	0.69 ± 0.10	99	133 ± 8	153 ± 9	238 ± 14	9.40 ± 0.60
Little River	0.82 ± 0.06	37	44 ± 2	67 ± 3	91 ± 5	7.03 ± 0.32
Pudding Creek	0.83 ± 0.03	417	519 ± 17	754 ± 23	1059 ± 34	28.39 ± 0.94
South Fork Noyo	0.82 ± 0.11	348	391 ± 26	480 ± 33	760 ± 50	17.18 ± 0.59