

A COMPARISON OF ESCAPEMENT ESTIMATE METHODS PLUS ESCAPEMENT-
RECRUITMENT RELATIONSHIPS FOR CHINOOK SALMON AND COHO
SALMON IN A COASTAL STREAM

by

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ABSTRACT

A Comparison of Escapement Estimate Methods Plus Escapement-Recruitment Relationships for Chinook Salmon and Coho Salmon in a Coastal Stream

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This study compares methods for estimating escapement of Chinook salmon (*Oncorhynchus tshawytscha*) and coho salmon (*Oncorhynchus mykiss*) in a coastal stream without a counting fence or weir. Relationships between escapement estimates and juvenile recruitment were also analyzed. A six-year data set, collected from Prairie Creek, California, spanning the 1998/1999 through 2003/2004 spawning seasons, was used for this project. Five methods of escapement estimation were considered: area-under-the-curve of live spawner observations, carcass mark-recapture using a modified Jolly-Seber method, carcass mark-recapture using the Petersen method, a redd count based estimate assuming one redd per female, and a redd count based estimate using a redd-area method. A logistic regression model was developed to distinguish Chinook salmon from coho salmon redds for those redds which did not have a known associated species when observed. The model predicted species with 93.3% accuracy when time (water year day) was the only available parameter and 98.7% to 99.4% concordance when time and other redd measurements were available. Chinook salmon area-under-the-curve and one redd per female escapement estimates were stronger correlated in Upper Prairie Creek (Reaches 3 and 4, $R^2 = 0.9145$) than the entire surveyed mainstem Prairie Creek (Reaches 1 through 4, $R^2 = 0.4789$). Coho salmon area-under-the-curve escapement estimates were linearly correlated with one redd per female ($R^2 = 0.7492$)

and redd-area estimates ($R^2 = 0.6922$) for the Prairie Creek Study Area. Carcass estimates were inconsistent with area-under-the-curve and redd-based estimates. Linear regression analyses of area-under-the-curve estimates and juvenile recruitment yielded R^2 values of 0.3780 for Chinook salmon in Mainstem Prairie Creek and 0.9079, 0.3035, and 0.6681 for coho salmon in Upper Prairie Creek, Streelaw Creek, and Boyes Creek, respectively. Linear regression analyses of redd-based escapement estimates and juvenile recruitment yielded R^2 values less than 0.0258 for Chinook salmon in Mainstem Prairie Creek and between 0.6422 and 0.9169 for coho salmon in Upper Prairie Creek, Streelaw Creek, and Boyes Creek.

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INTRODUCTION

To fulfill current management goals for Pacific salmon (*Oncorhynchus* spp.) fisheries, a specified number of fish are protected from the marine fishery and allowed to migrate upstream to spawn (Sykes and Botsford 1986). These fish are said to have “escaped” the fishery and escapement is defined as the number of mature salmon that return to freshwater environment (Ricker 1975, English et al. 1992). Escapement estimates are essential for quantifying long-term trends of important fisheries (Perrin and Irvine 1990). Therefore, information on accuracy and precision of estimates of spawner abundance (i.e., escapement) are necessary for effective assessment, conservation, and management of Pacific salmon populations (Walters and Ludwig 1981, Pearse 1982, Symons and Waldichuk 1984). Accurate spawning stock estimates are required to set spawning escapement goals, determine optimal stock sizes, and regulate harvest rates (Perrin and Irvine 1990, Schwarz et al. 1993, Bue et al. 1998, Manske and Schwarz 2000). Precise estimates are required to establish confidence in management strategies (Schwarz et al. 1993). Also, information on precision, or consistency, is valuable for understanding risk and establishing precautionary management principles. Precision of escapement estimates is considered the more important of the two for defining long-term stock-recruitment relationships (Symons and Waldichuk 1984).

There is a well-documented need for improved salmon escapement estimates and standardized estimation procedures (Walters and Ludwig 1981, Pearse 1982, Symons and Waldichuk 1984, Schwarz et al. 1993). The uncertain status of many stocks of Pacific salmonids has led to increased awareness among fishery managers of the need for

accurate escapement estimates. Northern California's coastal Chinook (*Oncorhynchus tshawytscha*) and coho salmon (*O. kisutch*) are of particular concern as they are listed as threatened species under the U.S. Endangered Species Act (Federal Register 1997, 1999).

Several methods of estimating escapements are available (Cousens et al. 1982, Irvine and Nelson 1995). However, they can yield widely different results for any one spawning run (cf. Beidler and Nickelson 1980, Flint 1984, Solazzi 1984, Johnston et al. 1986, 1987, Lewis 1987, Bocking et al. 1988). The main approaches to estimating the escapement of fish into a system are based on counts of live fish through a fishway or fence, visual counts of live fish, redd counts, carcass counts, tagging live fish, tagging carcasses, and the use of hydroacoustic equipment and electronic counters (Shardlow et al. 1986). Fishways and counting fences or weirs have traditionally provided the most reliable estimates of escapement (Shardlow et al. 1986, Schwarz et al. 1993, Miyakoshi and Kudo 1999). However, they are not always feasible. Counting fences or weirs must be maintained throughout the period of fish migration and are, therefore, labor intensive and costly to operate (Schwarz et al. 1993, Beland 1996, Miyakoshi and Kudo 1999). Thus, estimates of salmon abundance are often estimated from other sources of data (Beland 1996).

Several other approaches can be used to estimate salmon escapement: mark-recapture (Seber 1982), area-under-the-curve (Cousens et al. 1982, Irvine and Nelson 1995), and redd count methods (Meffe 1986, Beland 1996, Rieman and Myers 1997, Isaak et al. 2003). The method of choice may depend on characteristics of the system, the behavior of the fish, and availability of resources. Redd counts and visual counts of live fish are subject to biases of the individual surveyors and from the effects of other

variables such as turbidity (Shardlow et al. 1986). A Petersen estimate based on tagging of live fish, sampling for carcasses, and expanding the carcass count by the tagged-to-untagged ratio is frequently considered the second best to fishways and fence counts. Petersen estimates have also been attained by tagging carcasses, recapturing carcasses on subsequent surveys, and expanding the carcass count by the recapture rate (Shardlow et al. 1986). The stratified Petersen (Darroch 1961) in particular is often the preferred version of this method (Schwarz and Taylor 1998).

Salmon escapement is frequently estimated by fisheries biologists using the area-under-the-curve method (Irvine et al. 1993). Commonly used in the Pacific Northwest, area-under-the-curve methods are well documented (see for example Ames 1984, English et al. 1992, Hill 1997, Bue et al. 1998, and Parken et al. 2003). This approach is useful for streams where passage counts are unavailable, where redd counts are unreliable, or where the time when individual fish enter the study area is unknown (Hilborn et al. 1999). The area-under-the-curve method develops an estimate of total escapement based on repeated periodic counts of mature Pacific salmon spawners returning to a stream (Ames and Phinney 1977, Johnson and Barrett 1988, Perrin and Irvine 1990, English et al. 1992, Irvine et al. 1992, Irvine and Nelson 1995). Fish counts are based on observations of the number of returning spawners in a stream provided by periodic aerial or foot surveys generally collected at 7- to 10-day intervals throughout the time salmon are present in the study area (Hilborn et al. 1999).

Two additional pieces of information are required to obtain an estimate of total escapement: an estimate of observer efficiency and an estimate of individuals' mean residence time in the survey area (Perrin and Irvine 1990, English et al. 1992, Hilborn et

al. 1999). Survey counts are expanded by an estimate of observer efficiency and plotted against time, the points are connected, and the integral or area under the curve is calculated using one of a variety of algorithms, yielding the total spawner-days, or fish-days in the river (Ames 1984, Perrin and Irvine 1990, Hilborn et al. 1999). An escapement estimate can then be obtained by dividing the total number of fish-days by an auxiliary estimate of average stream residence time (English et al. 1992, Irvine et al. 1992). Observer efficiency and residence time are therefore particularly important variables having direct influence on escapement estimates using the area-under-the-curve method. If not measured, assumed observer efficiency and residence time must be carefully selected to avoid potential sources of bias that may introduce serious error to escapement estimates (Bocking et al. 1988, Adkison and Su 2001). Fish counts and the shape of the spawner curve may also contribute uncertainty to otherwise reliable area-under-the-curve-derived escapement estimates (Hill 1997, Hilborn et al. 1999, Manske and Schwarz 2000).

The probability of observing salmon is affected by species, surveyor experience, method of observation, stream habitat, water depth, and water clarity (Shardlow et al. 1987, English et al. 1992). Foot surveys often yield undercounts of spawning coho salmon in streams due to their occurrence in low densities and their cryptic coloration (Irvine et al. 1992). Less reliable observation efficiencies by inexperienced surveyors are quickly improved with careful training and modest amounts of practice (Shardlow et al. 1987). Surveyors for this project had either prior experience or were trained early in the season. Solazzi (1984) determined that habitat features and environmental variables do not significantly affect the percentage of salmon observed. Irvine et al. (1992), however,

argued that observation efficiency may vary among different streams.

A number of site-specific biological and geographic variables may have important influences on residence time (Perrin and Irvine 1990). Body size, fish maturity, sex ratio, run timing, extreme environmental events, selective fishing pressure, stream discharge, water temperature, and latitude may all affect residence time (Ames 1984, van den Berghe and Gross 1986, Perrin and Irvine 1990, English et al. 1992). Recent studies show residence times vary across streams, within and across years, and between sexes for a particular species (Ellis 1969, McCurdy 1984, Bocking et al. 1988, Dangel and Jones 1988, Perrin and Irvine 1990, English et al. 1992, Irvine et al. 1992). Chinook salmon spawner average residence times have been reported to range from 5.6 to 15.1 d (Envirocon Limited 1984, Hill and Irvine 2001, Parken et al. 2003). Residence times reported for spawning coho salmon have varied widely, ranging from averages of 7.8 to 30 d (Moring and Lantz 1975, Beidler and Nickelson 1980, Bocking et al. 1988, Irvine et al. 1992, Szerlong and Rundio 2008).

Predetermined constant values of average residence time are frequently applied to the area-under-the-curve method (Pirtle 1977, Beidler and Nickelson 1980, Ames 1984, Johnson and Barrett 1988). However, it has also been well documented that stream life varies throughout the spawning season with spawners earlier in the runs having longer stream life than spawners later in the run (Killick 1955, Neilson and Geen 1981, Thomason and Jones 1984, Dangel and Jones 1988, English et al. 1992, Su et al. 2001, Szerlong and Rundio 2008). Average early season residence times have been determined to be as high as approximately 30 d for coho salmon (Szerlong and Rundio 2008). Late season residence times have been determined to be as low as 7.7 d for Chinook salmon

(Neilson and Green 1981). The difference in average residence times between early and late season arrivers for single streams in the same year have been found to range from 5.4 to approximately 20 d for both species (Neilson and Geen 1981, Szerlong and Rundio 2008). Variation in residence times may also vary between sexes. Willis (1954) determined spawning ground life of male coho salmon averaged one day longer than females.

For the reasons listed above, Bue et al. (1998) noted that treating observation efficiency and residence time as constants may introduce unknown errors to escapement estimates. The application of a standard residence time to the area-under-the-curve method may potentially introduce serious bias to the estimate of escapement across years and across streams (Perrin and Irvine 1990). Contrary to this risk, uncertainty about escapement magnitude and timing would be increased by incorporating interannual fluctuation (Adkinson and Su 2001). Salmon in Prairie Creek have a relatively short spawning period compared to other streams. Most Prairie Creek salmon spawn within a four to six week period. Therefore applying a constant residence time to the area-under-the-curve method for this study should be appropriate. I also assumed that residence times in Prairie Creek are closer to early season residence times of salmon populations that have longer spawning periods.

When possible, stream-specific estimates of residence time should be developed each year and used to calculate area-under-the-curve method escapement estimates (Perrin and Irvine 1990, English et al. 1992, Lady and Skalski 1998). Due to variability of residence time within a single season, measured estimates of residence time derived from only one portion of the run should be avoided to reduce sources of bias in

escapement estimates (English et al. 1992). Bias in residence time estimates may be unpredictable, “widely variable, and most important, may introduce asymmetrical nonlinear error” in escapement estimates (Perrin and Irvine 1990). “In practice, true survey life cannot be measured with accuracy because fish are usually not observed for some time either before or after spawning” (Perrin and Irvine 1990).

Modifications to the Jolly-Seber model (Pollock et al. 1990) can make it an appropriate tool for estimating escapement of Pacific salmon from capture-recapture data (Schwarz et al. 1993). To obtain escapement estimates with the Jolly-Seber model, modifications must be made to incorporate the number of fish present during each sampling occasion plus those fish that enter the study area and die between surveys (Schwarz et al. 1993). Sykes and Botsford (1986) compared Jolly-Seber, Manly and Parr, and modified Jolly-Seber methods for estimating Chinook salmon spawning escapement from tagging and recovering carcasses. They determined the Jolly-Seber method to be the most precise of the three methods. However, the modified Jolly-Seber method yielded more than adequate precision estimate of the escapement.

Completed redds are constructed by females and redd counts are commonly used to index or estimate adult escapement of the effective population and assess population trends (Meffe 1986, Beland 1996, Rieman and Myers 1997, Isaak et al. 2003). Redd counts have been shown to be positively correlated with escapement or adult abundance in Atlantic salmon (*Salmo salar*) (Hay 1984, Heggberget et al. 1986, Madden et al. 1993, Semple et al. 1994), brook trout (*Salvelinus fontinalis*) (Benson 1953), brown trout (*Salmo trutta*) (Hobbs 1937, Benson 1953, Beard and Carline 1991), and bull trout (*Salvelinus confluentus*) (Dunham et al. 2001). Advantages of using redd counts to

monitor and inventory anadromous fish populations are that the method is less expensive than other techniques and may be less disruptive or invasive than alternative methods. Therefore redd counts may be implemented to survey a greater number of populations over longer periods when resources are limited (Dunham et al. 2001).

High variability in the ratio of spawning adults to redds may complicate the use of redd counts for salmonid population monitoring. This variability has been attributed to varying life history patterns among populations (Barlaup et al. 1994) and females making more than one redd (Crisp and Carling 1989, Gallagher and Gallagher 2005).

Uncertainty in associating redds with the species that constructed them may further reduce the reliability of redd counts (Gallagher and Gallagher 2005). Often only a fraction of redds observed have an associated fish upon initial detection. Species identification is complicated by the temporal and spatial overlap of Chinook and coho salmon spawning seasons in coastal Northern California (Gallagher and Gallagher 2005). Because of these uncertainties, a model is required to predict whether Chinook or coho salmon constructed those redds for which no spawning adults were observed.

The relationship between the number of spawners and subsequent recruits is one of the most important statistical relationships in fisheries management (Beland 1996). The ability to predict juvenile salmon abundance from escapement estimates could negate the need for annual juvenile population estimates as a means of predicting year-class strength. A linear relationship between Atlantic salmon parr abundance and redd counts has been reported, suggesting that future parr abundance can be predicted from redd counts (Beland 1996). However, stock-recruitment relationships are best derived using the most robust of escapement estimates (Chadwick 1982, Buck and Hay 1984, Chaput et

al. 1992). Therefore escapement-recruitment relationships using all available escapement estimates were considered in this analysis.

The purpose of this study was to compare methods of adult salmon escapement estimation and to identify relationships between estimates of adult escapement and juvenile recruitment in a coastal stream. There were two related goals for this research project. First, five different methods of estimating adult Chinook and coho salmon escapement to the study area were compared. Second, the relationship between escapement estimates and young-of-the-year (recruitment) abundance were examined. An additional focus of this study was to evaluate the effectiveness of different methods of determining adult salmon escapement for small coastal streams that do not have a fish counting device.

Escapement was estimated using the area-under-the-curve method, two methods of carcass mark-recapture, a modified Jolly-Seber method and a Chapman version of the Petersen estimate, and two methods using redd counts, one assuming each female constructed one redd and the other being a redd-area method. Young-of-the-year Chinook salmon were indexed using outmigrant traps. Population size of young-of-the-year coho salmon was estimated from surveys following Hankin and Mohr's (in preparation) modified protocol. This procedure is used to estimate juvenile salmonid populations in small streams based on a design that includes diver observations and electrofishing.

STUDY SITE

Prairie Creek and two tributaries to Prairie Creek, Streeflow Creek and Boyes Creek, were included in this study. Prairie Creek is a fourth order coastal stream in the Redwood Creek drainage in northern California's Redwood National Park. The Prairie Creek confluence with Redwood Creek is 6.0 river kilometers (rkm) upstream from the Pacific Ocean. Streeflow Creek and Boyes Creek are third order streams that enter Prairie Creek 6.2 rkm and 10.3 rkm upstream of the Redwood Creek confluence, respectively. Prairie Creek supports four species of Pacific salmonids: Chinook salmon, coho salmon, coastal cutthroat trout (*O. clarki clarki*), and steelhead (*O. mykiss*).

The Redwood Creek watershed lies in the coastal zone and experiences temperate climate. Mean annual rainfall in the Prairie Creek basin is 172 cm with most rainfall occurring from November through April. Consequently, Prairie Creek is a flashy system with a streamflow regime consisting of high peaky flows in the winter and steady low flow in the summer.

Within the Prairie Creek basin are a variety of geomorphological (Table 1), geological, and floral characteristics. "Stream substrate within the study area of Prairie Creek consists of well-sorted cobbles and gravels. The streambed of Streeflow Creek has cobbles mixed with sands. Boyes Creek streambed consists of cobbles mixed with large amounts of fine sediments and silts" (Sparkman 2003). The lower portion of the Prairie Creek basin is mostly underlain by shallow marine sands (Cashman et al. 1995). The upper portions of the basin mainly consist of coarse alluvial sedimentary rock. "The Prairie Creek watershed is forested with old growth redwood (*Sequoia sempervirens*) and

Table 1. Geomorphological features of the Prairie Creek watershed, Humboldt County, California. Data compiled from Lisle (1989).

Stream	Gradient (m/m)	Watershed Area (km ²)	Mean Annual Discharge (m ³ /s)	Bank Full Discharge (m ³ /s)
Prairie Creek	0.0032	34.4	1.49	5.6
Streelow Creek	0.004	5.7	0.25	-
Boyes Creek	0.089*	4.4	0.019	-

* gradient of Boyes Creek within the study area is 0.013 m/m

Sitka spruce (*Picea sitchensis*), mixed with western hemlock (*Tsuga heterophylla*), bay laurel (*Umbellularia californica*), big leaf maple (*Acer macrophyllum*), and red alder (*Alnus rubra*)” (Sparkman 2003). Strelow Creek, recovering from extensive logging in the 1950’s and 1960’s, is forested with second growth redwood mixed primarily with red alder. The Boyes Creek watershed is dominated by second growth redwood mixed with old growth redwood, big leaf maple, red alder, bay laurel, and western hemlock.

The Prairie Creek study area began 6.2 rkm upstream of the confluence with Redwood Creek (Figure 1). Four consecutive reaches totaling 13,440 m in Prairie Creek and one reach each in Strelow Creek and Boyes Creek, were included in the study site. Lengths of Prairie Creek Reaches 1, 2, 3, and 4 are 4,070 m, 3,380 m, 3,510 m, and 2,480 m, respectively. Middle Prairie Creek is comprised of Prairie Creek Reaches 1 and 2. Upper Prairie Creek is comprised of Prairie Creek Reaches 3 and 4. Strelow Creek and Boyes Creek were surveyed to 2,200 m and 1,970 m, respectively, upstream from their confluences with Prairie Creek.

Adult spawning surveys and juvenile population estimation surveys have been conducted in this study area since the 1998/1999 spawning season. This study will include the data collected from six consecutive seasons of spawning surveys from 1998/1999 through 2003/2004.



Figure 1. Map of the Prairie Creek Study Area, Humboldt County, California, showing the six reaches, four on the mainstem and two tributaries, sampled.

MATERIALS AND METHODS

Adult Spawner Surveys and Escapement Estimation

Stream study reaches were monitored for the presence of adult salmon regularly beginning in late-October of each year so that surveys could be initiated prior to the spawning migration of salmon into the study area. Surveys were initiated after adult salmon first entered Prairie Creek and were typically conducted every 5 to 9 days on each stream reach throughout the spawning period. Surveys ended each season with the end of the salmon spawning period. The spawning period was determined to be ended when two consecutive surveys did not detect any live salmon or new salmon redds. Steelhead and cutthroat trout were not included in surveys due to presumed low observer efficiency and small population size.

Each survey consisted of two trained and experienced surveyors walking upstream along the reach recording observations of live fish, carcasses, and redds. Information on the biology and temporal and spatial distribution of all live fish and carcasses encountered was recorded. Data recorded include; date, species, sex, size, tag number, condition, stream reach, and distance upstream. All carcasses were marked with a hog ring with a uniquely numbered tag on the lower jaw upon initial sighting. No Chinook salmon carcasses and only a portion of coho salmon carcasses were tagged during the first three years of study, while all salmon carcasses were tagged during the final three years of the study. Therefore, carcass mark-recapture escapement estimates are only available for the later three spawning seasons.

Size was recorded differently for carcasses and live fish. For carcasses, fork

lengths (FL) were measured. Sizes of live fish were visually estimated but methods differed each year. In 1998/1999, fork lengths were estimated to the nearest 5 cm increment. In 1999/2000, size was recorded as small (S, $FL \leq 60$ cm), medium, (M, $FL = 61$ to 79 cm), or large (L, $FL \geq 80$ cm). In 2000/2001 and 2001/2002, size was recorded as S, M, L, or jack (J). In 2002/2003 and 2003/2004, size was recorded as J or adult (A). Therefore, these last two spawning seasons do not offer an adult size variable. For the seasons in which jack, small, medium, and large fish were recorded, size small was assigned a value of '1', medium was assigned '2', and large was assigned '3'.

During spawner surveys, redd construction was monitored and the physical characteristics of all new redds was recorded. Surveyors were trained in recognizing channel features so that confusion between distinguishing redd development and natural hydrologic features was minimized. When possible, the following parameters were recorded for each redd observed: date, stream reach, distance upstream, total (pot plus tail) length, maximum width, pot depth, head depth, and species if live fish were observed on the redd. The following additional information was recorded for 2002/2003 and 2003/2004: pot length, pot width, lateral position in the stream, habitat type, immediate cover, and substrate. Lateral position of a redd was assigned a number of 1, 2, or 3 where '1' was within a third of the distance from the bank to the middle of the channel, '2' was between one- and two-thirds of the distance from the bank to the middle of the channel, and '3' was the middle third of the channel. Immediate cover referred to percentage of overhanging vegetation directly over a redd up to two meters above the water level.

Surface substrate of the tail mound was visually assessed by surveyors and

classified according to the Wentworth (1922) scale as sand (62.5 μm to 2 mm), gravel (2 mm to 64 mm), or cobble (64 mm to 256 mm) by the length of the secondary axis.

