An Investigation into the Efficiency of Observers to Visually Detect Adult Salmon Spawning in the Prairie Creek Watershed, Humboldt County, California

By

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ABSTRACT

Investigations into Spawning Surveyor Observer Efficiency and Adult Salmonid Movement in the Prairie Creek Watershed, Humboldt County, California

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I estimated the observer efficiency of spawning surveyors conducting foot surveys for live coho and Chinook salmon in Prairie Creek, Humboldt County, California, during the 2007-2008 spawning season, and in Prairie Creek and its main tributary, Lost Man Creek, during the 2008-2009 spawning season. A dual-mark recapture design was utilized whereby adult salmon caught at weirs below the spawning grounds were tagged with both passive integrated transponder (PIT) tags and externally-visible Peterson disc tags. An array of in-stream PIT interrogation antennae was used to monitor movement of tagged individuals into and out of survey reaches. Individuals that died within survey reaches, and whose exact date of mortality was unknown, were removed from the pool of observable tagged individuals through a process that involved estimating a range of probable dates of mortality from confidence intervals constructed around survey life estimates; the process produced two counts of tagged fish available to be observed – one based on removing individuals at the beginning of the estimated range of mortality, and one based on removing them at the end of the range. Survey life of tagged individuals was estimated as a linear function of date of arrival at the weir, condition upon arriving at the weir, and sex.

Surveyors counted the numbers of tagged and untagged fish they observed on each spawning survey. Observer efficiency was calculated in two ways: observer efficiency was calculated as the ratio of the number of tagged fish observed on a given survey to the number of tagged individuals estimated to be present in the survey reach on the survey date from the antenna data (‘comparison’ method); the second method involved alternately substituting the weir-based mark-recapture escapement estimate, the lower- and upper-bounds of its confidence interval, and the lower- and upper bounds of the confidence interval of the survey life estimate into the area-under-the-curve escapement estimation formula and solving for the observer efficiency term (‘solution’ method). Due to a mid-season funding freeze and resulting lack of data, observer efficiency calculations were not possible for the 2008-2009 spawning season. Observer efficiency estimates obtained with the comparison method from the surveys conducted during the 2007-2008 spawning season ranged from 0 to 1, with a median value of 0.167 based on the low count of tagged individuals available to be observed, and 0.114 based on the high count. The solution method observer efficiency estimates ranged from 0.130, as calculated from the upper bounds of the escapement estimate and survey life confidence intervals, to 0.491 as calculated with the lower bounds of the escapement estimate and survey life confidence intervals.

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INTRODUCTION

Pacific Coast populations of anadromous salmonids are generally in decline due to both anthropogenic and natural disturbances (Nehlsen et al. 1991; Moyle 2002). On California's North Coast, both common species of Pacific salmon (coho salmon, *Oncorhynchus kisutch* and Chinook salmon, *O. tshawytscha*) and steelhead, *O. mykiss*, are listed as threatened in one or more evolutionarily significant units (ESUs) under the United States Endangered Species Act (ESA) of 1976. Coho salmon are listed in the Southern Oregon/Northern California Coastal (SONCC) ESU, Chinook salmon are listed in the California Coastal ESU, and steelhead are listed in the Northern California ESU (NOAA 1997, 1999, 2000).

Under the ESA, species listed as threatened or endangered must be restored to self-sustaining levels before de-listing is possible, and recovery of the species is deemed complete when a sufficient number of populations within the ESU have achieved sustainable numbers of individuals. The recovery assessment is based on assessments of both population size and trajectory. In California, the California Department of Fish and Game (CDFG) has developed a monitoring strategy for anadromous salmonids, the goal of which is to facilitate efficient management of anadromous salmonid populations by generating the necessary population size and trend data. The California monitoring plan for anadromous salmonids calls for using stream survey counts of live fish and redds in the estimation of adult escapement to small streams and rivers (Adams et al. 2011).

Periodic counts of live fish are commonly used to estimate escapement of adult anadromous Pacific salmonids using the area-under-the-curve (AUC) methodology (Ames and Phinney 1977; Perrin and Irvine 1990; English et al 1992; Bue et al 1998; Hilborn et al 1999; Szerlong and Rundio 2008). AUC estimates, like any estimate of escapement derived from survey counts, are sensitive to the accuracy of the counts, or observer efficiency when counting fish. Several studies have attempted to quantify observer efficiency during spawner surveys. However, most of these studies have been conducted on streams in Oregon, Washington, or British Columbia, and few actually measured efficiency of observers conducting foot surveys for live fish. Solazzi (1984) investigated observer efficiency of surveyors conducting foot surveys for spawning coho and Chinook salmon in several Oregon streams as well as the influence of several environmental factors on observer efficiency. He calculated observer efficiency as the ratio of the number of fish observed to the total number of fish in the survey reach, estimated using depletion-removal electrofishing, and estimated it to be approximately 75 percent for adult salmon. Shardlow et al. (1987) estimated observer efficiency of several salmonid spawning survey methods, including foot surveys, by comparing observer counts in an isolated reach of stream to weir counts made at the downstream end of the isolated reach; resulting estimates of observer efficiency were found to be lowest for foot surveys (less than 30 percent). Bue et al. (1998) used a calibration regression method to estimate observer efficiency, regressing aerial survey counts against estimates of the total number of fish present during surveys and using the slope of the regression line as the estimate of observer efficiency, which was found to range from 17 to 89 percent.