Dominant and secondary substrate type and relative abundance were recorded. Substrate composition was later classified using a scale of one through five where

- 1: dominant substrate = sand
- 2: dominant substrate = gravel, secondary substrate = sand
- 3: 100% gravel (dominant substrate = gravel, no secondary substrate)
- 4: dominant substrate = gravel, secondary substrate = cobble
- 5: dominant substrate = cobble

Redd areas and pot areas were calculated using length and width measurements.

Redds and redd pots were treated as ellipses for calculating areas. Pot length was measured from the upstream edge of the pot depression to the upstream edge of the tail mound following Schmetterling (2000). Width was measured across the widest section of the pot. Dig depth was calculated by subtracting the head depth from the pot depth.

Measured redds were flagged to prevent recounting on subsequent surveys. If redds were found with fish on them, the species of the fish was noted and the redd was distinguished with different colored flagging. To avoid disturbing spawning fish, these redds were measured upon a subsequent survey.

Live Fish and Area-Under-the-Curve

Individual fish that could not be identified to species were assigned a species using a logistic regression model based on observations of live fish of known species. The appropriate logistic regression model was determined using concordance with the existing data set and Akaike's information criterion from a suite of equations in the form,

$$P = \frac{1}{1 + e^{-(b_0 + b_1x_1 + b_2x_2 + \dots + b_nx_n)}} \quad (\text{Equation 1})$$

spanning various combinations, including interaction terms, of three explanatory variables: time, size, and distance upstream. Year-specific models were considered as well as models for which data from all six spawning seasons were pooled (Table 2). A time parameter was assigned for every fish and redd. Dates were transformed to ‘water year day’ indicating the number of days since October 1, the start of the water year. Distance upstream was applied only to fish in Mainstem Prairie Creek. Distances on Streelow and Boyes Creeks are not comparable to distances on Prairie Creek and sample sizes were too low in those two streams to merit their own models with distance as a variable. Distance fish moved upstream to spawn changed each year due to varying flow. Spawning time also varied each year due to frequency, size, and timing of rain events. Despite varying spawning time and available upstream distance between years, models for which the six spawning seasons were pooled included time and distance as the only variables.

Three species with overlapping spawning seasons were considered for this model: Chinook salmon, coho salmon, and steelhead. Logistic regressions were used to first separate steelhead from salmon, and then a second phase of logistic regressions was used to distinguish Chinook salmon from coho salmon. An assumption was made that all unknown jacks were either Chinook or coho salmon and were not included in the ‘salmon-or-steelhead’ model. To assign a species to unknown jacks, models that contained time and distance upstream variables were considered. These models were based on data from jacks observed over all six spawning seasons combined. Year-

Table 2. Equation combinations considered for live fish logistic regression model applied to the Prairie Creek Study Area, Humboldt County, California. Available parameters were day of water year (t), distance upstream (u ; Mainstem Prairie Creek only), and size (s).

Data Set		Available Parameters
Time Frame	Location	
Year-specific (1998/1999, 1999/2000, ...2003/2004)	Mainstem only	t, u t, u, s
	Entire Study Area	t t, s
All years pooled (1998/1999 - 2003/2004)	Mainstem only	t, u t, u, s
	Entire Study Area	t t, s

specific jack models could not be constructed due to small sample sizes.

Area-under-the-curve escapement estimates of Chinook and coho salmon were calculated for Middle Prairie Creek, Upper Prairie Creek, Stree low Creek, and Boyes Creek. A software package developed by Irvine et al. (1993) was used to calculate area-under-the-curve estimates of escapement. This program yields an escapement estimate through three steps: 1) daily mean population estimates, 2) area under the population curve estimates, and 3) the area-under-the-curve escapement estimate.

Daily mean population estimates first require the mean density, y , of fish for each survey period (i) to be estimated by

$$\bar{y}_i = \frac{fo_i}{oe} \quad (\text{Equation 2})$$

where fo = number of fish observed and

oe = observation efficiency.

Observer efficiency is a correction factor for visibility of fish and was defined as the ratio of the total number of fish seen to the total number actually present during the survey (Korman et al. 2002). A constant observation efficiency of 76% was assumed for both Chinook and coho salmon throughout the survey area. Solazzi (1984) determined that surveyors on average observed 76.1% of the adult Chinook salmon and 75.5% of the adult coho salmon on streams of similar size and character to Prairie Creek. Johnston et al. (1987) determined a slightly lower efficiency of 69% for observing coho salmon in French Creek, Vancouver Island. French Creek has an average width of 12 m. It also compares closely to Prairie Creek in size. Jacks, due to their small size and greater dependence on cover, tend to be less observable than adult salmon (Solazzi 1984). Solazzi's (1984) surveyors observed Chinook salmon jacks with 63.6% efficiency and

coho salmon jacks with 49.1% efficiency. Bocking et al. (1988) found the efficiency of observing jack coho salmon was 57% of the efficiency of observing adults on Black Creek and the Trent River on Vancouver Island.

I also assumed that the efficiency of the various surveyors in observing fish was similar among surveys within a year and between years. This assumption is supported by Willis (1964) who found no significant differences between individual surveyor counts or between counts grouped by time of day. Beidler and Nickelson (1980) also stated that significant error in spawning fish surveys are not likely to result from variation in surveyor efficiency and that assumptions of constant efficiency are inherent in most sampling schemes involving repeated surveys.

Since surveys on each reach were not conducted on the same day, survey periods were constructed and used instead of survey days. Three main rules were used to break down the spawning season into periods. First, each period was constructed so that, ideally, it included surveys on all six reaches. For survey periods that did not contain a survey on one or more reaches, a linear interpolation function within the area-under-the-curve software package was implemented. Second, no more than one survey on the same reach was included in a period. Third, periods were arranged to begin the day after the last survey from the previous period and end with the last survey within the period. This minimized the amount of fish that may enter the system after the surveys are conducted for that period. This final day of the survey period was the date entered in the program as the survey day. Survey periods ranged from one to fourteen days (mean = 7 d). A single survey period in December 2002 lasted 22 days due to an extended storm event.

It is assumed in area-under-the-curve calculations that fish are not double-counted

over two reaches within the same spawning period. Intervals between surveys of individual reaches were therefore kept to a minimum to reduce the probability that individual fish would be double counted or missed entirely as a consequence of migration between survey reaches. The stratified mean density, y_{st} , for each survey period was then estimated by

$$\bar{y}_{st_i} = \sum_{h=1}^L \frac{\bar{y}_{ih}}{L} \quad (\text{Equation 3})$$

where L = the number of strata.

An estimate of the daily population on day i , p_i , was then obtained by

$$p_i = L \cdot \bar{y}_{st_i} . \quad (\text{Equation 4})$$

The area under the population curve, AUC , could then be estimated by

$$AUC = \frac{\sum_{i=2}^n (t_i - t_{i-1}) \cdot (p_i + p_{i-1})}{2} \quad (\text{Equation 5})$$

where t_i = the date of the i th survey.

Daily populations of the first and last surveys, p_1 and p_n , are equal to zero. If fish were observed during the first visual survey, then the date of the first survey was defined as the date a sharp increase in stream discharge began since salmon cannot access this watershed until rains breach a sand barrier separating Redwood Creek and the Pacific Ocean.

Finally, the area-under-the-curve escapement estimate was obtained by

$$\hat{E}_{AUC} = \frac{AUC}{rt} \quad (\text{Equation 6})$$

where rt = residence time.

Stream residence time, also sometimes referred to as ‘survey life’ or ‘stream life’, is defined as the average number of days that a mature salmon is alive in the survey area (Ames 1984, Perrin and Irvine 1990, Irvine et al. 1992, English et al. 1992). Perrin and Irvine (1990) compiled a list of estimates of survey life from a number of sources. The average survey life estimate from these sources was 12.1 days for Chinook salmon. In my analysis, a constant value of 12 days was used as the residence time for Chinook salmon. Perrin and Irvine’s (1990) assemblage yielded an average survey life estimate of 11.4 days for coho salmon. In my study, a constant value of 11 days was used as the residence time for coho salmon.

Carcass Mark-Recapture

Individual carcasses that could not be identified to species were assigned a species using a logistic regression model based on data from carcasses of known species. Logistic regression models based on data from carcasses of known species were created to assign a species to these unknowns using the same procedure as live fish (Table 3).

Carcass mark-recapture data were applied to calculate escapement estimates using two different methods, a modified version of the Jolly-Seber method and the Petersen formula.

Estimates of escapement, E , based on the mark-recapture of carcasses were calculated using a modified version of the Jolly-Seber method as described by Sykes and Botsford (1984). This estimate was calculated by

$$\hat{E}_{JS} = n_1 + \left(\frac{\hat{N}_2 - (R_1 \cdot \Phi_1)}{\sqrt{\Phi_1}} \right) + \sum_{i=1}^{final} \hat{D}_i \quad (\text{Equation 7})$$

Table 3. Equation combinations considered for carcass logistic regression model applied to the Prairie Creek Study Area, Humboldt County, California. Available parameters were day of water year (t), distance upstream (u ; Mainstem Prairie Creek only), and fork length (f).

Data Set		Available Parameters
Time Frame	Location	
Year-specific (2001/2002, 2002/2003, 2003/2004)	Mainstem only	t, u t, u, f
	Entire Study Area	t t, f
All years pooled (2001/2002 - 2003/2004)	Mainstem only	t, u t, u, f
	Entire Study Area	t t, f

where i = sample time,

n_1 = number of carcasses sampled at first sample time,

R_1 = number of carcasses tagged and released at first sample time,

N_2 = estimated carcass sample size at the second sample time,

$D_i = B_i/(\Phi_i)^{0.5}$,

Φ_i = survival rate of carcasses from i to $i+1$, and

B_i = estimated number of carcasses still present at sample time $i+1$ which immigrated between i and $i+1$.

For my project, complete recapture histories were used in calculations. Sykes and Botsford (1984) assumed that all carcasses were destroyed when captured. I also modified Sykes and Botsford's method in that apparent survival (Φ), and capture probability (P) were estimated using Program MARK (White and Burnham 1999). Program MARK uses a mark-recapture history to create four possible models with parameter estimates: 1) constant survival and constant capture probability, 2) constant survival and capture probability as a function of time, 3) survival as a function of time and constant capture probability, and 4) survival and capture probability as functions of time. Model selection was based on Akaike's information criterion.

Escapement was also estimated using the Petersen mark-recapture formula adjusted for bias (Seber 1982, Krebs 1999). In cases for which every carcass was tagged, spawner escapement was estimated using

$$\hat{E}_p = \frac{(C+1)^2}{(R+1)} - 1 \quad (\text{Equation 8})$$

where C = the number of carcasses captured and tagged and

R = the number of tagged carcasses recovered.

95% confidence limits for the Petersen method were calculated using the equation:

$$\pm 1.96 \sqrt{\frac{(C+1)^2 (C-R)^2}{(R+1)^2 (R+2)}}. \quad (\text{Equation 9})$$

Employing the stratified Petersen method of carcass mark-recapture escapement estimation was not feasible with the survey schedule.

Redd Counts

Individual redds observed not associated with identified live fish were assigned a species using a logistic regression model based on observations of redds with fish of known species. The appropriate logistic regression model was determined using percentage concordance and Akaike's information criterion from a suite of models that spanned various combinations of explanatory variables. Year-specific models were considered as well as models for which data from all six spawning seasons were pooled (Table 4). Eight variables were evaluated for their ability to classify unknown redds as either Chinook or coho salmon redds. These included four variables recorded during all six seasons (time, distance upstream, redd area, and dig depth) and four additional variables recorded only during the 2002/2003 and 2003/2004 seasons (pot area, substrate size, lateral position, and cover).

Escapement estimates were made assuming each female constructed one redd. The number of redds, R , representing the number of females, f , was added to the product of the number of redds and the male-to-female ratio, where the abundance of males includes both adult males, m_a , and jacks, m_j , by the equation:

$$\hat{E}_{RI} = \left[\left(\frac{m_a + m_j}{f} \right) \cdot R \right] + R. \quad (\text{Equation 10})$$

Table 4. Equation combinations considered for redd logistic regression model applied to the Prairie Creek Study Area, Humboldt County, California. Available parameters were day of water year (t), distance upstream (u ; Mainstem Prairie Creek only), redd area (a), dig depth (d), pot area (p), substrate (r), lateral position (l), and percent cover (c).

Data Set		Available Parameters
Time Frame	Location	
Year-specific (1998/1999, 1999/2000, ...2001/2002)	Mainstem only	t, u t, u, a, d
	Entire Study Area	t t, a, d
Year-specific (2002/2003, 2003/2004)	Mainstem only	t, u t, u, a, d, p, r, l, c
	Entire Study Area	t t, a, d, p, r, l, c
All years combined (1998/1999 - 2003/2004)	Mainstem only	t, u t, u, a, d
	Entire Study Area	t t, a, d
Years combined (2002/2003 - 2003/2004)	Mainstem only	t, u, a, d, p, r, l, c
	Entire Study Area	t, a, d, p, r, l, c

Male-to-female ratios were determined for each year and based on the carcasses observed in the study area.

Coho salmon escapement was also estimated with an alternative approach using redd surface area. Maahs and Gilleard (1994) estimated that coho salmon produce between one and four redds per female in Mendocino County streams. The redd-area method for estimating escapement assumes female salmon are capable of building multiple redds, but that the energy available to a female is limited and the number of redds a female is capable of making depends on the size of the redd(s) she builds. Maahs and Gilleard (1994) categorized redd surface areas for coho salmon into three sizes: 1) greater than or equal to 5.1 m² represented one female, 2) between 2.1 and 5.0 m² represented one half of a female, and 3) less than or equal to 2.0 m² represented one quarter of a female. Redd counts by surface area category were first reduced to estimate the spawning female population, $\hat{F}$:

$$\hat{F} = \sum_{s=1}^3 R_s \quad (\text{Equation 11})$$

where s = the three surface area categories listed above.

The spawning female population was then expanded by the observed carcass male-to-female ratio to yield an escapement estimate,

$$\hat{E}_{RA} = \left[\left(\frac{m_a + m_j}{f} \right) \cdot \hat{F} \right] + \hat{F} . \quad (\text{Equation 12})$$

This method was not used for estimating Chinook salmon escapement since a redd-area per female relationship was not available. However, Maahs and Gilleard (1994) estimated that Chinook salmon females produce between 1.0 and 1.8 redds in Mendocino

County streams. Average redd counts for Chinook salmon in Mill Creek from 1980 to 1987 were 1.4 redds/adult salmon and 2.5 redds/female salmon (Waldvogel 1988).

Comparison of Escapement Estimation Methods

Adult area-under-the-curve escapement estimates were compared with the other four methods of estimating escapement using linear regression analyses. The present data set is not large enough to fit an otherwise preferable Ricker curve.

Juvenile Population Estimates and Escapement-Recruitment Relationships

Chinook salmon migrate downstream out of the study area before juvenile population estimates are conducted. Young-of-the-year Chinook salmon abundances were based on catch data collected using outmigrant traps. Each year fyke nets were placed at two locations of Prairie Creek and at the mouths of Boyes and Streelow Creeks. The Middle Prairie Creek trap was located at the downstream end of Prairie Creek Reach 1 and collects fish from all four Prairie Creek reaches as well as fish coming out of Boyes Creek. The other trap was located at the downstream end of Prairie Creek Reach 3 and collects fish from Upper Prairie Creek.

A portion of juvenile coho salmon migrate downstream out of the study area in the spring. These fish are caught in the outmigrant traps. Surveys in the study area were conducted each summer by the California Cooperative Fish Research Unit to estimate the population of the remaining juvenile coho salmon. These surveys consist of diver observations and electrofishing as described by Hankin and Mohr's (in preparation) modified protocol. Surveys on Boyes and Streelow creeks were conducted using

electrofishing only. Prairie Creek Reaches 1 and 2 were not included in these surveys. Surface-area adjusted juvenile coho salmon population estimates include young-of-the-year and age 1+ fish. Each season, fork lengths of a systematically sampled subset of juvenile coho salmon were measured on each reach. Length-frequency graphs were constructed with this data, yielding a cut-off length to distinguish age young-of-the-year and age 1+ fish. The proportion of young-of-the-year was then used to adjust the juvenile population estimate to obtain a young-of-the-year population estimate. The total young-of-the-year coho salmon estimate each year was obtained by adding the spring outmigrant catch to the estimate from the summer survey.

Chinook and coho salmon spawner (E)-recruitment (YOY) relationships were modeled using simple linear regression:

$$\hat{YOY} = m + b \cdot \hat{E} . \quad (\text{Equation 13})$$

Only Mainstem Prairie Creek was included in determining Chinook salmon spawner-recruitment relationships. Coho salmon spawner-recruitment relationships were determined separately by reach.

RESULTS

Live Fish and Area-Under-the-Curve

Each year, 4.4 to 16.9% of live fish that were observed could not be identified to species. Three variables, time, distance upstream, and individual size, provided differing amounts of differentiation between Chinook salmon, coho salmon, and steelhead. Time (day of water year) most clearly varied among the three species (Figure 2) while species overlapped considerably in spatial distribution (Figure 3). Despite the lack of spatial separation among species, distance upstream was still considered for inclusion in logistic regression models since it could contribute minor influences to models. Coho salmon and steelhead had similar size compositions, while Chinook salmon tended to be larger (Figure 4).

Models based on single seasons and (or) Mainstem Prairie Creek only usually performed better than broad scaled models, based on all years and/or the entire study area. Logistic regression models to distinguish live Chinook and coho salmon from steelhead exhibited at least 93.0% concordance with the data set of known species (Table 5). Logistic regression models to distinguish live adult coho salmon from Chinook salmon exhibited at least 87.5% concordance with the data set of known species (Table 6, Appendix A). Jack Chinook and coho salmon were distinguished with 90.6 to 90.8% concordance.

Adults and jacks were combined for our escapement estimate calculations since jack samples sizes were too small for separate analysis (Appendix B, C). Jacks were not observed during most surveys and rarely were more than one jack seen during a survey.

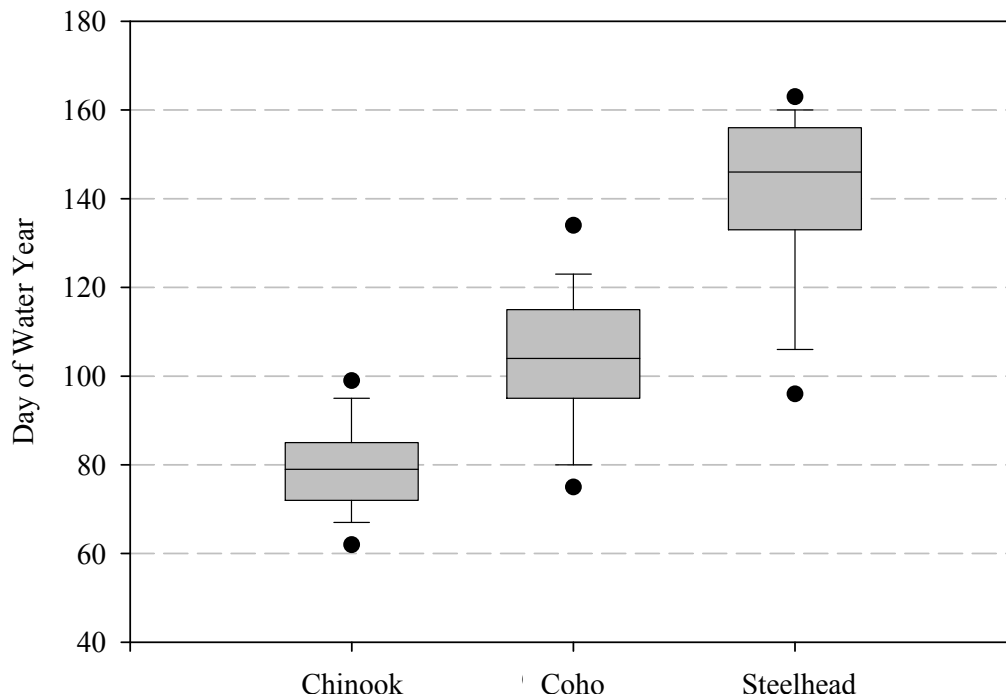


Figure 2. Day of water year live Chinook salmon (n=1931), coho salmon (n=1398), and steelhead (n=143) spawners were observed in the Prairie Creek Study Area, Humboldt County, California, over six spawning seasons (1998/1999 to 2003/2004). The water year of each season begins on October.

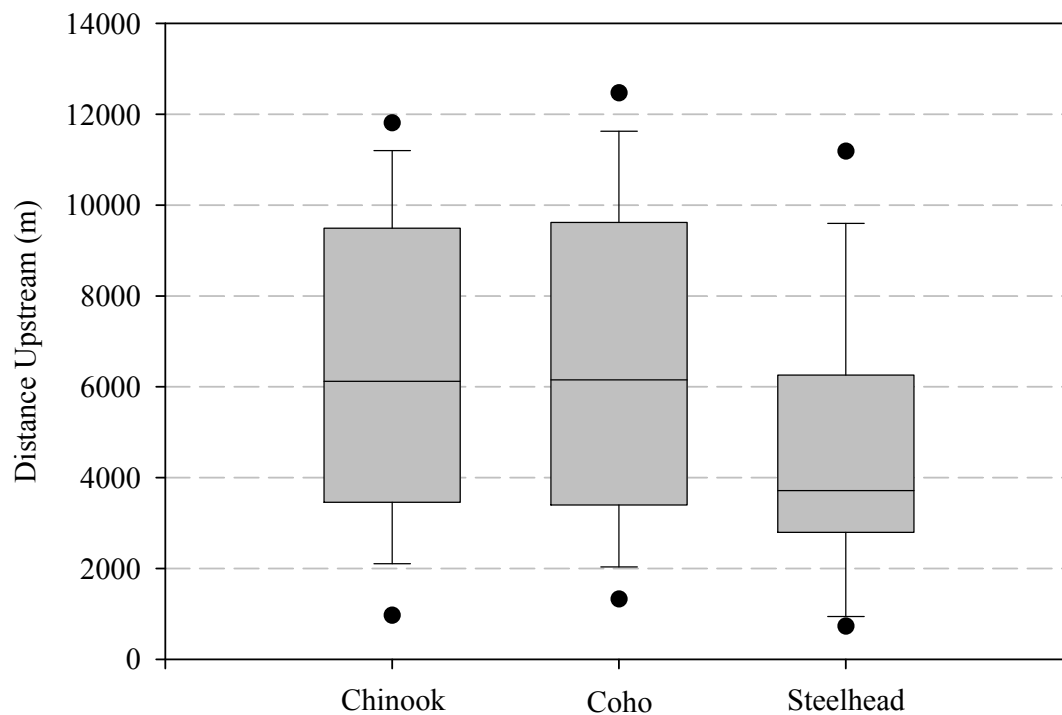


Figure 3. Box plot of distance upstream at which live Chinook salmon (n=1920), coho salmon (n=1201), and steelhead (n=141) spawners were observed in Mainstem Prairie Creek, Humboldt County, California, over six spawning seasons (1998/1999 to 2003/2004).

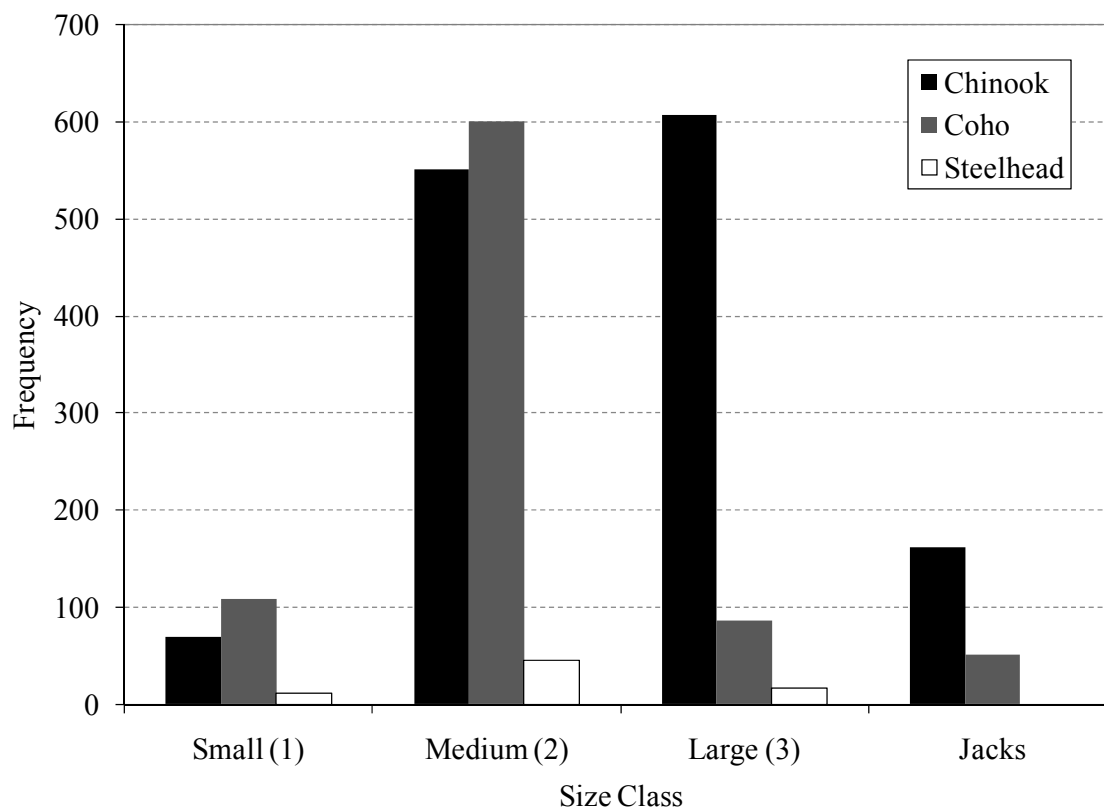


Figure 4. Size frequency of live Chinook salmon (n=1389), coho salmon (n=847), and steelhead (n=74) spawners in the Prairie Creek Study Area, Humboldt County, California, over six spawning seasons (1998/1999 to 2003/2004). Size breakdown of mature (non-jack) salmon and steelhead was not available for 2002/2003.

Table 5. Logistic regression model used to distinguish live Chinook and coho salmon from steelhead in the Prairie Creek Study Area, Humboldt County, California. The three variables presented are water year day (t), distance upstream in meters (u), and size (s ; $S=1$, $M=2$, and $L=3$). Equations derived from the applicable data set with the highest concordance and lowest Akaike's information criterion (AIC) were used for each season, stream, and data availability scenario. After variables are plugged into the pertinent equation, a fish was predicted to be a salmon if the probability of being a salmon (P_{salmon}) was greater than 0.5 and predicted to be a steelhead if P_{salmon} was less than 0.5. The table only lists retained equations used and their acceptable alternatives.

				Association of Predicted Probabilities and Observed Responses				
Equation	Data Set		$P_{salmon} = 1/(1 + e^{-x})$ where $x =$	Sample Size			AIC	Equation
Application	Season(s)	Reaches		n(salmon); n(steelhead)	Percent Concordant	Percent Tied		
Year-specific								
	2000/2001	Mainstem	$30.97 - 0.22 \cdot t + 0.00069 \cdot u$	472; 31	99.0	0.0	66.76	14.1a
	2000/2001	Mainstem	$48.04 - 0.33 \cdot t - 0.0038 \cdot u + 0.00003 \cdot d \cdot u$	472; 31	99.1	0.0	66.64	14.1b
	2000/2001	Mainstem	$55.66 - 0.36 \cdot t - 0.0042 \cdot u - 1.84 \cdot s + 0.000034 \cdot t \cdot u$	450; 30	99.4	0.0	56.09	14.2a
	2000/2001	Mainstem	$-5.56 + 0.045 \cdot t + 0.0011 \cdot u + 21.10 \cdot s - 0.15 \cdot t \cdot s$	450; 30	99.4	0.0	56.22	14.2b
	2000/2001	Study Area	$27.93 - 0.18 \cdot t$	483; 31	98.3	0.8	76.80	14.3
	2000/2001	Study Area	$29.30 - 0.17 \cdot t - 1.52 \cdot s$	461; 30	98.7	0.3	67.99	14.4a
	2000/2001	Study Area	$3.39 + 0.0022 \cdot t + 11.93 \cdot s - 0.090 \cdot t \cdot s$	461; 30	99.0	0.3	67.07	14.4b
	2002/2003	Mainstem	$55.37 - 0.47 \cdot t + 0.00052 \cdot u$	262; 19	99.5	0.0	32.32	14.5a
	2002/2003	Mainstem	$105.10 - 0.89 \cdot t - 0.0070 \cdot u + 0.000062 \cdot t \cdot u$	262; 19	99.5	0.0	31.79	14.5b
	2002/2003	Study Area	$42.68 - 0.34 \cdot t$	323; 19	97.6	1.1	52.02	14.6
	2003/2004	Mainstem	$34.98 - 0.25 \cdot t - 0.00015 \cdot u$	536; 38	99.9	0.0	30.78	14.7a
	2003/2004	Mainstem	$17.75 - 0.12 \cdot t + 0.0051 \cdot u - 0.00004 \cdot t \cdot u$	536; 38	99.9	0.0	29.99	14.7b
	2003/2004	Study Area	$26.71 - 0.20 \cdot t$	555; 40	99.5	0.1	42.36	14.8
Years pooled								
	1998/1999 - 2003/2004	Mainstem	$15.29 - 0.11 \cdot t + 0.000024 \cdot u$	2919; 141	93.4	2.0	512.78	14.9a
	1998/1999 - 2003/2004	Mainstem	$15.99 - 0.11 \cdot t + 0.00011 \cdot u + 0.0000010 \cdot t \cdot u$	2919; 141	93.4	2.0	514.53	14.9b
	1998/1999 - 2003/2004	Mainstem	$1.79 - 0.0072 \cdot t + 0.000086 \cdot u + 7.02 \cdot s - 0.052 \cdot t \cdot s$	1917; 74	97.0	0.4	268.22	14.10
	1998/1999 - 2003/2004	Study Area	$15.99 - 0.11 \cdot t$	3115; 143	93.0	2.3	539.83	14.11
	1998/1999 - 2003/2004	Study Area	$1.69 - 0.0027 \cdot t + 7.87 \cdot s - 0.058 \cdot t \cdot s$	2022; 74	96.4	0.6	276.19	14.12

Table 6. Logistic regression model used to distinguish live coho salmon from Chinook salmon in the Prairie Creek Study Area, Humboldt County, California. The three variables presented are water year day (t), distance upstream in meters (u), and size (s ; $S=1$, $M=2$, and $L=3$). Equations derived from the applicable data set with the highest concordance and lowest Akaike's information criterion (AIC) were used for each season, stream, and data availability scenario. After variables are plugged into the pertinent equation, a fish was predicted to be a coho salmon if the probability of being a coho salmon (P_{coho}) was greater than 0.5 and predicted to be a Chinook salmon if P_{coho} was less than 0.5. The table only lists retained equations used and their acceptable alternatives.

Equation Application	Data Set		$P_{coho} = 1/(1 + e^{-x})$ where $x =$	Sample Size	Association of Predicted Probabilities and Observed Responses		AIC	Equation
	Season(s)	Reaches		n(Chinook); n(coho)	Percent Concordant	Percent Tied		
Year-specific								
	1998/1999	Study Area	$-7.32 + 0.14 \cdot t - 3.42 \cdot s$	371; 53	94.0	2.1	152.99	15.1a
	1998/1999	Study Area	$-2.09 + 0.075 \cdot t - 6.25 \cdot s + 0.036 \cdot t \cdot s$	371; 53	93.9	2.1	154.55	15.1b
	1999/2000	Mainstem	$-13.44 + 0.13 \cdot t + 0.000056 \cdot u$	274; 51	88.1	0.9	178.57	15.2a
	1999/2000	Mainstem	$-14.00 + 0.14 \cdot t - 0.00013 \cdot u - 0.00000084 \cdot t \cdot u$	274; 51	88.1	0.9	180.55	15.2b
	1999/2000	Mainstem	$-35.40 + 0.41 \cdot t + 0.00012 \cdot u + 9.22 \cdot s - 0.12 \cdot t \cdot s$	268; 48	92.4	0.4	135.45	15.3
	1999/2000	Study Area	$-35.78 + 0.42 \cdot t + 9.58 \cdot s - 0.13 \cdot t \cdot s$	271; 51	91.2	3.0	136.53	15.4
	2000/2001	Mainstem	$-11.78 + 0.11 \cdot t + 0.00024 \cdot u$	257; 215	88.4	0.5	386.34	15.5a
	2000/2001	Mainstem	$-14.46 + 0.13 \cdot t + 0.00082 \cdot u - 0.0000060 \cdot t \cdot u$	257; 215	88.9	0.5	385.53	15.5b
	2000/2001	Mainstem	$-8.50 + 0.10 \cdot t + 0.00030 \cdot u - 1.60 \cdot s$	251; 199	92.4	0.3	313.49	15.6a
	2000/2001	Mainstem	$-11.18 + 0.13 \cdot t + 0.00089 \cdot u - 1.61 \cdot s - 0.0000062 \cdot t \cdot u$	251; 199	92.6	0.3	312.71	15.6b
	2000/2001	Mainstem	$-16.49 + 0.19 \cdot t + 0.00030 \cdot u + 1.98 \cdot s - 0.038 \cdot t \cdot s$	251; 199	92.3	0.2	310.32	15.6c
	2000/2001	Mainstem	$-9.99 + 0.10 \cdot t + 0.00065 \cdot u - 0.89 \cdot s - 0.00017 \cdot u \cdot s$	251; 199	92.4	0.3	313.65	15.6d
	2000/2001	Mainstem	$-12.81 + 0.13 \cdot t + 0.00079 \cdot u - 0.62 \cdot s - 0.0000025 \cdot t \cdot u \cdot s$	251; 199	92.6	0.2	309.44	15.6e
	2000/2001	Study Area	$-16.47 + 0.20 \cdot t + 2.56 \cdot s - 0.043 \cdot t \cdot s$	251; 210	90.4	1.7	331.45	15.7
	2001/2002	Study Area	$-5.09 + 0.12 \cdot t - 1.35 \cdot s - 0.0081 \cdot t \cdot s$	334; 481	89.5	1.5	642.40	15.9b
	2003/2004	Mainstem	$-18.00 + 0.19 \cdot t + 0.000049 \cdot u$	408; 128	91.4	0.8	271.95	15.10a
	2003/2004	Mainstem	$-18.82 + 0.20 \cdot t + 0.00017 \cdot u - 0.0000014 \cdot t \cdot u$	408; 128	91.2	0.6	273.85	15.10b
	2003/2004	Study Area	$-16.30 + 0.17 \cdot t$	410; 145	88.0	3.3	315.23	15.11

Table 6. Logistic regression model used to distinguish live coho salmon from Chinook salmon in the Prairie Creek Study Area, Humboldt County, California. The three variables presented are water year day (t), distance upstream in meters (u), and size (s ; $S=1$, $M=2$, and $L=3$). Equations derived from the applicable data set with the highest concordance and lowest Akaike's information criterion (AIC) were used for each season, stream, and data availability scenario. After variables are plugged into the pertinent equation, a fish was predicted to be a coho salmon if the probability of being a coho salmon (P_{coho}) was greater than 0.5 and predicted to be a Chinook salmon if P_{coho} was less than 0.5. The table only lists retained equations used and their acceptable alternatives (continued).

Equation Application	Data Set		$P_{coho} = 1/(1 + e^{-x})$ where $x =$	Sample Size	Association of Predicted Probabilities and Observed Responses			AIC	Equation
	Season(s)	Reaches		n(Chinook); n(coho)	Percent Concordant	Percent Tied			
Years pooled									
1998/1999-2003/2004	1998/1999-2003/2004	Mainstem	$-19.53 + 0.19 \cdot t + 0.00017 \cdot u$	160; 42	90.6	1.5	113.06	15.12a*	
1998/1999-2003/2004	1998/1999-2003/2004	Mainstem	$-17.47 + 0.17 \cdot t - 0.00011 \cdot u + 0.0000031 \cdot t \cdot u$	160; 42	90.8	0.2	115.00	15.12b*	
1998/1999-2003/2004	1998/1999-2003/2004	Study Area	$-11.33 + 0.12 \cdot t$	1769; 1346	87.5	1.4	2691.24	15.13	
1998/1999-2003/2004	1998/1999-2003/2004	Study Area	$-6.54 + 0.10 \cdot t - 1.33 \cdot s$	1227; 795	88.4	0.7		15.14	

* equation based on jack data only

Jacks comprised only 3.7 to 11.1% of Chinook salmon spawners and only 1.2 to 12.5% of coho salmon spawners. Annual area-under-the-curve estimates in the entire study area ranged from 106 to 531 for Chinook salmon and 67 to 658 for coho salmon (Table 7, Appendix D). More live fish were typically observed in the lower reaches of Prairie Creek than in the upper reaches. Coho salmon were observed in Streelow and Boyes Creeks in moderate numbers. However, Chinook salmon were rarely observed in these tributaries.

Carcass Mark-Recapture

Each year of the study, 2.7 to 5.8% of carcasses observed could not be identified to species (Appendix E). Three variables, time, size, and distance upstream, from Chinook salmon and coho salmon carcasses observed during surveys provided differing amounts of separation between species. Time (day of water year) and size (fork length) allowed for most separation between the two species (Figure 5, 6). Distance upstream contained the most overlap between both species (Figure 7). All logistic regression models to distinguish coho salmon from Chinook salmon carcasses exhibited at least 83.7% agreement with the data set of known species (Table 8).

Petersen estimates for both species ranged from 13.4 to 108.4% higher than Jolly-Seber estimates for study area. Petersen and Jolly-Seber estimates for Chinook and coho salmon are summarized in Table 9 and Appendix F, G.

Table 7. Area-under-the-curve estimates from live Chinook and coho salmon spawners observed in the Prairie Creek Study Area, Humboldt County, California, 1998/1999 to 2003/2004.

Year	Chinook		Coho	
	Mainstem	Study Area	Mainstem	Study Area
1998/1999	461	466	41	67
1999/2000	301	301	73	78
2000/2001	219	221	211	224
2001/2002	531	531	606	658
2002/2003	95	106	352	439
2003/2004	408	419	142	163

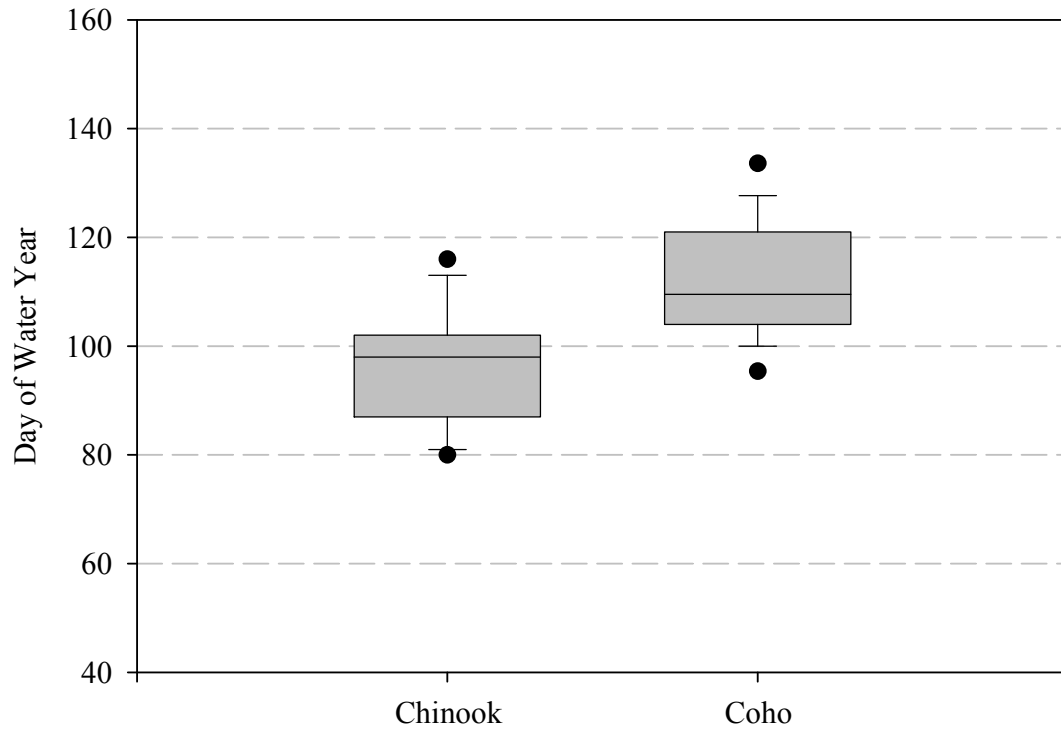


Figure 5. Box plot of day of water year that Chinook (n=458) and coho (n=339) salmon carcasses were observed in the Prairie Creek Study Area, Humboldt County, California. Data were taken from the initial encounter of each carcass over the final three spawning seasons (2001/2002, 2002/2003, and 2003/2004).

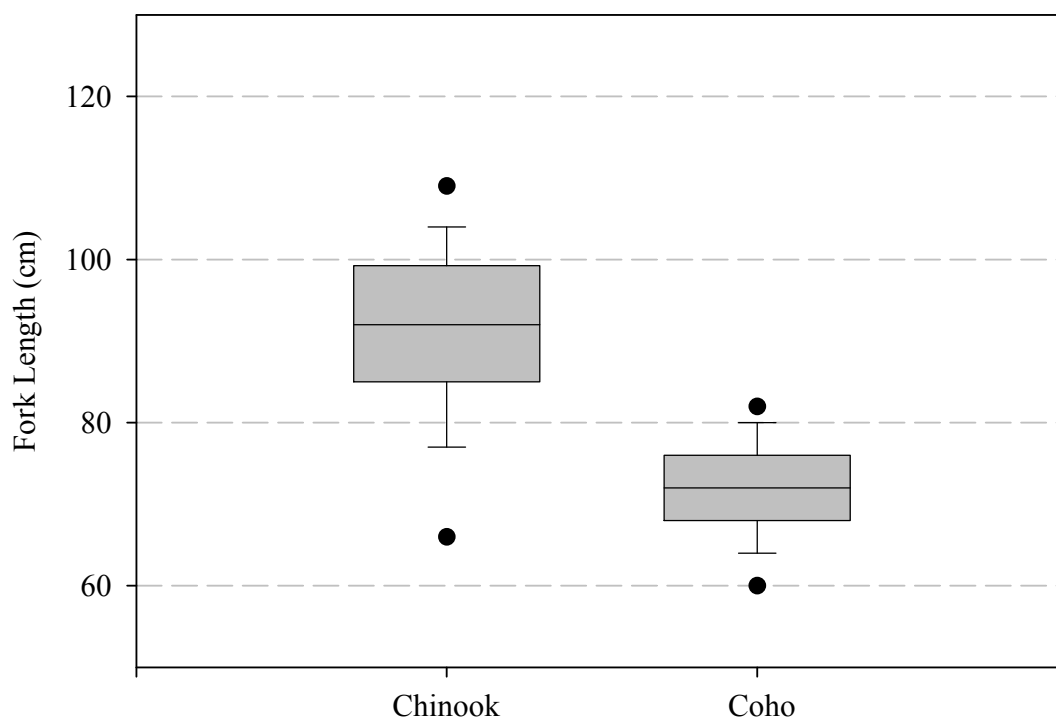


Figure 6. Box plot of size of Chinook (n=424) and coho (n=308) salmon carcasses observed in the Prairie Creek Study Area, Humboldt County, California. Data were taken from the initial encounter of each carcass over the final three spawning seasons (2001/2002, 2002/2003, and 2003/2004).

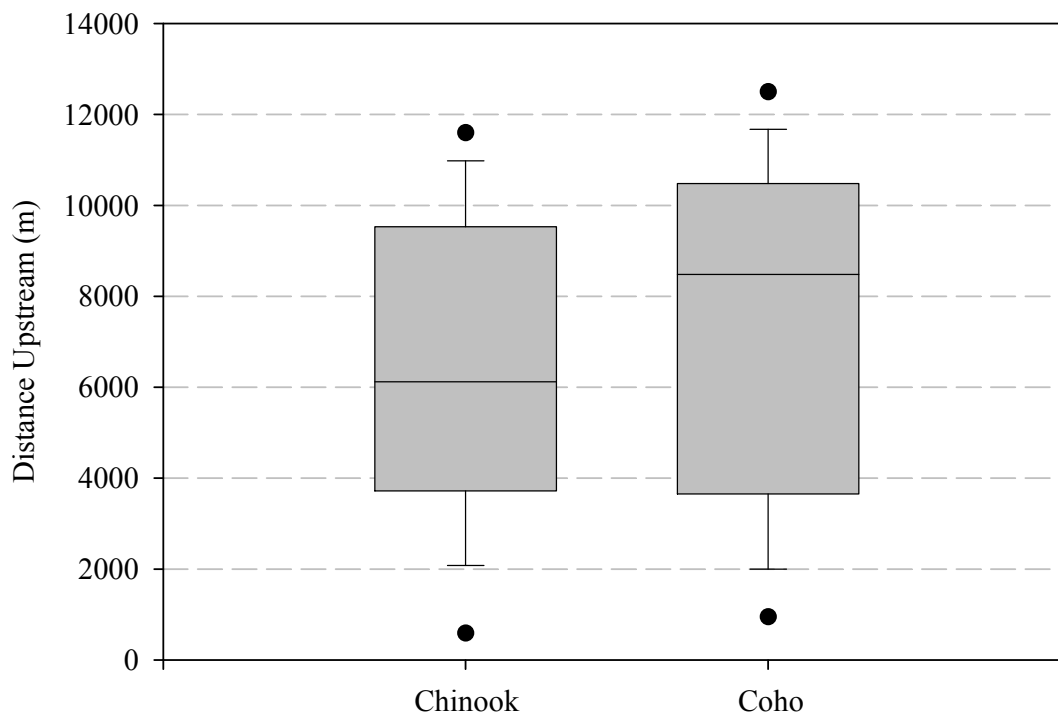


Figure 7. Box plot of distance upstream that Chinook (n=455) and coho (n=269) salmon carcasses were observed in Mainstem Prairie Creek, Humboldt County, California. Data was taken from the initial encounter of each carcass over the final three spawning seasons (2001/2002, 2002/2003, and 2003/2004).

Table 8. Logistic regression models used to distinguish coho salmon from Chinook salmon carcasses in the Prairie Creek Study Area, Humboldt County, California. The three variables presented are water year day (t), distance upstream in meters (u), and fork length in centimeters (f). Equations derived from the applicable data set with the highest concordance and lowest Akaike's information criterion (AIC) were used for each season, stream, and data availability scenario. After variables are plugged into the pertinent equation, a fish was predicted to be a coho salmon if the probability of being a coho salmon (P_{coho}) was greater than 0.5 and predicted to be a Chinook salmon if P_{coho} was less than 0.5. The table only lists retained equations used and their acceptable alternatives.

Equation Application	Data Set		$P_{coho} = 1/\left(1 + e^{-x}\right)$ where $x =$	Sample Size n(Chinook); n(coho)	Association of Predicted Probabilities and Observed Responses		AIC	Equation
	Season(s)	Reaches			Percent Concordant	Percent Tied		
Year-specific								
	2001/2002	Mainstem	$-11.64 + 0.099 \cdot t + 0.00020 \cdot u$	190; 170	83.7	0.2	361.91	16.1a
		Mainstem	$-7.71 + 0.062 \cdot t - 0.00041 \cdot u + 0.0000057 \cdot t \cdot u$	190; 170	83.9	0.2	361.07	16.1b
		Mainstem	$8.76 + 0.11 \cdot t + 0.00019 \cdot u - 0.27 \cdot f$	170; 150	97.2	0.1	137.12	16.2a
		Mainstem	$12.36 + 0.079 \cdot t - 0.00036 \cdot u - 0.26 \cdot f + 0.0000052 \cdot t \cdot u$	170; 150	97.3	0.1	138.51	16.2b
		Mainstem	$-4.89 + 0.25 \cdot t - 0.00019 \cdot u - 0.095 \cdot f + 0.0017 \cdot t \cdot f$	170; 150	97.3	0.1	138.67	16.2c
		Mainstem	$5.87 + 0.11 \cdot t + 0.00069 \cdot u - 0.23 \cdot f - 0.0000063 \cdot u \cdot f$	170; 150	97.3	0.1	138.64	16.2d
		Mainstem	$8.96 + 0.11 \cdot t + 0.00017 \cdot u - 0.27 \cdot f + 0.00000000 \cdot t \cdot u \cdot f$	170; 150	97.2	0.1	139.12	16.2e
		Study Area	$11.52 + 0.11 \cdot t - 0.28 \cdot f$	193; 170	97.1	0.2	150.07	16.3a
		Study Area	$-10.09 + 0.32 \cdot t - 0.013 \cdot f - 0.0023 \cdot t \cdot f$	193; 170	97.2	0.2	150.99	16.3b
	2002/2003	Mainstem	$-15.03 + 0.12 \cdot t + 0.00011 \cdot u$	165; 66	84.5	0.3	209.04	16.4a
		Mainstem	$-22.38 + 0.19 \cdot t + 0.0011 \cdot u - 0.0000094 \cdot t \cdot u$	165; 66	84.4	0.2	207.47	16.4b
	2003/2004	Mainstem	$-12.92 + 0.12 \cdot t + 0.000080 \cdot u$	116; 34	88.3	0.4	122.39	16.5a
		Mainstem	$-7.10 + 0.066 \cdot t - 0.0010 \cdot u + 0.0000095 \cdot t \cdot u$	116; 34	88.4	0.5	122.67	16.5b
		Mainstem	$10.43 + 0.21 \cdot t - 0.00047 \cdot u - 0.38 \cdot f$	101; 31	99.1	0.0	37.11	16.6a
		Mainstem	$-0.99 + 0.36 \cdot t - 0.0013 \cdot u - 0.42 \cdot f - 0.000020 \cdot t \cdot u$	101; 31	99.0	0.0	37.87	16.6b
		Mainstem	$14.02 + 0.18 \cdot t - 0.00047 \cdot u - 0.44 \cdot f + 0.00049 \cdot t \cdot f$	101; 31	99.1	0.0	39.10	16.6c
		Mainstem	$7.35 + 0.22 \cdot t - 0.000027 \cdot u - 0.35 \cdot f - 0.0000067 \cdot u \cdot f$	101; 31	99.0	0.0	38.99	16.6d
		Mainstem	$0.38 + 0.29 \cdot t + 0.00035 \cdot u - 0.35 \cdot f + 0.00000012 \cdot t \cdot u \cdot f$	101; 31	99.0	0.0	38.26	16.6e
		Study Area	$8.51 + 0.15 \cdot t - 0.31 \cdot f$	101; 33	98.1	0.1	44.33	16.7a
		Study Area	$-90.46 + 0.24 \cdot t - 0.19 \cdot f - 0.0012 \cdot t \cdot f$	101; 33	98.2	0.1	46.29	16.7b

Table 8. Logistic regression models used to distinguish coho salmon from Chinook salmon carcasses in the Prairie Creek Study Area, Humboldt County, California. The three variables presented are water year day (t), distance upstream in meters (u), and fork length in centimeters (f). Equations derived from the applicable data set with the highest concordance and lowest Akaike's information criterion (AIC) were used for each season, stream, and data availability scenario. After variables are plugged into the pertinent equation, a fish was predicted to be a coho salmon if the probability of being a coho salmon (P_{coho}) was greater than 0.5 and predicted to be a Chinook salmon if P_{coho} was less than 0.5. The table only lists retained equations used and their acceptable alternatives (continued).

Equation Application	Data Set		$P_{coho} = 1/\left(1 + e^{-x}\right)$ where $x =$	Sample Size n(Chinook); n(coho)	Association of Predicted Probabilities and Observed Responses			AIC	Equation
	Season(s)	Reaches			Percent Concordant	Percent Tied			
Years pooled									
1998/1999-2003/2004	Mainstem		$8.44 + 0.095 \cdot t + 0.000068 \cdot u - 0.24 \cdot f$	417; 239	96.3	0.1	312.69	16.8a	
	Mainstem		$8.97 + 0.090 \cdot t - 0.00001 \cdot u - 0.24 \cdot f + 0.00000074 \cdot t \cdot u$	417; 239	96.3	0.0	314.66	16.8b	
	Mainstem		$12.17 + 0.059 \cdot t + 0.000068 \cdot u - 0.44 \cdot f + 0.00046 \cdot t \cdot f$	417; 239	96.3	0.1	314.62	16.8c	
	Mainstem		$8.28 + 0.095 \cdot t - 0.000092 \cdot u - 0.24 \cdot f - 0.00000031 \cdot u \cdot f$	417; 239	96.3	0.1	314.69	16.8d	
	Mainstem		$9.24 + 0.091 \cdot t + 0.0000077 \cdot u - 0.24 \cdot f - 0.0000000073 \cdot t \cdot u \cdot f$	417; 239	96.3	0.0	314.65	16.8e	
	Mainstem		$-7.92 + 0.10 \cdot t$	764; 387	84.3	1.5	1065.66	16.9	
	Study Area		$8.98 + 0.10 \cdot t - 0.25 \cdot f$	419; 298	96.4	0.1	339.40	16.10a	
	Study Area		$8.71 + 0.10 \cdot t - 0.24 \cdot f - 0.000030 \cdot t \cdot f$	419; 298	96.4	0.1	341.40	16.10b	

Table 9. Petersen and Jolly-Seber escapement estimates for Chinook and coho salmon from carcass mark-recapture experiments in the Prairie Creek Study Area, Humboldt County, California, 2001/2002 to 2003/2004.

Species	Season	Reaches	Petersen						Jolly-Seber
			Captured and Marked	Recaptured	Recapture Rate (%)	Estimate	confidence limits		Estimate
							95% Lower	95% Upper	
Chinook	2001/2002	Mainstem	183	132	72.1%	254	242	266	207
	2002/2003	Mainstem	164	79	48.2%	339	301	377	172
	2003/2004	Mainstem	123	73	59.3%	207	188	226	106
	2001/2002	Study Area	183	132	72.1%	254	242	266	224
	2002/2003	Study Area	166	79	47.6%	348	308	388	167
	2003/2004	Study Area	124	73	58.9%	210	191	229	108
Coho	2001/2002	Mainstem	173	116	67.1%	258	242	273	184
	2002/2003	Mainstem	79	33	41.8%	187	151	223	115
	2003/2004	Mainstem	45	15	33.3%	131	90	172	104
	2001/2002	Study Area	222	137	61.7%	359	337	382	238
	2002/2003	Study Area	94	35	37.2%	250	200	300	155
	2003/2004	Study Area	53	15	28.3%	181	120	242	147

Redd Identification and Count Expansion

Each year, 54.3% to 79.7% of redds that were observed could not be associated with a species (Appendix H). Time (day of water year) was the only variable recorded that distinctly separated Chinook and coho salmon redds (Figure 8). Despite the lack of separation among species provided by the other seven variables (Figure 8, 9), they were still considered for logistic regression since they still may contribute minor influences to the model. The only redd parameters that demonstrated pairwise correlations were redd area and pot area, and redd area and dig depth (Appendix I).

Stream width was considered as a parameter for logistic regression but not included due to low sample size (Appendix J). Also not included were alternate methods for measuring substrate (Appendix K).

For redds not measured, Chinook and coho salmon redds were distinguished with 93.3% concordance with the known data set using only time of redd construction as the only available parameter (Table 10). Among the other seven variables recorded, only pot area and substrate size were retained for measured redds. Measured redds of Chinook and coho salmon could be differentiated with 99.4% concordance.

Annual one redd per female coho salmon escapement estimates in the study area ranged from 13.4 to 106.7% higher than redd-area method estimates. Chinook salmon escapement estimates based on redd counts assuming one redd per female ranged from 32 to 382 in the study area while coho salmon escapement estimates ranged from 75 to 945 (Table 11). Coho salmon escapement estimates based on redd counts using the redd-area method ranged from 63 to 833 in the study area (Table 11).

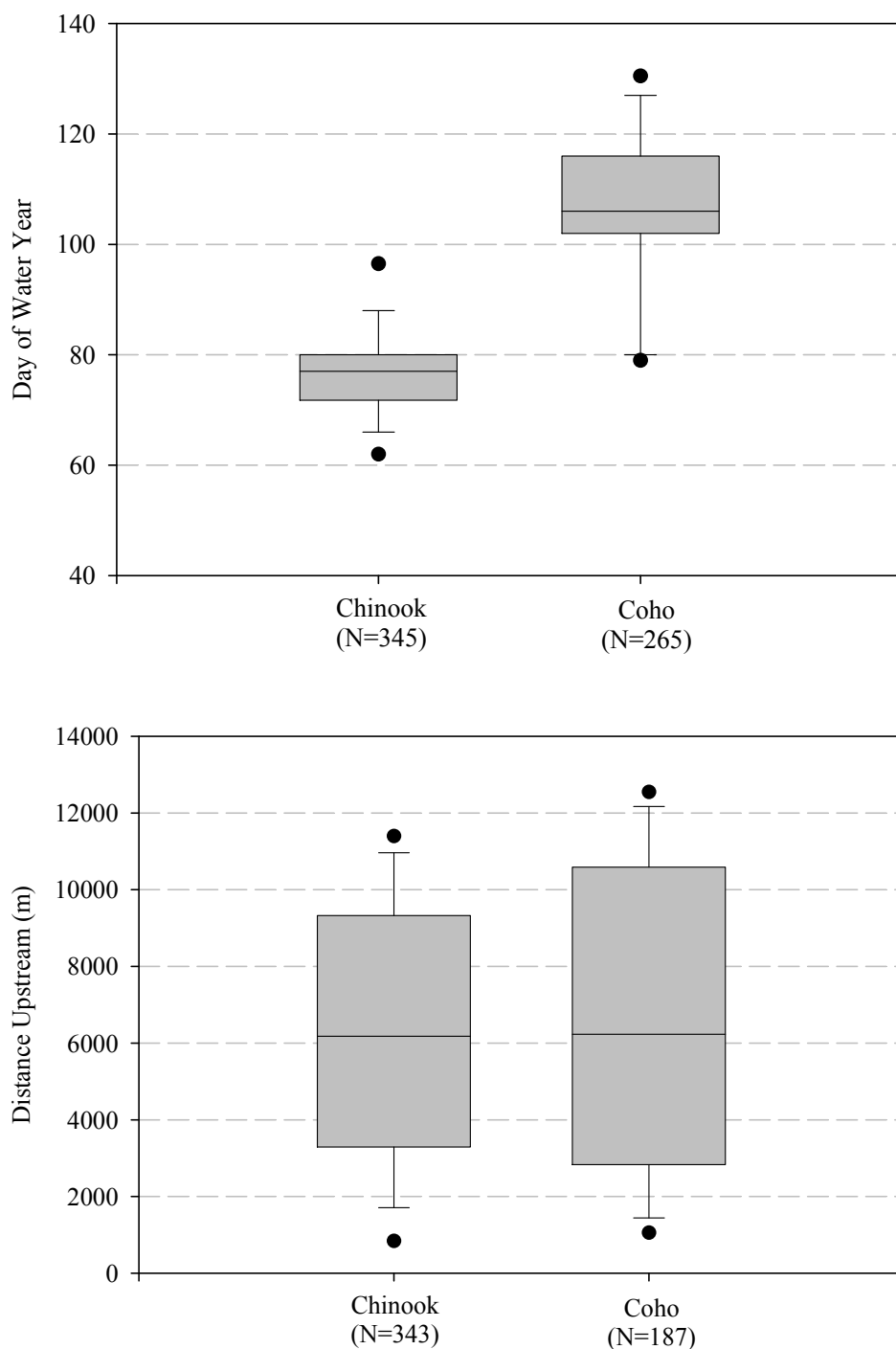


Figure 8. Box plots of variables associated with known Chinook and coho salmon redds during all years (1998/1999 to 2003/2004). Water year day contains data from all six reaches in the Prairie Creek Study Area, Humboldt County, California. Distance upstream, redd area, and dig depth contain data from Mainstem Prairie Creek only.

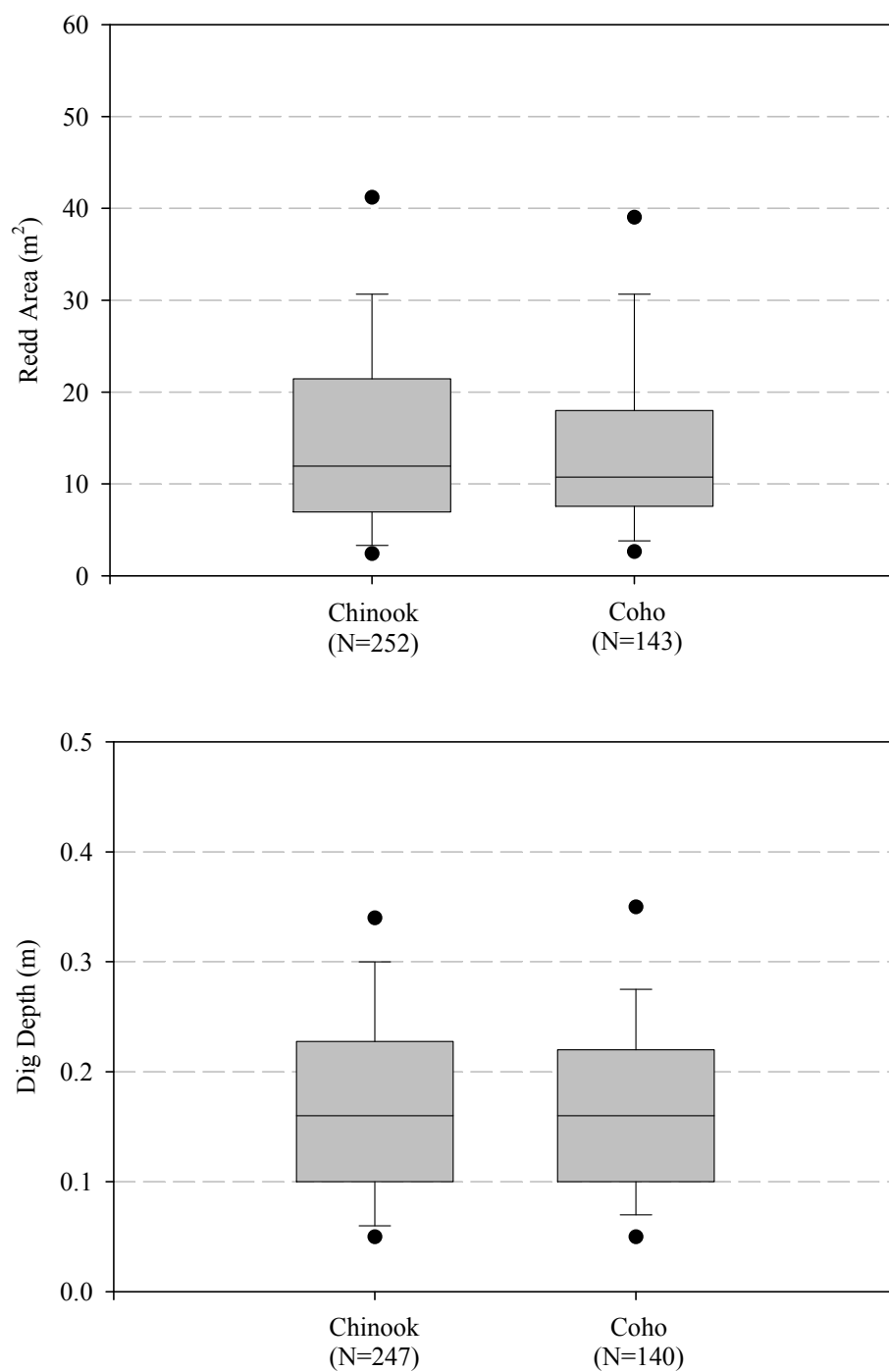


Figure 8. Box plots of variables associated with known Chinook and coho salmon redds during all years (1998/1999 to 2003/2004). Water year day contains data from all six reaches in the Prairie Creek Study Area, Humboldt County, California. Distance upstream, redd area, and dig depth contain data from Mainstem Prairie Creek only (continued).

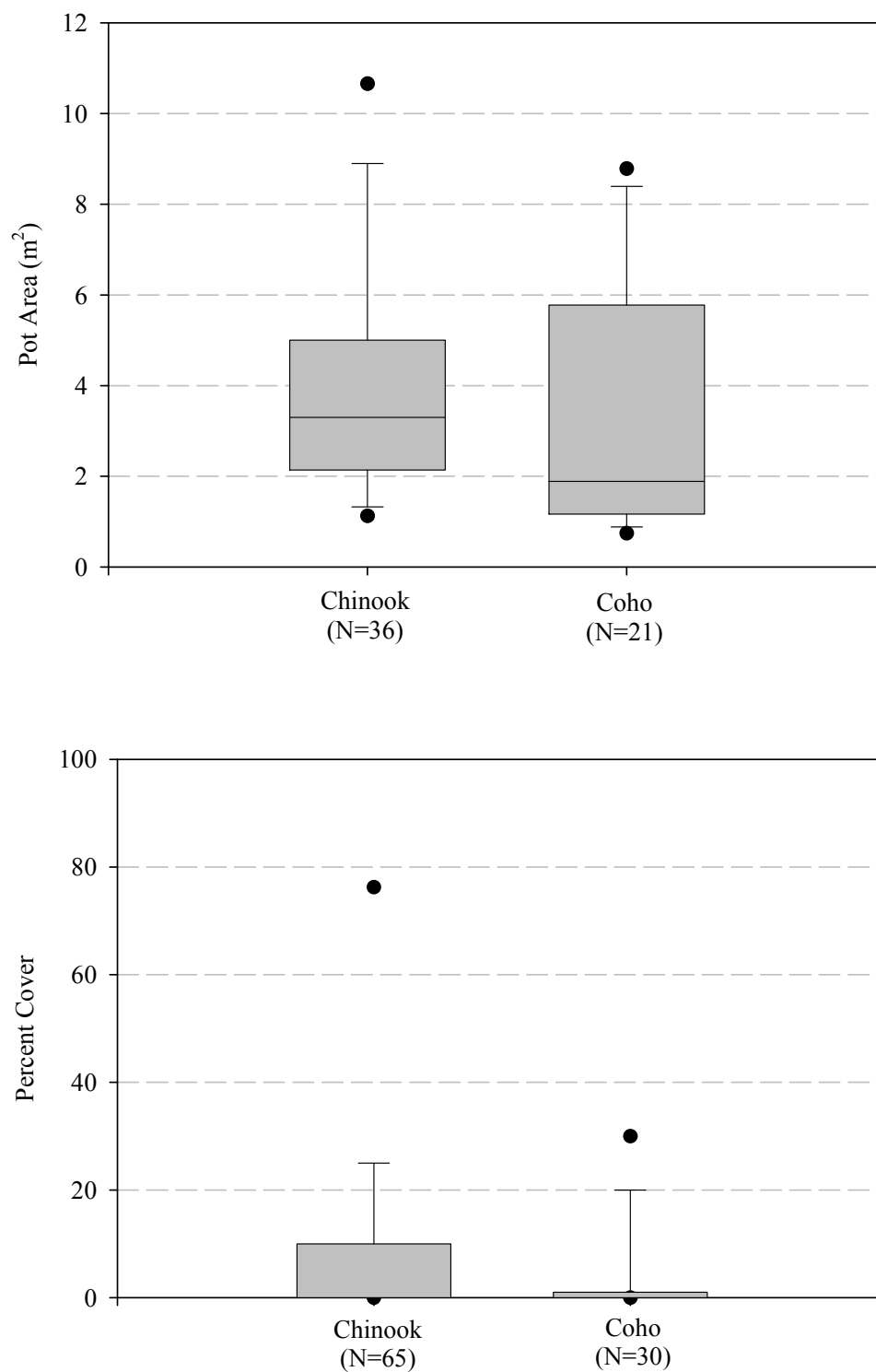


Figure 9. Plots of variables associated with known Chinook and coho salmon redds in Mainstem Prairie Creek, Humboldt County, California, during 2002/2003 and 2003/2004.

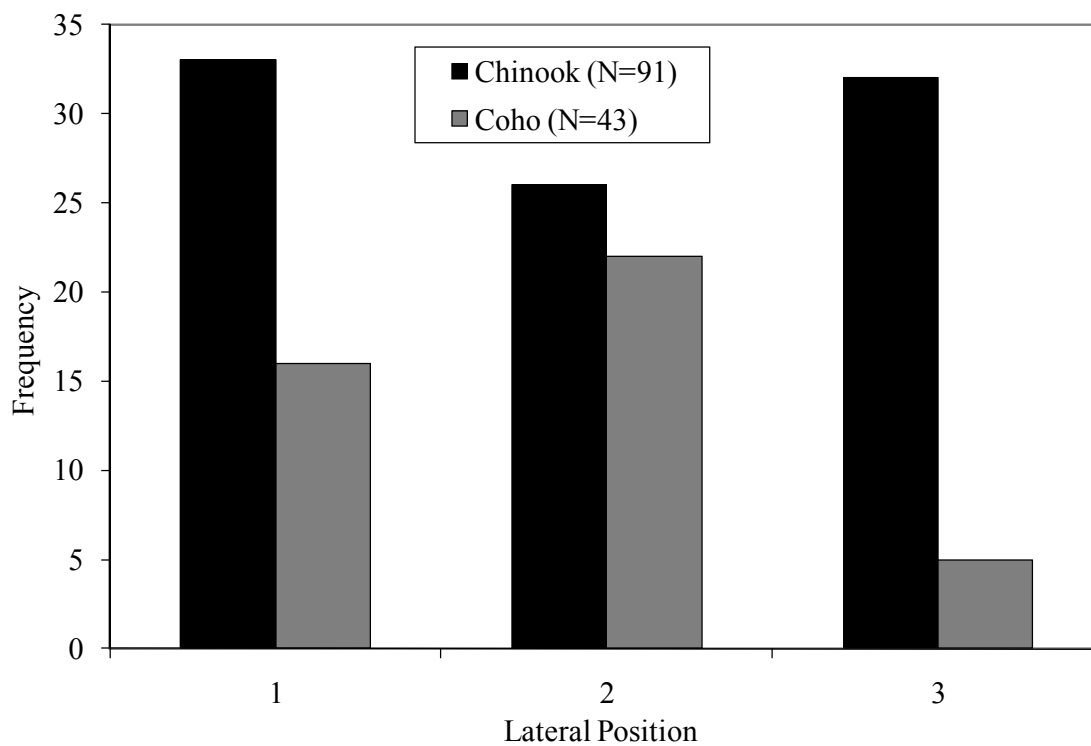
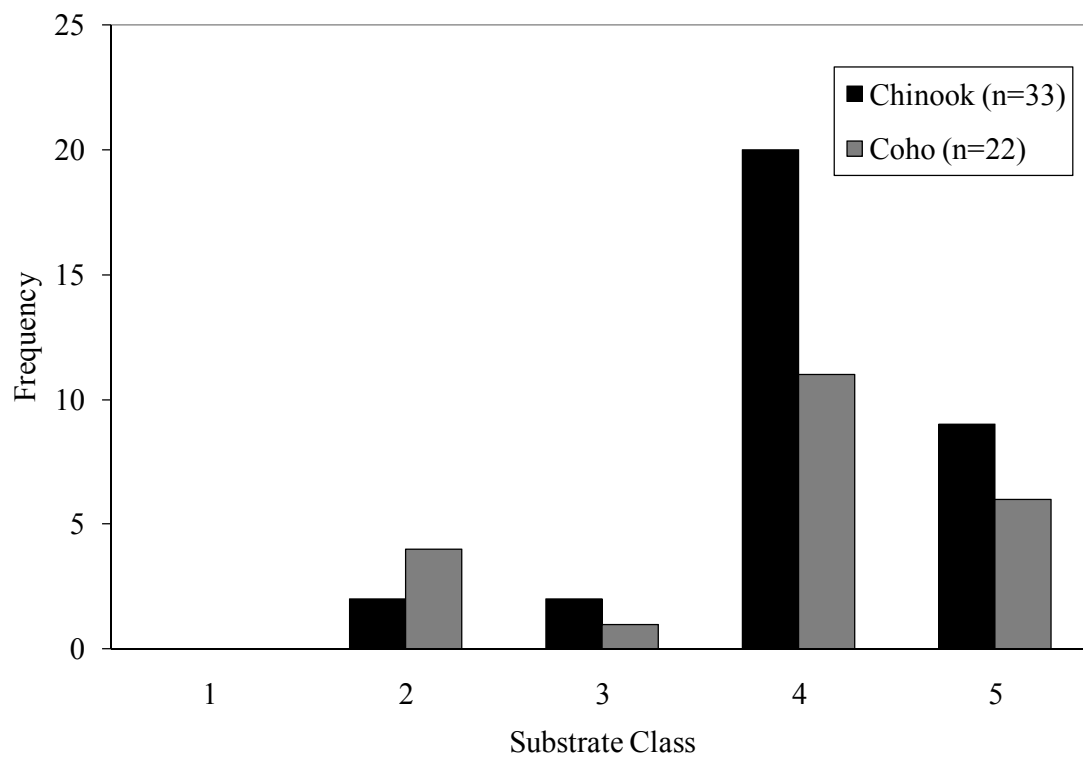


Figure 9. Plots of variables associated with known Chinook and coho salmon redds in Mainstem Prairie Creek, Humboldt County, California, during 2002/2003 and 2003/2004 (continued).

Table 10. Logistic regression model used to distinguish coho salmon redds from Chinook salmon redds in the Prairie Creek Study Area, Humboldt County, California. The three variables presented are water year day (t), distance upstream (u ; rkm), redd area (a ; m²), dig depth (d ; m), pot area (p ; m²), and substrate (r ; 1 through 5 classification). Equations derived from the applicable data set with the highest concordance and lowest Akaike's information criterion (AIC) were used for each season, stream, and data availability scenario. After variables are plugged into the pertinent equation, a redd was predicted to been constructed by coho salmon if the probability of being a coho salmon redd (P_{coho}) was greater than 0.5 and predicted to have been constructed by a Chinook salmon if P_{coho} was less than 0.5. Equation 16.1 was applied to Boyes and Streelow creeks and when water year day was the only available variable. Equation 16.2 was used when time and redd measurements were available.

Data Source		$P_{coho} = 1/(1 + e^{-x})$ where $x =$	Sample Size n(Chinook); n(coho)	Association of Predicted Probabilities and Observed Responses		AIC	Equation
Season(s)	Reaches			Percent Concordant	Percent Tied		
1998/1999 - 2003/2004	Study Area	$-14.03 + 0.15 \cdot t$	345; 265	93.3	1.0	368.60	17.1
2002/2003 - 2003/2004	Mainstem	$-48.52 + 0.45 \cdot t + 0.00055 \cdot u + 0.10 \cdot a + 21.62 \cdot d - 0.39 \cdot r$	31; 20	98.7	0.0	25.15	17.2a
2002/2003 - 2003/2004	Mainstem	$-50.93 + 0.46 \cdot t + 0.00051 \cdot u + 0.51 \cdot a + 50.21 \cdot d - 4.38 \cdot a \cdot d - 0.58 \cdot r$	31; 20	99.2	0.0	24.92	17.2b
2002/2003 - 2003/2004	Mainstem	$-47.74 + 0.44 \cdot t + 0.00056 \cdot u + 0.21 \cdot p + 22.42 \cdot d - 0.38 \cdot r$	31; 20	98.7	0.0	25.03	17.2c
2002/2003 - 2003/2004	Mainstem	$-49.75 + 0.45 \cdot t + 0.00060 \cdot u - 0.017 \cdot a \cdot p + 23.86 \cdot d - 0.39 \cdot r$	31; 20	98.9	0.0	24.87	17.2d
2002/2003 - 2003/2004	Mainstem	$-46.91 + 0.42 \cdot t + 0.00055 \cdot u - 0.052 \cdot a + 22.64 \cdot d + 0.26 \cdot p - 0.34 \cdot r$	31; 20	98.7	0.0	27.02	17.2e
2002/2003 - 2003/2004	Mainstem	$-54.30 + 0.50 \cdot t + 0.00044 \cdot u + 0.064 \cdot a + 56.87 \cdot d - 5.10 \cdot a \cdot d - 0.32 \cdot p - 0.51 \cdot r$	31; 20	99.4	0.0	26.77	17.2f
2002/2003 - 2003/2004	Mainstem	$-48.88 + 0.45 \cdot t + 0.00050 \cdot u - 0.32 \cdot a + 29.12 \cdot d + 0.43 \cdot p + 0.067 \cdot a \cdot p - 0.012 \cdot r$	31; 20	99.0	0.0	28.52	17.2g
2002/2003 - 2003/2004	Mainstem	$-46.17 + 0.43 \cdot t + 0.00026 \cdot u + 0.93 \cdot a + 48.17 \cdot d - 11.93 \cdot d \cdot p - 0.19 \cdot r$	31; 20	99.0	0.0	25.45	17.2h
2002/2003 - 2003/2004	Mainstem	$-58.09 + 0.53 \cdot t + 0.00048 \cdot u + 1.07 \cdot a + 60.96 \cdot d - 6.29 \cdot a \cdot d - 0.24 \cdot p - 0.036 \cdot a \cdot p - 0.84 \cdot r$	31; 20	99.2	0.0	28.72	17.2i

Table 11. One redd per female spawner estimates of Chinook and coho salmon and redd-area method estimates of coho salmon in the Prairie Creek Study Area, Humboldt County, California, 1998/1999 to 2003/2004.

Season	Reach	Method		
		One Redd per Female		Redd Area
		Chinook	Coho	Coho
1998/1999	Mainstem	337	42	34
	Study Area	342	88	73
1999/2000	Mainstem	377	65	57
	Study Area	382	75	63
2000/2001	Mainstem	330	441	327
	Study Area	339	568	394
2001/2002	Mainstem	329	712	637
	Study Area	344	945	833
2002/2003	Mainstem	30	261	126
	Study Area	32	339	164
2003/2004	Mainstem	356	233	147
	Study Area	360	276	166

Escapement Estimate Comparison

Different methods for estimating escapement of Chinook and coho salmon yielded a range of escapement values, but the trends mimicked each other over the six-year period. For Chinook salmon, highest escapement estimates were from the live fish area-under-the-curve method most years (Table 7). For coho salmon, highest escapement estimates were obtained from redd counts most years (Table 11). As expected, the one-redd-per female method yielded higher estimates for coho salmon than redd-area method. Area-under-the-curve and redd estimates yielded similar trends for both species. A linear regression of area-under-the-curve estimates against one-redd-per-female estimates for Chinook salmon in Mainstem Prairie Creek only yielded an R^2 value of 0.4789 (Figure 10). However, when only Upper Prairie Creek was considered, the relationship greatly improved ($R^2 = 0.9145$). A linear regression of area-under-the-curve estimates against one-redd-per-female estimates and redd-area estimates in coho salmon yielded R^2 values of 0.7492 and 0.6922, respectively (Figure 11). Estimates based on carcass mark-recapture methods yielded estimates inconsistent with the live fish and redd methods for both species. Statistical comparisons of carcass mark-recapture estimates with other methods were not implemented due to small sample size.

Escapement-Recruitment Relationships

The relationship between Chinook salmon escapement estimates and downstream migrant catches the following spring was evaluated for Mainstem Prairie Creek for five spawning seasons from 1998/1999 to 2003/2004 (Appendix L). Boyes and StreeLOW

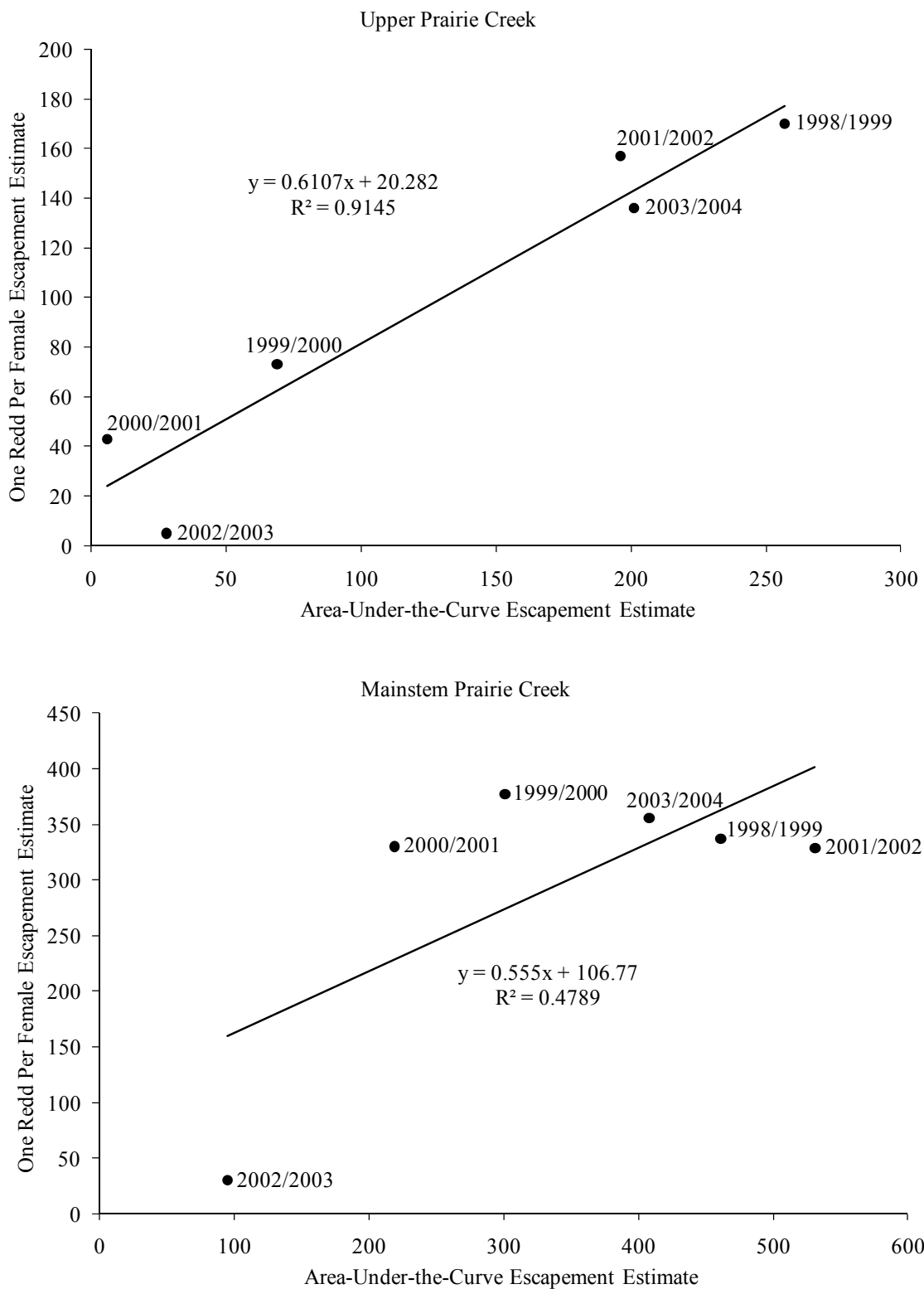


Figure 10. Relationships between area-under-the-curve escapement estimates and one-redd-per-female escapement estimates for Chinook salmon in Upper Prairie Creek and the entire surveyed mainstem Prairie Creek, Humboldt County, California.

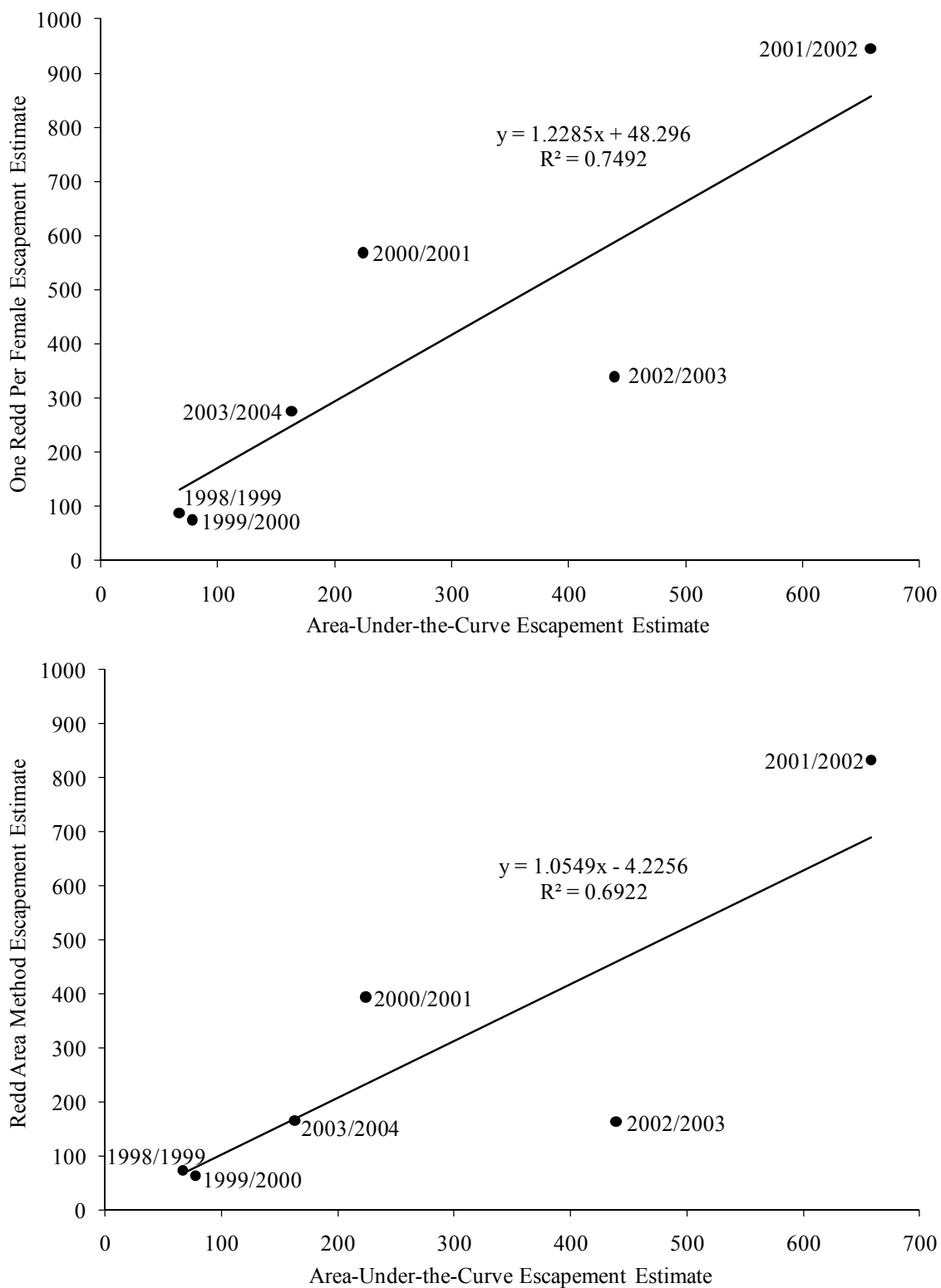


Figure 11. Relationships between area-under-the-curve escapement estimates and both methods of redd escapement estimation for coho salmon in the Prairie Creek Study Area, Humboldt County, California.

creeks were omitted from this analysis because they were seldom used by Chinook salmon. Only three live Chinook salmon in Boyes Creek and seven in Streelow Creek were observed over six years of the study. The lower Prairie Creek outmigrant trap was located at the downstream end of Prairie Creek Reach 1 and, therefore, downstream of the Boyes Creek confluence. The Boyes Creek outmigrant trap captured between 0.0 and 8.6% (mean = 2.7%) of the catch of the lower Prairie Creek trap. Therefore, juvenile Chinook salmon contribution from Boyes Creek into Prairie Creek was considered negligible. The area-under-the-curve escapement estimate method proved to be most closely correlated with downstream migrant catch ($R^2 = 0.3780$) for Chinook salmon in Prairie Creek (Figure 12). The linear relationship between adult escapement estimates based on one redd per female and downstream migrant catches had an R^2 value of only 0.0258. This relationship improved to $R^2 = 0.4411$ when only Upper Prairie Creek was considered.

During the 2002/2003 season, spawning surveys were inhibited by storm events in December 2002. As a result, escapement estimates of Chinook salmon were negatively affected. The fit of the adult (area-under-the-curve escapement, E_{AUC})-juvenile (outmigrant catch, YOY) relationship improved substantially ($R^2 = 0.9721$) when the 2002/2003 data are omitted, yielding a re-estimated

$$YOY = -79678 + 378.83 \cdot \hat{E}_{AUC} . \quad (\text{Equation 18})$$

The relationship between coho salmon escapement estimates and age young-of-the-year coho salmon population estimates were examined independently for Upper Prairie, Boyes, and Streelow creeks (Figure 13, 14, 15, Appendix M). Juvenile population estimate surveys were not conducted on Middle Prairie Creek.

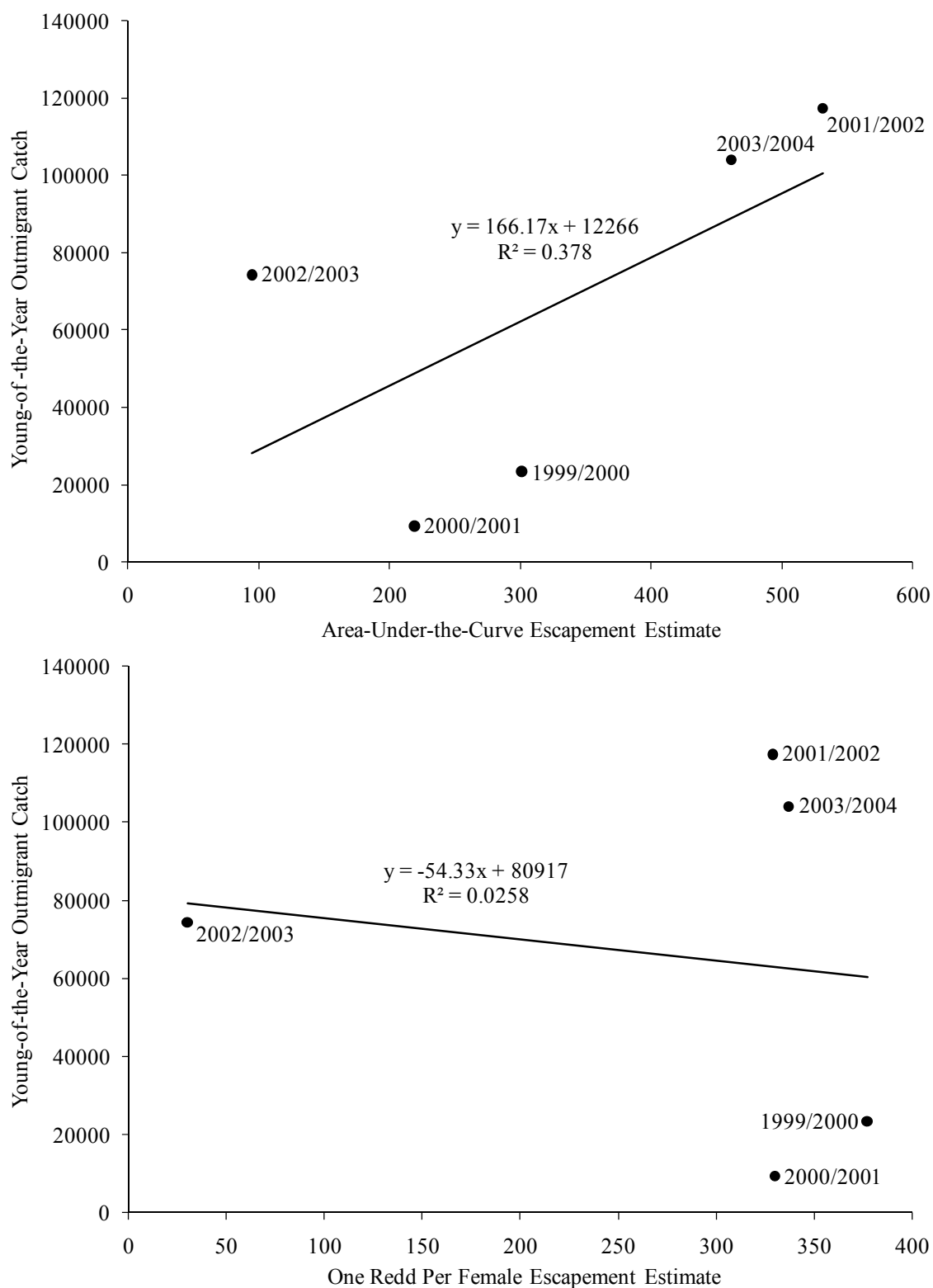


Figure 12. Relationships between young-of-the-year population outmigrant catches and escapement estimates from the corresponding spawning season for Chinook salmon in Mainstem Prairie Creek, Humboldt County, California. Five spawning seasons, 1998/1999 to 2002/2003, were available.

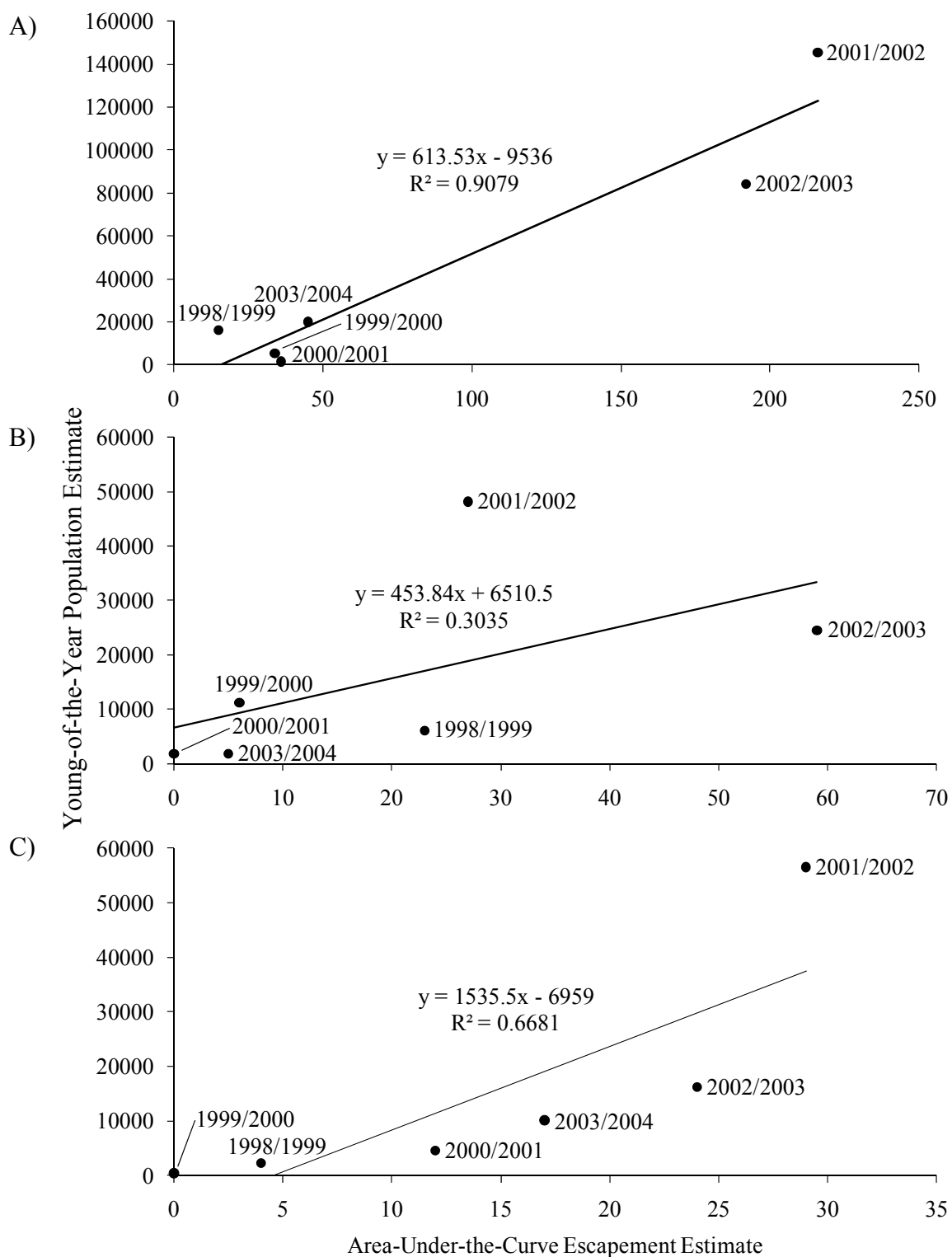


Figure 13. Relationships between young-of-the-year population estimates and area-under-the-curve live fish estimates from the corresponding spawning season for coho salmon in A) Upper Prairie, B) Streelow, and C) Boyes creeks, Humboldt County, California.

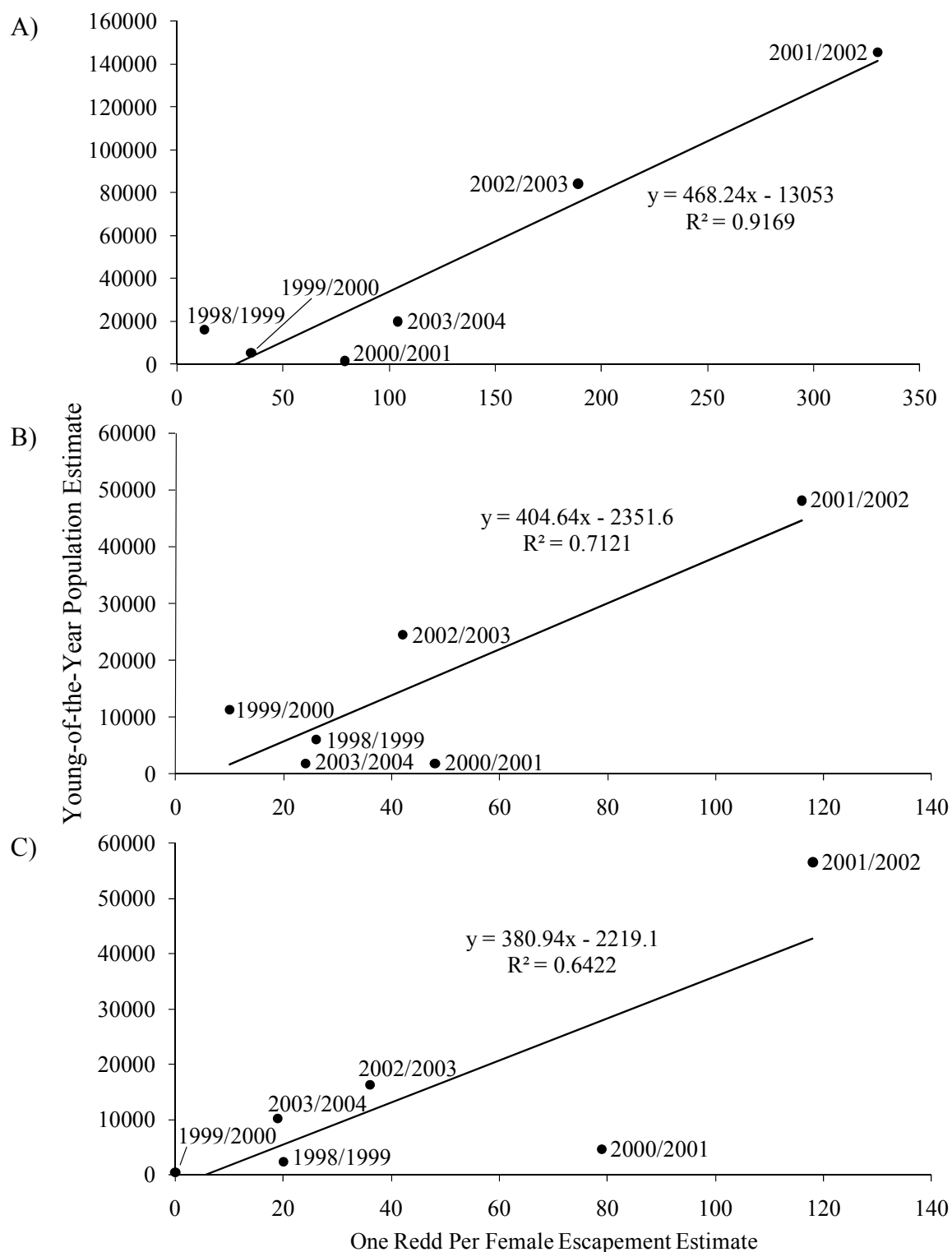


Figure 14. Relationships between young-of-the-year population estimates and one redd per female escapement estimates from the corresponding spawning season for coho salmon in A) Upper Prairie, B) Streeflow, and C) Boyes creeks, Humboldt County, California.

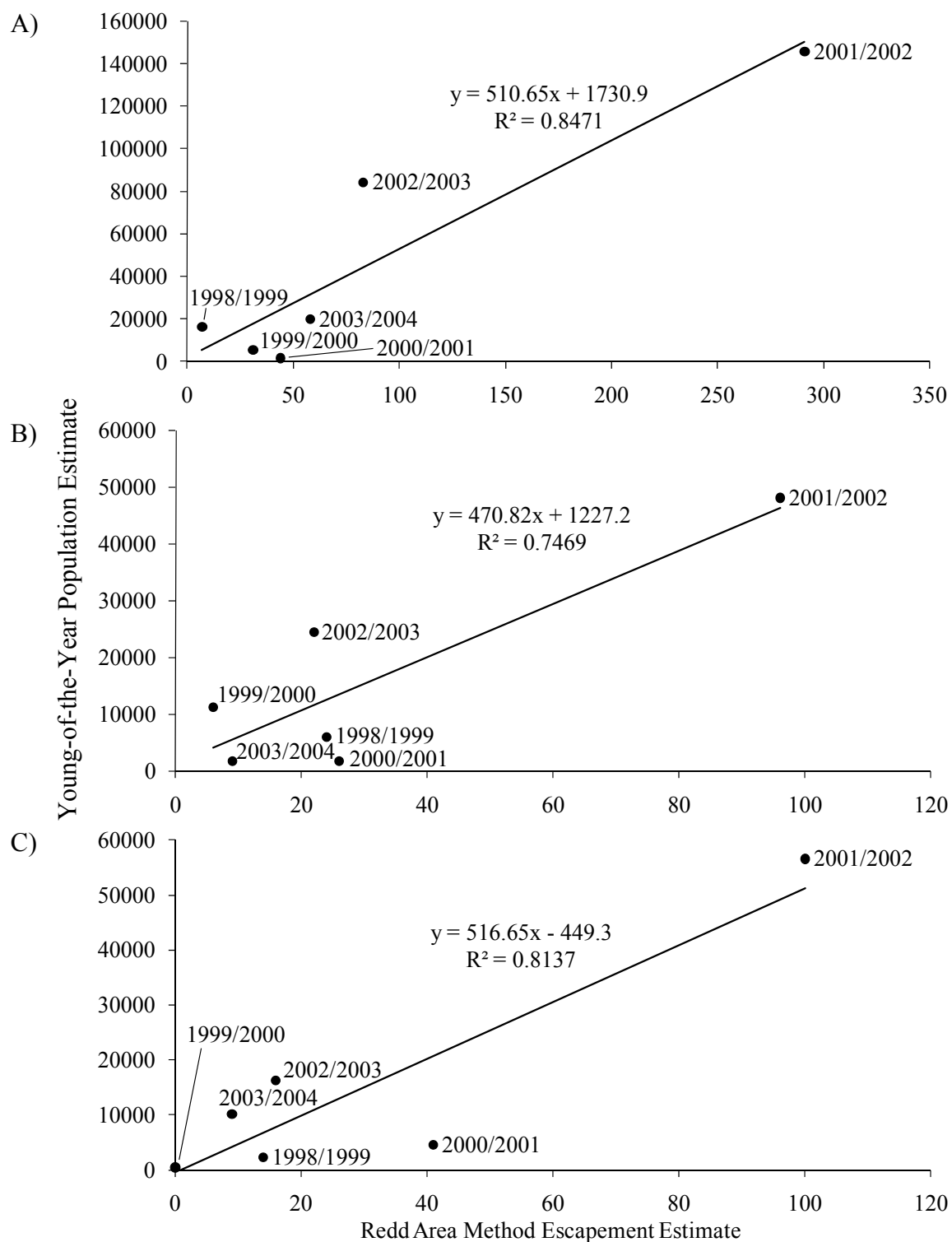


Figure 15. Relationships between young-of-the-year population estimates and redd area method escapement estimates from the corresponding spawning season for coho salmon in Upper Prairie, Boyes, and Streeflow creeks, Humboldt County, California.

DISCUSSION

Live fish area-under-the-curve is supported by the literature as being the preferred method for estimating escapement when counting fences or weirs, the ability to tag live fish, and adequate redd survey conditions are unavailable (Hilborn et al. 1999). Although Prairie Creek usually offers sufficient redd survey conditions, area-under-the-curve was assumed to produce more reliable escapement estimates than methods based on carcass or redd counts. Therefore escapement and recruitment relationships were evaluated using area-under-the-curve estimates as a standard to compare against. Carcass- and redd-based estimates contain more sources of error and bias. The downfalls of these alternate survey methods as they pertain to Prairie Creek are described below.

Live fish area-under-the-curve and redd count based estimates of Chinook and coho salmon escapement were similar in trend over the six seasons. However, no one method consistently over- or underestimated escapement in comparison to other methods. This may be due to observer variation or different flow regimes favoring observation efficiency for some methods over others. Variation in Chinook salmon estimates were much less when only Upper Prairie Creek was considered than the surveyed main stem. This may be due to the fact that Middle Prairie Creek is generally deeper, making live fish harder to observe and often less regularly surveyed during some flow regimes.

Total redd counts may vary widely among observers, flow conditions, and redd characteristics. Redds may be undercounted as a result of scouring, poor visibility, superimposition, or actual redds misidentified as tests. Redds may be over-counted by misidentifying natural geomorphologic features as redds and misidentifying dig tests as

actual redds. Dunham et al.'s (2001) observer counts ranged from 23% to 254% of the best estimates of actual redd numbers. Factors believed to contribute to errors in redd counts are typically those which affect visibility and identification of redds (Dunham et al. 2001). Redd size, age, density, superimposition, distance to cover, water depth, and substrate composition all may influence observer recognition of redds. Common redd survey counting errors will need to be identified and either remedied or reduced if redd counts are to be used for long term population monitoring (Maxell 1999).

Estimates based on carcass mark-recapture in Prairie Creek likely yielded the least reliable estimates of the methods considered. Carcass mark-recapture methodologies are designed for larger rivers with higher spawner numbers and are not as reliable in smaller streams with smaller run sizes. Prairie Creek discharges flashy flows and Redwood National Park contains plenty of scavenging wildlife. Many fresh carcasses are never encountered since they are either flushed downstream by fluctuations in discharge or removed from the system by scavengers. Low carcass numbers coupled with low carcass retention, as a direct relation to flow and inverse relation to scavenging (Riggers et al. 1999), are sources of bias. Carcass mark-recapture expansions magnified by lowered recapture rates produce overestimates of escapement. Increasing the frequency with which surveys are conducted may partially counteract the impact of flow and scavenging on carcass-based escapement estimates (Riggers et al. 1999). Riggers et al. (1999) suggested optimum intervals of three days to five days. Carcasses not immediately removed often remain in the system until fully decayed. These carcasses are either in areas where flows do not affect their location or not chosen by scavengers since fresher carcasses are available. The result of these activities is a low initial encounter rate

and a high recapture rate that, in turn, should contribute to an underestimate of escapement.

Carcass-based estimates were only available for three survey years but displayed greater variation in trend and magnitude to other methods, particularly for Chinook salmon. Whereas escapement estimates based on live fish observations and redd counts displayed similar patterns, estimates based on carcass mark-recapture did not necessarily mimic these other estimates. Jolly-Seber and Petersen estimates were, however, similar to each other with the Petersen method tending to produce slightly higher estimates. The sample size was not sufficient to statistically test carcass mark-recapture estimates against estimates from other methods. Results from future carcass surveys on Prairie Creek should be appended to obtain an adequate comparison.

Measures of uncertainty are often not applied to area-under-the-curve-based estimates of escapement (Hilborn et al. 1999). Parken et al. (2003) described procedures to calculate confidence intervals for area-under-the-curve escapement estimates following the trapezoidal method that include four common factors associated with uncertainty: fish counts, the shape of the spawner curve, observer efficiency, and residence time. Observer efficiency and residence time information necessary for the calculations of confidence intervals for area-under-the-curve estimates were not available for this study. Applying correction factors that account for spatial and temporal variability in biological factors, physical factors, and survey conditions to annual estimates of residence time and observer efficiency could significantly strengthen area-under-the-curve estimates (English et al. 1992, Bue et al. 1998). Such correction factors were not developed or applied in this study. Korman et al. (2002) found spawner distribution to influence

observer efficiency. However, spawner density each season remained relatively low (maximum = 72.3 total live salmon observed over the season per km in 2001/2002) in the Prairie Creek study area. Therefore, the assumption of constant observation probability was justified. Fluctuation in visibility was a much more pertinent potential source for variable observer efficiency in this water system. Prairie Creek discharges flashy flows during the time period when salmon spawn. Surveys were conducted between hydrograph spikes and when visibility was optimal to maximize consistency in observer efficiency. Previous studies have shown that uncertainty in escapement estimates increased with the time between surveys and the number of pulses of fish into the system (Hill 1997, Bue et al. 1998). Bue et al. (1998) concluded that accuracy deteriorated when the time interval between surveys exceeded seven days. Surveys in Prairie Creek for my project were surveyed at intervals of less than seven days when possible. Weather induced declines in visibility or ability to walk along the creek occasionally prolonged intervals. Regardless of the time elapsed between surveys, the shape of the standard area-under-the-curve spawner curve was linearly interpolated between survey-specific estimates.

Previous studies found that water depth, water velocity, stream gradient, substrate, and redd size were significant in separating redds of salmonids (Fukushima and Smoker 1998, Zimmerman and Reeves 2000, Gallagher and Gallagher 2005). On Prairie Creek, spawning time proved to be the most important parameter in distinguishing coho from Chinook salmon redds. The remaining seven parameters considered contained considerable overlap between Chinook and coho salmon. The limited value of substrate in separating redds may be influenced by periodic high flows after spawning that change

substrate composition from that which the fish selected for nest construction (McNeil and Ahnell 1964). Water depth and velocity were not measured or recorded for this project because of frequent variations of flow in Prairie Creek. Water depth and velocity at the time redds were encountered are not necessarily the same as when they were constructed. Stream gradient was not considered for this study since there is little variation throughout the study area.

Chinook and coho salmon redds in Prairie Creek were distinguished with less error (approximately one percent when time and physical measurements are used; 5.7% when time was the only variable used) than past studies discriminating between salmonid redds. Fukushima and Smoker (1998) discriminated sockeye and pink salmon redds with an error rate of 33%. Zimmerman and Reeves (2000) differentiated anadromous and resident steelhead redds with an error rate greater than 28%. Gallagher and Gallagher (2005) differentiated Chinook and coho salmon redds with an error rate of 5.9%.

The model used to distinguish between Chinook and coho salmon redds should be recognized as specific to Prairie Creek. Spawning areas suitable for salmon spawning are similar throughout this stream with regard to substrate size. A wider variety of spawning substrate may allow Chinook salmon to dig redds in areas of larger substrate than coho salmon. Most of Prairie Creek is also relatively narrow. Therefore stream width may be a factor determining redd size. Differences in the parameters considered may be greater between Chinook and coho salmon redds in streams where areas suitable for spawning are not limited in size or accessibility.

Catch of young-of-the-year Chinook salmon outmigrants showed a better linear correlation with area-under-the-curve than with one redd per female escapement

estimates. Coho salmon young-of-the-year estimates demonstrated similar relationships to area-under-the-curve ($R^2 = 0.3035$ to 0.9079) compared to redd-based escapement estimates ($R^2 = 0.6422$ to 0.9169). These results are only partially in agreement with Beland's (1996) conclusion "that redd counts can be used to predict the future abundance of parr when direct estimates of the numbers of spawners are unavailable and the level of egg deposition is unlikely to result in density-dependent mortality". Past studies also found significant linear and logarithmic relationships between numbers of young-of-the-year fish and redd counts in the previous year and age-1 parr and redd counts obtained two years earlier for Atlantic salmon (*Salmo salar*) and brown trout (*Salmo trutta*) (Beard and Carline 1991; Semple et al. 1994; Beland et al. 1996). Although density-dependent superimposition may occasionally be a factor, I also attribute any poor relationship between redds and recruits to inaccurate redd counts due to occasional poor visibility and redds being scoured beyond recognition. This claim is supported by the marked improvement in the redd-based estimate to recruitment relationship for Chinook salmon when the spatial scale used was reduced from the entire surveyed mainstem Prairie Creek to only the upper reaches. Upper Prairie Creek often offered better survey conditions. Salmonid spawner-recruitment relationships may have also been complicated by abiotic and density dependent factors (Frenette et al. 1984, Seelbach 1987, Gibson and Myers 1988, Clark 1992).

After the completion of data collection for this study, a weir was installed near the entrance to the Prairie Creek study area. Accuracy and precision of the escapement estimation methods addressed in this study will be better understood when compared with weir-based estimates. Continuing surveys on Prairie Creek will provide a larger data set

for which to base escapement method comparisons and spawner-recruitment relationships. Particularly valuable would be sufficient data to fit a Ricker spawner-recruitment curve. Adding to the redd parameter data set with continued surveys could also fortify the redd species logistic regression model with larger sample sizes.

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Appendix A. Observed and predicted live Chinook and coho salmon by season and reach in the Prairie Creek Study Area, Humboldt County, California. Predictions are based on logistic regression analysis.

Season	Reach	Chinook Salmon			Coho Salmon		
		Observed	Predicted	Total	Observed	Predicted	Total
1998/1999	Prairie Creek						
	Reach 1	90	11	101	9	2	11
	Reach 2	84	4	88	17	0	17
	Reach 3	140	7	147	17	1	18
	Reach 4	149	7	156	1	0	1
	Streelow Creek	0	0	0	22	5	27
	Boyes Creek	0	0	0	7	0	7
1999/2000	Prairie Creek						
	Reach 1	121	25	146	16	6	22
	Reach 2	110	20	130	6	3	9
	Reach 3	67	12	79	20	4	24
	Reach 4	6	3	9	9	1	10
	Streelow Creek	3	1	4	3	0	3
	Boyes Creek	0	1	1	0	0	0
2000/2001	Prairie Creek						
	Reach 1	141	8	149	103	11	114
	Reach 2	122	10	132	101	6	107
	Reach 3	5	2	7	35	2	37
	Reach 4	0	0	0	4	6	10
	Streelow Creek	0	2	2	0	0	0
	Boyes Creek	0	1	1	11	1	12
2001/2002	Prairie Creek						
	Reach 1	91	8	99	169	38	207
	Reach 2	117	7	124	104	10	114
	Reach 3	152	9	161	166	11	177
	Reach 4	13	2	15	75	0	75
	Streelow Creek	0	0	0	39	0	39
	Boyes Creek	0	0	0	36	2	38
2002/2003	Prairie Creek						
	Reach 1	26	3	29	39	4	43
	Reach 2	6	0	6	35	2	37
	Reach 3	16	0	16	76	2	78
	Reach 4	3	0	3	67	2	69
	Streelow Creek	0	0	0	47	1	48
	Boyes Creek	3	0	3	13	1	14
2003/2004	Prairie Creek						
	Reach 1	87	12	99	47	3	50
	Reach 2	127	24	151	36	6	42
	Reach 3	165	2	167	27	2	29
	Reach 4	80	2	82	22	2	24
	Streelow Creek	4	1	5	4	1	5
	Boyes Creek	0	1	1	15	1	16

Appendix B. Live Chinook salmon data used to calculate area-under-the-curve escapement estimates. Sample periods listed were used for estimates for the Prairie Creek Study Area, Humboldt County, California. Sample periods were modified for calculating estimates for individual reaches, Middle Prairie Creek, Upper Prairie Creek, and the entire surveyed mainstem Prairie Creek.

Year	Sample Period		Reach				StreeLOW Creek	Boyes Creek
			Prairie Creek					
	Number	Dates	Reach 1	Reach 2	Reach 3	Reach 4		
1998 - 1999	1	Nov 20	0	0	0	0	0	0
	2	Nov 21 - Dec 1	-	-	39	37	-	-
	3	Dec 2 - Dec 10	20	31	32	60	0	-
	4	Dec 11 - Dec 18	23	25	50	44	-	-
	5	Dec 19 - Dec 22	-	-	14	10	0	0
	6	Dec 23 - Dec 30	29	15	8	5	0	0
	7	Dec 31 - Jan 6	29	17	2	0	0	0
	8	Jan 7 - Jan 13	0	0	2	0	0	0
	9	Jan 14 - Jan 16	0	0	0	0	0	0
1999 - 2000	1	Nov 15	0	0	0	0	0	0
	2	Nov 16 - Nov 22	3	2	0	0	-	-
	3	Nov 23 - Dec 3	8	1	7	3	0	1
	4	Dec 4 - Dec 10	31	7	5	2	1	0
	5	Dec 11 - Dec 16	21	60	28	1	1	0
	6	Dec 17 - Dec 23	41	47	27	1	-	0
	7	Dec 24 - Dec 30	27	10	5	0	0	0
	8	Dec 31 - Jan 7	13	2	1	0	-	0
	9	Jan 8 - Jan 21	-	0	4	2	-	-
	10	Jan 22 - Jan 28	-	1	1	0	2	-
	11	Jan 29 - Feb 4	1	0	0	0	0	0
	12	Feb 5 - Feb 11	1	0	0	0	0	0
	13	Feb 12 - Feb 18	-	-	0	0	-	-
	14	Feb 19 - Feb 25	0	0	0	0	0	0
2000 - 2001	1	Nov 22	0	0	0	0	0	0
	2	Nov 23 - Dec 1	0	0	2	0	2	-
	3	Dec 2 - Dec 8	6	1	0	0	0	0
	4	Dec 9 - Dec 15	9	0	0	0	-	-
	5	Dec 16 - Dec 21	54	38	5	0	0	1
	6	Dec 22 - Dec 29	48	40	0	0	0	0
	7	Dec 30 - Jan 5	19	32	0	0	0	0
	8	Jan 6 - Jan 13	2	10	0	0	0	0
	9	Jan 14 - Jan 18	7	6	0	0	0	0
	10	Jan 19 - Jan 24	2	2	0	0	-	-
	11	Jan 25 - Feb 2	2	3	0	0	0	0
	12	Feb 3 - Feb 7	0	0	0	0	0	0

Appendix B. Live Chinook salmon data used to calculate area-under-the-curve escapement estimates. Sample periods listed were used for estimates for the Prairie Creek Study Area, Humboldt County, California. Sample periods were modified for calculating estimates for individual reaches, Middle Prairie Creek, Upper Prairie Creek, and the entire surveyed mainstem Prairie Creek (continued).

Year	Sample Period		Reach				StreeLOW Creek	Boyes Creek
			Prairie Creek					
	Number	Dates	Reach 1	Reach 2	Reach 3	Reach 4		
2001 - 2002	1	Nov 15	0	0	0	0	0	0
	2	Nov 16 - 20	1	-	-	-	-	-
	3	Nov 21 - Nov 27	13	21	-	-	-	-
	4	Nov 28 - Dec 4	-	-	35	3	-	-
	5	Dec 5 - Dec 13	53	-	65	-	0	0
	6	Dec 14 - Dec 22	-	64	45	12	-	-
	7	Dec 23 - Dec 27	19	31	14	-	-	0
	8	Dec 28 - Jan 5	-	-	-	0	0	0
	9	Jan 6 - Jan 12	9	6	2	0	0	0
	10	Jan 13 - Jan 17	2	0	0	0	0	0
	11	Jan 18 - Jan 24	0	1	0	0	0	0
	12	Jan 25 - Jan 30	1	1	0	0	0	0
	13	Jan 31 - Feb 6	0	0	0	0	0	0
	14	Feb 7 - Feb 13	1	0	0	0	0	0
	15	Feb 14 - Feb 19	0	0	0	0	0	0
2002 - 2003	1	Dec 9	0	0	0	0	0	0
	2	Dec 10 - Dec 12	10	-	-	-	-	-
	3	Dec 13 - Jan 3	-	-	13	2	0	-
	4	Jan 4 - Jan 8	19	4	3	1	0	3
	5	Jan 9 - Jan 17	-	1	-	0	0	-
	6	Jan 18 - Jan 25	0	0	0	0	0	0
	7	Jan 26 - Jan 30	-	1	0	0	-	-
	8	Jan 31 - Feb 8	0	0	0	0	0	0
2003 - 2004	1	Nov 21	0	0	0	0	0	0
	2	Nov 22 - Dec 4	2	0	0	0	-	-
	3	Dec 5 - Dec 11	26	43	-	-	0	0
	4	Dec 12 - Dec 18	46	51	79	38	2	0
	5	Dec 19 - Dec 22	19	50	68	39	2	1
	6	Dec 23 - Dec 28	-	-	18	4	-	-
	7	Dec 29 - Jan 11	3	4	2	1	1	0
	8	Jan 12 - Jan 15	1	2	0	0	0	0
	9	Jan 16 - Jan 18	2	1	0	-	0	0
	10	Jan 19 - Jan 26	0	0	0	0	0	0

Appendix C. Live coho salmon data used to calculate area-under-the-curve escapement estimates. Sample periods listed were used for estimates for the Prairie Creek Study Area, Humboldt County, California. Sample periods were modified for calculating estimates for individual reaches, Middle Prairie Creek, Upper Prairie Creek, and the entire surveyed mainstem Prairie Creek.

Year	Sample Period		Reach				Steelelow Creek	Boyes Creek
			Prairie Creek					
	Number	Dates	Reach 1	Reach 2	Reach 3	Reach 4		
1998 - 1999	1	Dec 1	0	0	0	0	0	0
	2	Dec 2 - Dec 10	0	0	3	1	0	-
	3	Dec 11 - Dec 18	1	4	6	0	-	-
	4	Dec 19 - Dec 22	-	-	2	0	0	0
	5	Dec 23 - Dec 30	4	5	1	0	0	0
	6	Dec 30 - Jan 6	7	8	3	0	2	0
	7	Jan 7 - Jan 13	0	0	3	0	5	0
	8	Jan 14 - Jan 16	-	-	0	-	-	-
	9	Jan 17 - Jan 23	0	0	0	0	14	-
	10	Jan 24 - Jan 27	0	0	0	0	3	2
	11	Jan 28 - Jan 29	-	-	0	0	-	4
	12	Jan 30 - Feb 3	0	0	0	0	0	1
	13	Feb 4 - Feb 13	0	0	0	0	0	0
	14	Feb 14 - Feb 17	-	0	0	0	2	-
	15	Feb 18 - Feb 22	-	-	0	0	1	-
	16	Feb 23 - Mar 5	0	0	0	0	0	0
1999 - 2000	1	Dec 10	0	0	0	0	0	0
	2	Dec 11 - Dec 16	0	1	3	0	0	0
	3	Dec 17 - Dec 23	4	0	1	1	-	0
	4	Dec 24 - Dec 30	8	0	4	0	0	0
	5	Dec 31 - Jan 7	4	0	1	0	-	0
	6	Jan 8 - Jan 21	-	2	9	7	-	-
	7	Jan 22 - Jan 28	-	4	6	2	3	-
	8	Jan 29 - Feb 4	4	0	0	0	0	0
	9	Feb 5 - Feb 11	2	1	0	0	0	0
	10	Feb 12 - Feb 18	-	-	0	0	-	-
	11	Feb 19 - Feb 25	0	0	0	0	0	0
2000 - 2001	1	Nov 22	0	0	0	0	0	0
	2	Nov 23 - Dec 1	0	0	1	0	0	-
	3	Dec 2 - Dec 8	0	0	1	0	0	0
	4	Dec 9 - Dec 15	0	0	1	2	-	-
	5	Dec 16 - Dec 21	5	5	1	2	0	0
	6	Dec 22 - Dec 29	10	9	0	0	0	0
	7	Dec 30 - Jan 5	7	11	0	0	0	0
	8	Jan 6 - Jan 13	0	22	9	4	0	5
	9	Jan 14 - Jan 18	23	14	3	0	0	3
	10	Jan 19 - Jan 24	11	11	0	0	-	-
	11	Jan 25 - Feb 2	7	8	10	0	0	2
	12	Feb 3 - Feb 7	10	5	4	0	0	1
	13	Feb 8 - Feb 14	20	9	6	2	0	1
	14	Feb 15 - Feb 21	5	6	0	-	-	-
	15	Feb 22 - Feb 28	8	0	1	0	-	0
	16	Mar 1 - Mar 7	1	2	0	0	0	0
	17	Mar 8 - Mar 14	2	2	-	-	0	0
	18	Mar 15 - Mar 23	0	2	-	-	0	-
	19	Mar 24 - Mar 28	0	0	0	0	0	0

Appendix C. Live coho salmon data used to calculate area-under-the-curve escapement estimates. Sample periods listed were used for estimates for the Prairie Creek Study Area, Humboldt County, California. Sample periods were modified for calculating estimates for individual reaches, Middle Prairie Creek, Upper Prairie Creek, and the entire surveyed mainstem Prairie Creek (continued).

Year	Sample Period		Reach				Stree low Creek	Boyes Creek
			Prairie Creek					
	Number	Dates	Reach 1	Reach 2	Reach 3	Reach 4		
2001 - 2002	1	Nov 20	0	0	0	0	0	0
	2	Nov 21 - Nov 27	0	1	-	-	-	-
	3	Nov 28 - Dec 4	-	-	8	7	-	-
	4	Dec 5 - Dec 13	18	-	18	-	0	0
	5	Dec 14 - Dec 22	-	61	17	1	-	-
	6	Dec 23 - Dec 27	15	22	19	-	-	0
	7	Dec 28 - Jan 5	-	-	-	11	0	0
	8	Jan 6 - Jan 12	53	15	36	20	26	7
	9	Jan 13 - Jan 17	73	3	37	3	6	0
	10	Jan 18 - Jan 24	31	5	14	8	4	17
	11	Jan 25 - Jan 30	4	1	12	14	0	13
	12	Jan 31	-	-	12	11	-	-
	13	Feb 1 - Feb 6	8	2	5	0	3	1
	14	Feb 7 - Feb 13	4	3	0	0	0	0
	15	Feb 14 - Feb 22	3	1	0	0	-	-
	16	Feb 23 - Feb 28	0	0	0	0	0	0
2002 - 2003	1	Dec 3	0	0	0	0	0	0
	2	Dec 4 - Dec 12	3	-	-	-	-	-
	3	Dec 13 - Jan 3	-	-	31	23	20	-
	4	Jan 4 - Jan 8	26	19	28	8	11	1
	5	Jan 9 - Jan 17	-	7	-	18	10	-
	6	Jan 18 - Jan 25	14	7	19	13	6	7
	7	Jan 26 - Jan 30	-	2	0	5	-	-
	8	Jan 31 - Feb 8	0	2	0	2	1	6
	9	Feb 9 - Feb 15	0	0	0	0	0	-
	10	Feb 16 - Feb 18	0	0	0	0	0	0
2003 - 2004	1	Dec 4	0	0	0	0	0	0
	2	Dec 5 - Dec 11	0	0	-	-	0	4
	3	Dec 12 - Dec 18	1	3	3	6	0	3
	4	Dec 19 - Dec 22	1	6	2	2	0	1
	5	Dec 23 - Dec 28	-	-	1	1	-	-
	6	Dec 29 - Jan 11	9	11	10	4	1	6
	7	Jan 12 - Jan 15	10	8	8	8	0	0
	8	Jan 16 - Jan 21	17	8	3	0	2	0
	9	Jan 22 - Jan 31	6	5	0	1	0	1
	10	Feb 1 - Feb 9	5	1	1	2	1	1
	11	Feb 10 - Feb 14	0	0	0	0	0	0
	12	Feb 15 - Feb 24	1	0	0	0	0	0
	13	Feb 25 - Mar 8	0	0	0	0	0	0

Appendix D. Area-under-the-curve estimates from live Chinook and coho salmon spawners observed in the Prairie Creek Study Area, Humboldt County, California, 1998/1999 to 2003/2004.

		Reach(es)									
		Prairie Creek									
Species	Season	Reach 1	Reach 2	Reach 3	Reach 4	Middle (Reaches 1, 2)	Upper (Reaches 3, 4)	Mainstem (Reaches 1-4)	Streelow Creek	Boyes Creek	Prairie Creek Study Area
Coho	1998/1999	10	16	15	1	25	15	41	23	4	67
	1999/2000	29	8	23	11	37	34	73	6	0	78
	2000/2001	92	86	29	8	178	36	211	0	12	224
	2001/2002	218	163	157	60	381	216	606	27	29	658
	2002/2003	87	54	107	78	153	192	352	59	24	439
	2003/2004	50	41	24	20	93	45	142	5	17	163
Chinook	1998/1999	101	102	117	134	200	257	461	0	0	466
	1999/2000	130	98	62	8	227	69	301	5	1	301
	2000/2001	118	104	6	0	222	6	219	2	1	221
	2001/2002	141	183	164	26	330	196	531	0	0	531
	2002/2003	56	10	24	4	67	28	95	0	7	106
	2003/2004	79	122	128	65	200	201	408	4	1	419

Appendix E. Observed and predicted Chinook and coho salmon carcasses by season and reach in the Prairie Creek Study Area, Humboldt County, California. Predictions are based on logistic regression analysis.

Season	Reach	Chinook Salmon			Coho Salmon		
		Observed	Predicted	Total	Observed	Predicted	Total
2001/2002	Prairie Creek						
	Reach 1	65	1	66	40	0	40
	Reach 2	51	0	51	16	0	16
	Reach 3	55	0	55	72	6	78
	Reach 4	9	2	11	35	2	37
	Streelw Creek	0	0	0	19	0	19
	Boyes Creek	0	0	0	29	0	29
2002/2003	Prairie Creek						
	Reach 1	46	0	46	20	3	23
	Reach 2	40	3	43	14	2	16
	Reach 3	55	1	56	19	3	22
	Reach 4	19	0	19	16	2	18
	Streelw Creek	1	0	1	8	0	8
	Boyes Creek	1	0	1	6	1	7
2003/2004	Prairie Creek						
	Reach 1	27	0	27	15	3	18
	Reach 2	35	1	36	10	0	10
	Reach 3	43	1	44	9	3	12
	Reach 4	18	0	18	5	0	5
	Streelw Creek	0	0	0	1	0	1
	Boyes Creek	1	0	1	7	0	7

Appendix F. Petersen and Jolly-Seber escapement estimates for Chinook salmon from carcass mark-recapture experiments in the Prairie Creek Study Area, Humboldt County, California, 2001/2002 to 2003/2004.

Season	Reach(es)	Petersen					Jolly-Seber
		Captured and Marked	Recaptured	Recapture Rate	Estimate	95% c.i. +/-	Estimate
2001/2002	Prairie Creek						
	Reach 1	66	43	65.15%	101	10	55
	Reach 2	51	33	64.71%	79	9	49
	Reach 3	55	46	83.64%	66	3	78
	Reach 4	11	10	90.91%	12	1	25
	Middle (Reaches 1, 2)	117	76	64.96%	180	14	104
	Upper (Reaches 3, 4)	66	56	84.85%	78	3	103
	Mainstem (Reaches 1-4)	183	132	72.13%	254	12	207
	Streelow Creek	0	0	-	0	-	0
	Boyes Creek	0	0	-	0	-	0
	Study Area	183	132	72.13%	254	12	224
2002/2003	Prairie Creek						
	Reach 1	46	7	15.22%	275	150	38
	Reach 2	43	25	58.14%	73	11	63
	Reach 3	56	36	64.29%	87	10	49
	Reach 4	19	11	57.89%	32	7	22
	Middle (Reaches 1, 2)	89	32	35.96%	244	52	101
	Upper (Reaches 3, 4)	75	47	62.67%	119	12	71
	Mainstem (Reaches 1-4)	164	79	48.17%	339	38	172
	Streelow Creek	1	0	0.00%	3	3	1
	Boyes Creek	1	0	0.00%	3	3	1
	Study Area	166	79	47.59%	348	40	167
2003/2004	Prairie Creek						
	Reach 1	26	14	53.85%	48	11	23
	Reach 2	36	19	52.78%	67	13	27
	Reach 3	43	29	67.44%	64	7	38
	Reach 4	18	11	61.11%	29	6	18
	Middle (Reaches 1, 2)	62	33	53.23%	116	18	50
	Upper (Reaches 3, 4)	61	40	65.57%	93	10	56
	Mainstem (Reaches 1-4)	123	73	59.35%	207	19	106
	Streelow Creek	0	0	-	0	-	0
	Boyes Creek	1	0	0.00%	3	3	1
	Study Area	124	73	58.87%	210	19	108

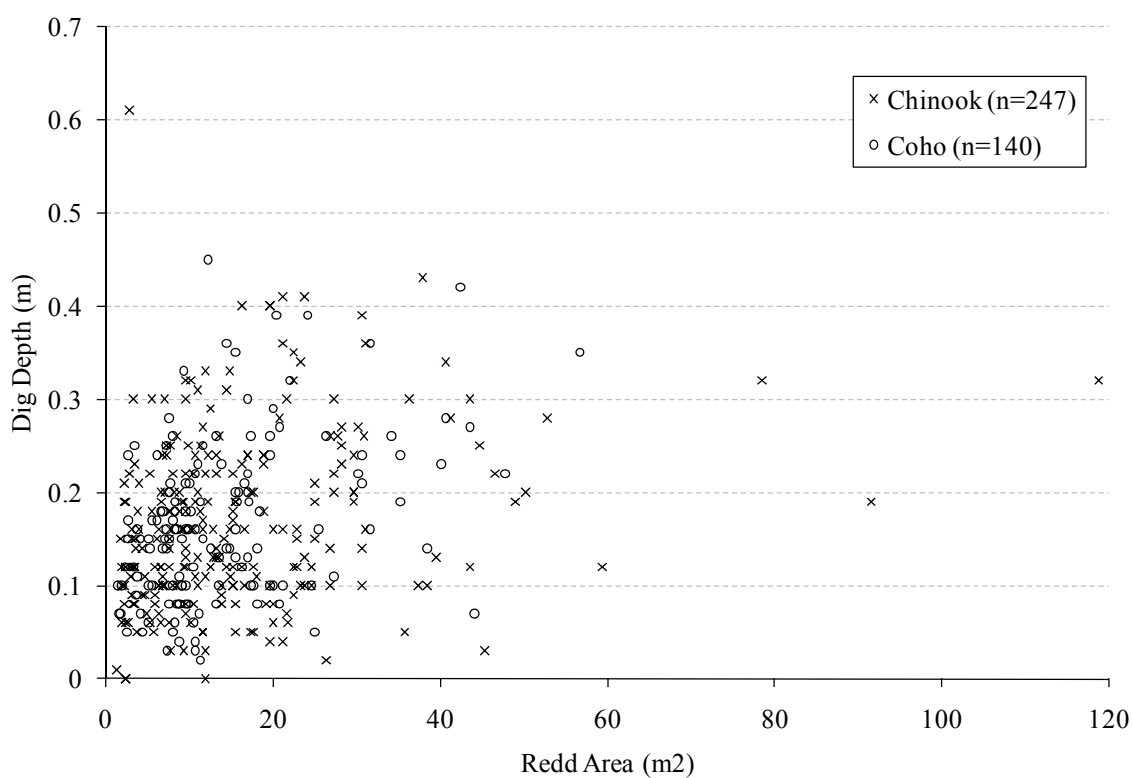
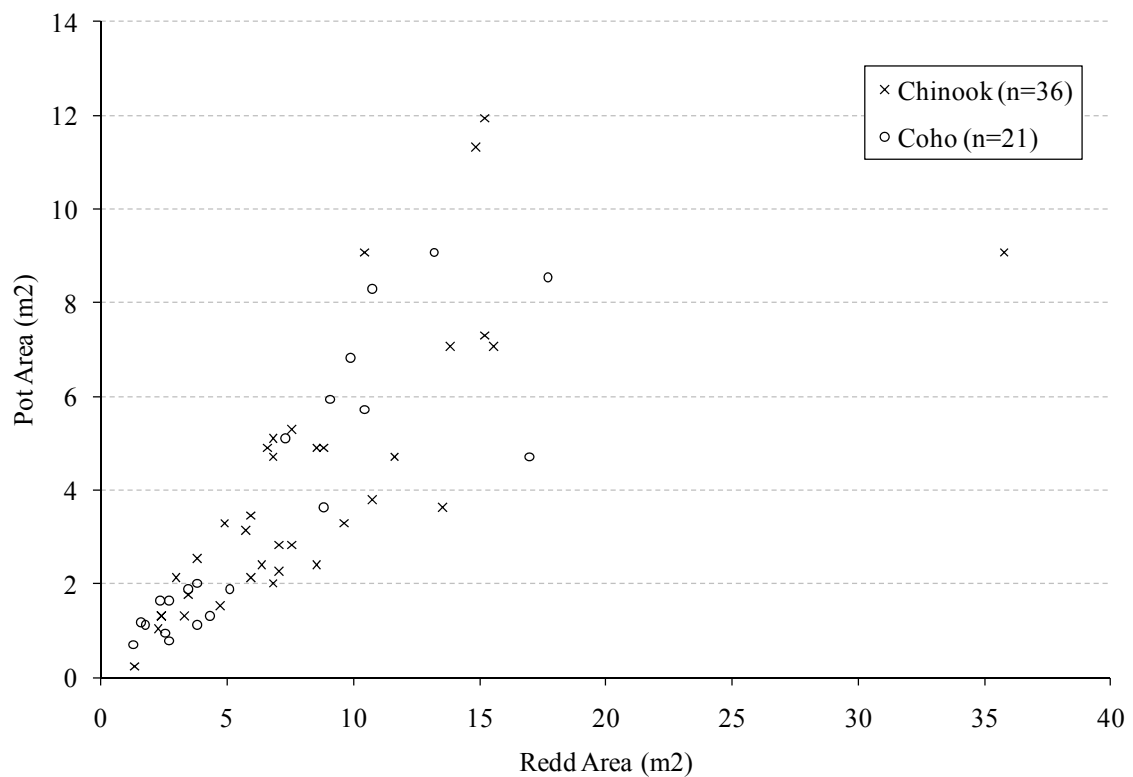
Appendix G. Petersen and Jolly-Seber escapement estimates for coho salmon from carcass mark-recapture experiments in the Prairie Creek Study Area, Humboldt County, California, 2001/2002 to 2003/2004.

Season	Reach(es)	Petersen					Jolly-Seber
		Captured and Marked	Recaptured	Recapture Rate (%)	Estimate	95% c.i. +/-	Estimate
2001/2002	Prairie Creek						
	Reach 1	40	25	62.50%	64	9	36
	Reach 2	16	11	68.75%	23	4	18
	Reach 3	80	55	68.75%	116	9	94
	Reach 4	37	25	67.57%	55	7	36
	Middle (Reaches 1, 2)	56	36	64.29%	87	10	54
	Upper (Reaches 3, 4)	117	80	68.38%	171	12	130
	Mainstem (Reaches 1-4)	173	116	67.05%	258	15	184
	Streelow Creek	20	9	45.00%	43	14	26
	Boyes Creek	29	12	41.38%	68	21	28
	Study Area	222	137	61.71%	359	23	238
2002/2003	Prairie Creek						
	Reach 1	23	7	30.43%	71	31	23
	Reach 2	16	4	25.00%	57	33	47
	Reach 3	22	10	45.45%	47	14	26
	Reach 4	18	12	66.67%	27	5	19
	Middle (Reaches 1, 2)	39	11	28.21%	132	51	70
	Upper (Reaches 3, 4)	40	22	55.00%	72	13	45
	Mainstem (Reaches 1-4)	79	33	41.77%	187	36	115
	Streelow Creek	8	1	12.50%	40	36	10
	Boyes Creek	7	1	14.29%	31	27	30
	Study Area	94	35	37.23%	250	50	155
2003/2004	Prairie Creek						
	Reach 1	18	6	33.33%	51	23	46
	Reach 2	10	3	30.00%	29	17	30
	Reach 3	12	4	33.33%	33	17	20
	Reach 4	5	2	40.00%	11	6	8
	Middle (Reaches 1, 2)	28	9	32.14%	83	33	78
	Upper (Reaches 3, 4)	17	6	35.29%	45	20	28
	Mainstem (Reaches 1-4)	45	15	33.33%	131	41	104
	Streelow Creek	1	0	0.00%	3	3	4
	Boyes Creek	7	0	0.00%	63	78	64
	Study Area	53	15	28.30%	181	61	147

Appendix H. Observed and predicted Chinook and coho salmon redds by season and reach in the Prairie Creek Study Area, Humboldt County, California. Predictions are based on logistic regression analysis.

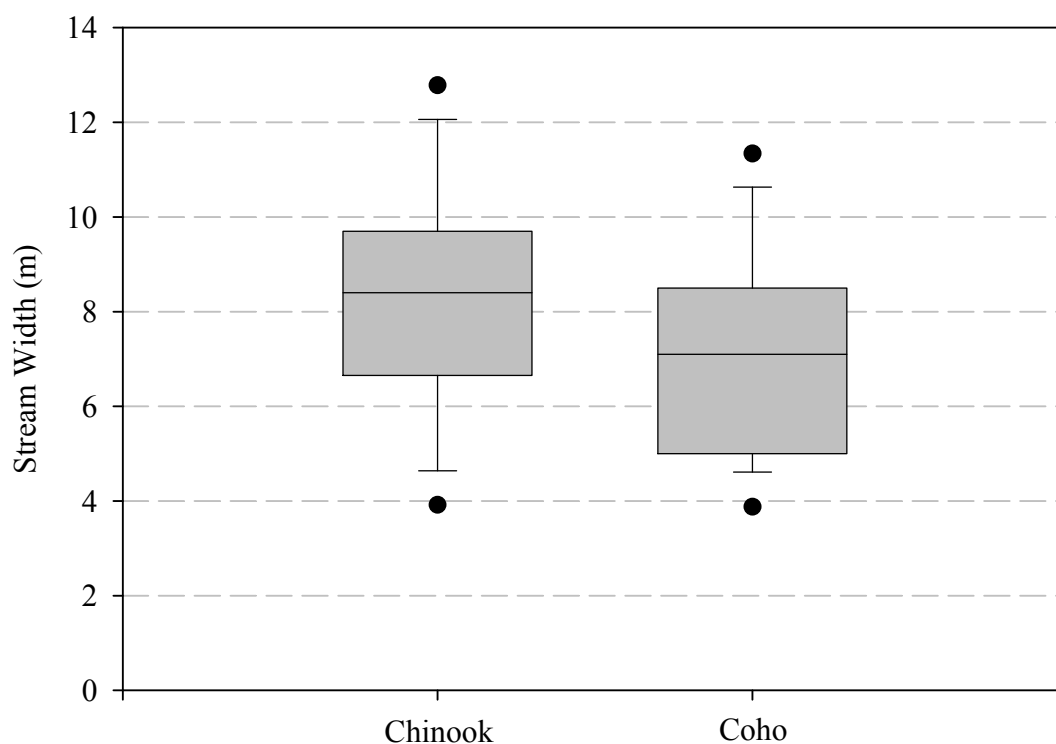
Season	Reach	Coho Salmon			Chinook Salmon		
		Observed	Predicted	Total	Observed	Predicted	Total
1998/999	Prairie Creek						
	Reach 1	1	2	3	22	25	47
	Reach 2	1	9	10	18	24	42
	Reach 3	2	2	4	21	29	50
	Reach 4	0	2	2	23	18	41
	Streelow Creek	8	4	12	0	3	3
	Boyes Creek	6	3	9	0	0	0
1999/2000	Prairie Creek						
	Reach 1	0	5	5	20	53	73
	Reach 2	0	7	7	19	29	48
	Reach 3	5	5	10	13	15	28
	Reach 4	2	2	4	0	1	1
	Streelow Creek	1	3	4	1	1	2
	Boyes Creek	0	0	0	0	0	0
2000/2001	Prairie Creek						
	Reach 1	13	58	71	24	86	110
	Reach 2	7	28	35	12	25	37
	Reach 3	4	12	16	1	14	15
	Reach 4	1	6	7	0	7	7
	Streelow Creek	0	14	14	0	0	0
	Boyes Creek	7	16	23	0	5	5
2001/2002	Prairie Creek						
	Reach 1	31	78	109	13	18	31
	Reach 2	22	51	73	25	27	52
	Reach 3	26	49	75	32	38	70
	Reach 4	23	59	82	3	3	6
	Streelow Creek	19	36	55	0	7	7
	Boyes Creek	16	40	56	0	0	0
2002/2003	Prairie Creek						
	Reach 1	7	10	17	8	4	12
	Reach 2	3	14	17	3	1	4
	Reach 3	8	52	60	2	0	2
	Reach 4	9	20	29	0	1	1
	Streelow Creek	8	12	20	0	0	0
	Boyes Creek	8	9	17	1	0	1
2003/2004	Prairie Creek						
	Reach 1	12	13	25	21	46	67
	Reach 2	4	31	35	23	20	43
	Reach 3	1	32	33	35	15	50
	Reach 4	6	9	15	9	9	18
	Streelow Creek	1	10	11	0	2	2
	Boyes Creek	4	5	9	0	0	0

Appendix I. Pairwise correlations between redd area and pot area and redd area and dig depth for Chinook and coho redds in the Prairie Creek Study Area, Humboldt County, California, 1998/1999 to 2003/2004.



Appendix J. Consideration of stream width as a logistic regression parameter for distinguishing Chinook and coho salmon redds in the Prairie Creek Study Area, Humboldt County, California.

During the 2002/2003 spawning surveys, stream widths at redd sites were measured. Due to low sample sizes, this parameter was not included in the redd identification logistic regression model. Chinook salmon adults tend to be of larger size than coho salmon adults and are usually capable of constructing larger redds. It may therefore be possible that Chinook salmon spawners choose areas of the stream where a larger stream width could accommodate a larger redd. According to preliminary results, there was not enough evidence to support this claim. However, further investigations on this matter should be explored. The graph below displays stream widths at Chinook salmon (n=12) and coho salmon (n=26) redd sites during the 2002/2003 spawning season in Mainstem Prairie Creek.



Appendix K. Alternative methods for the substrate parameter for use in logistic regression models for distinguishing Chinook and coho salmon redds in the Prairie Creek Study Area, Humboldt County, California.

Three different methods for quantifying substrate were considered for redd identification logistic regression model. The substrate classification system as described in the Materials and Methods portion of this paper was ultimately used. The two other methods, which use substrate measurements were explored in 2002/2003 and 2003/2004.

In 2002/2003, redds were revisited after juvenile hatching so as not to disturb incubating eggs or developing alevins. Thirty pieces of substrate were randomly selected from the upstream end of each redd tail and diameters were measured along the secondary axes. Random selection was attempted through blind selection. The substrate size P90 was then calculated for each redd.

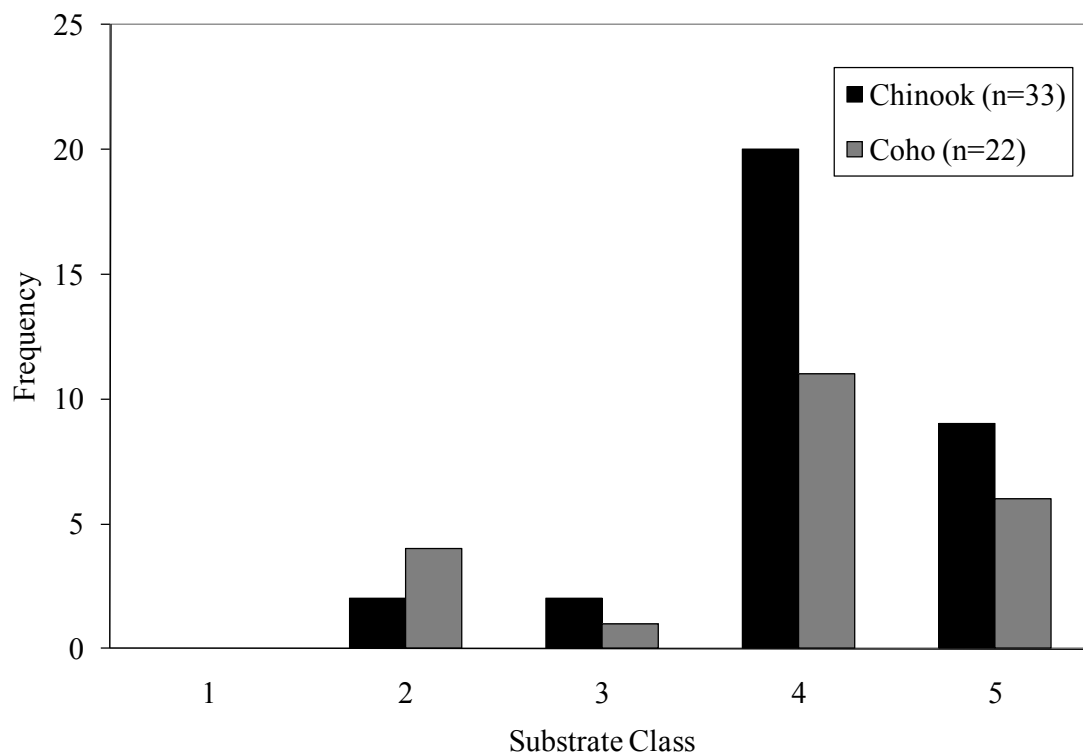
In 2003/2003, redds were also revisited after the juvenile hatching so as not to disturb incubating eggs or developing alevins. Digital photographs of each redd were taken from a height of approximately one meter. A measuring stick was placed on the redd and included in the photograph for later measurement calibration. A polarized lens and umbrellas for shade were used to reduce glare. Three transect lines were drawn across each digital image. Every third piece of substrate was measured until a sample size of 30 was reached. Individual substrate diameters along the secondary axis were measured using ImagePro software. The substrate size P90 was then calculated for each redd.

The digital imaging method yielded lower P90 values than the random selection method for both species. This may be due to selection bias or a product of low sample

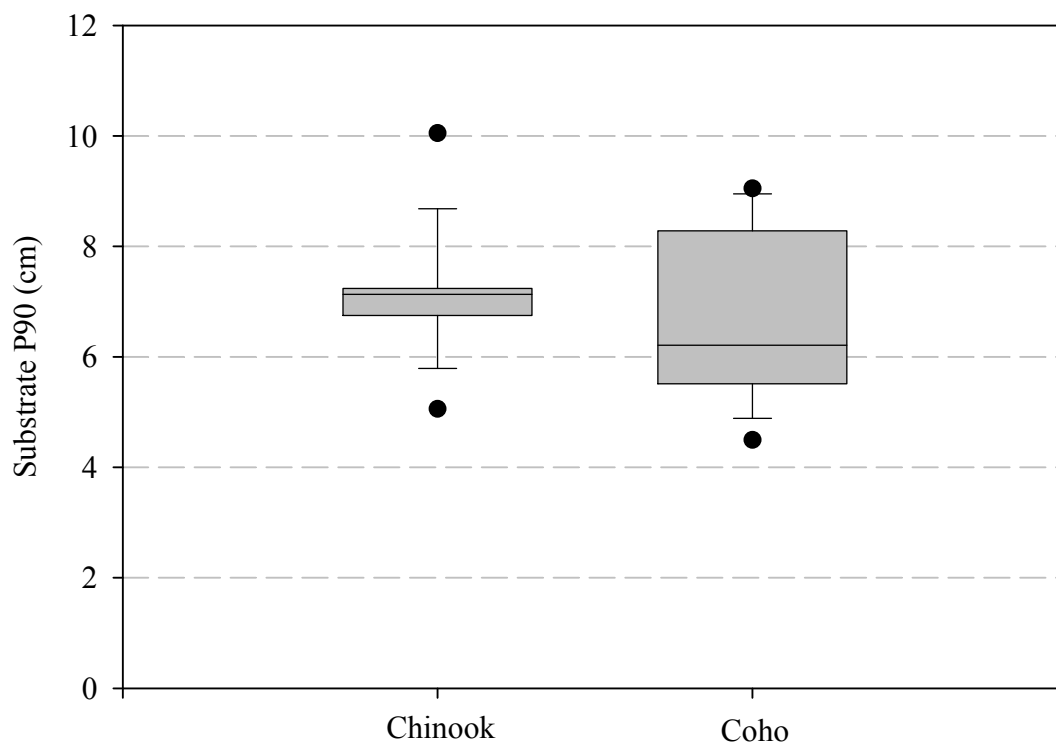
size. Larger pieces of substrate may be more likely to be encountered during blind random selection.

Both substrate measurement methods are far more time consuming than the visual composition estimation method, without yielding improved results. The digital photograph measurement was particularly time consuming. However, imaging software with an automatic measurement tool may greatly increase productivity. Another problem encountered with the digital image method was poor image quality. Although measurements were taken to reduce glare from the water surface, eliminating glare was usually not possible. Redds are usually constructed in faster moving water. Therefore, substrate images are often obscured by rippling at the water surface. Imaging software may be able to improve image quality.

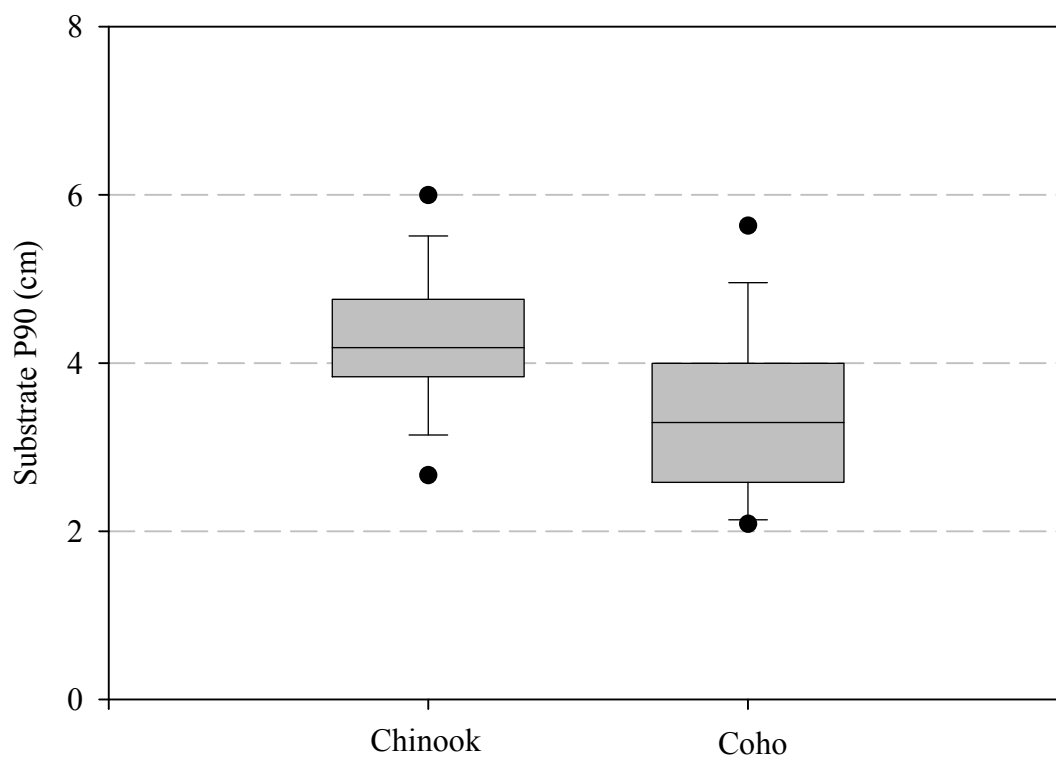
Actual substrate measurements may prove to be more beneficial than substrate composition estimates if they can be obtained in a timely manner. Therefore, this component may merit further investigation.



Substrate size classification frequency for Chinook salmon (n=33) and coho salmon (n=22) redds during the 2002/2003 and 2003/2004 spawning seasons in Mainstem Prairie Creek, Humboldt County, California.



Substrate size P90 frequency for Chinook salmon (n=10) and coho salmon (n=23) redds during the 2002/2003 spawning season in Mainstem Prairie Creek, Humboldt County, California, using the random selection method.



Substrate size P90 frequency for Chinook salmon (n=48) and coho salmon (n=18) redds during the 2003/2004 spawning season in Mainstem Prairie Creek, Humboldt County, California, using the digital image method.

Appendix L. Young-of-the-year Chinook salmon outmigrant catch used for spawner-recruitment analysis in the Prairie Creek Study Area, Humboldt County, California. Data compiled from W. Duffy, U.S. Geological Survey, California Cooperative Fish Research Unit (unpublished data). Data for missed trapping days were linearly interpolated.

Season	Reach			
	Upper Prairie Creek	Mainstem Prairie Creek	Streelow Creek	Boyes Creek
1998/1999	57272	103957	822	111
1999/2000	11510	23435	6	93
2000/2001	207	9316	5	0
2001/2002	63531	117377	20	10
2002/2003	55301	74274	1635	95
2003/2004	45358	NA	1553	0

Appendix M. Young-of-the-year coho salmon numbers used for spawner-recruitment analysis in the Prairie Creek Study Area, Humboldt County, California. Data compiled from W. Duffy, U.S. Geological Survey, California Cooperative Fish Research Unit (unpublished data).

Reach	Season	Spring Outmigrant Catch*	Summer Population Estimate	Total
Upper Prairie Creek	1998/1999	9069	7104	16173
	1999/2000	2210	3099	5309
	2000/2001	193	1374	1567
	2001/2002	138986	6647	145633
	2002/2003	76207	7955	84162
	2003/2004	15765	4252	20017
Streelaw Creek	1998/1999	3885	2164	6049
	1999/2000	10648	592	11240
	2000/2001	269	1530	1799
	2001/2002	43635	4510	48145
	2002/2003	20262	4215	24477
	2003/2004	593	1221	1814
Boyes Creek	1998/1999	108	2229	2337
	1999/2000	224	227	451
	2000/2001	1163	3411	4574
	2001/2002	52235	4350	56585
	2002/2003	13866	2362	16228
	2003/2004	7946	2181	10127

* data for missed trapping days were linearly interpolated