Korman et al. (2002) measured observer efficiency of divers conducting dive surveys by using a method combining radio telemetry tags and externally visible spaghetti tags applied simultaneously to steelhead in a British Columbia stream, and found that observer efficiency was highly variable, ranging from almost zero to approximately 60 percent over the course of the study.

These studies exemplify the typical methods used to measure observer efficiency: comparing survey counts to estimates of total fish present (developed using any of a variety of methods), mark-recapture designs coupled with some method for determining the total number of marked fish present in the survey reach at the time of the survey, and regression analysis. A fourth method for quantifying observer efficiency, which requires simultaneous use of multiple escapement estimation methods, is to solve for the observer efficiency term in an escapement estimation equation. This method has been used to deduce that observer efficiency of surveyors conducting foot surveys on a small coastal stream in Northern California was approximately 25 percent for coho salmon (Ricker 2007, personal communication).

The coastal anadromous salmonid monitoring plan adopted by CDFG calls for the use of spawner survey counts of live fish to estimate adult escapement as one element of population assessment. Existing evidence points to high inherent levels of variation in observer efficiency within and between streams. Therefore, to increase the dependability of adult escapement estimates there is a need to quantify the variability of observer efficiency in small streams in California. This study was designed to quantify the observer efficiency of surveyors conducting spawner surveys for live fish in a small coastal watershed in Northern California. I estimated observer efficiency using a dual mark-recapture design similar to that of Korman et al. (2002).

The objectives of this study were to: 1) quantify observer efficiency of counts of live adult salmonids resulting from foot surveys; and 2) evaluate dependence of observer efficiency with on environmental variables.

SITE DESCRIPTION

Prairie Creek is a fourth-order tributary to Redwood Creek with a 102 km^2 drainage area (Figure 1). The vast majority of the Prairie Creek watershed lies within the boundaries of Redwood National and State Parks in Humboldt County, California. The Prairie Creek watershed is underlain by a combination of weakly consolidated marine sediments (i.e. the Franciscan and Prairie Creek formations) and alluvial sedimentary rock (i.e. cobbles and sediments deposited by the ancestral Klamath River) that have been folded and faulted to produce the current topography (Cashman et al 1995).

Climate in the Prairie Creek watershed is generally described as temperate or temperate/rainforest, with a mean annual precipitation of 172 cm, which falls mainly between October and March. Mean annual air temperature is 11°C, and air temperature in general is moderated by the watershed's proximity to the Pacific Ocean.

The dominant species of trees found in the watershed are coast redwood (*Sequoia sempervirens*, old growth and regenerative), Sitka spruce (*Picea sitchensis*), and Douglas fir (*Pseudotsuga menscezii*), with western hemlock (*Tsuga heterophylla*) and California bay laurel (*Umbellaria californica*) present in lower numbers. The understory is characterized by black huckleberry (*Vacinium ovatum*), red huckleberry (*V. parvifolium*), and sword fern (*Polystichum munitum*). The riparian is dominated by red alder (*Alnus rubra*), big leaf maple (*Acer macrophyllum*), salmonberry (*Rubus spectabilis*), and stink current (*Ribes bracteosum*).

The fish community is typical of a northern California coastal stream, with anadromous salmonids including coho and Chinook salmon, steelhead, and coastal cutthroat trout (*O. clarki clarki*), as well as prickly and coast range sculpin (*Cottus asper* and *C. aleuticus*, respectively), Pacific and western brook lamprey (*Lampetra tridentata* and *L. richardsoni*, respectively), three-spine stickleback (*Gasterosteus aculeatus*), and Sacramento sucker (*Catostomus occidentalis*).

This study will focus on two distinct areas within the Prairie Creek watershed: Prairie Creek from a point just downstream of the confluence of Prairie and Streelow creeks to a point approximately 13.5 km upstream, and Lost Man Creek from its confluence with Prairie Creek to a point approximately 5 km upstream. These stream reaches comprise the majority of the available spawning habitat in the Prairie Creek watershed. Previous studies have constructed four adjacent spawning survey reaches on the main stem of Prairie Creek in the Prairie Creek study area. These survey reaches were utilized in this study to facilitate comparison with previous escapement estimates.

MATERIALS AND METHODS

Weir Operation

A resistance panel weir (Tobin 1994), modified for use in a small stream, was used to intercept adult salmonids on their upstream migration to the spawning grounds. In the 2007-2008 and 2008-2009 spawning seasons, a weir was installed and operated on the main stem of Prairie Creek above the confluence with Streelow Creek. In the 2008-2009 spawning season, a second weir was installed on the main stem of Lost Man Creek approximately 300 m upstream from its confluence with Prairie Creek (Figure 1). Data recorded for each fish caught at either weir included species, sex, and fork length. Each target salmonid (Chinook salmon, coho salmon, and steelhead) received a uniquely coded, 32 mm passive integrated transponder (PIT) tag, inserted anteriorly between the flesh and skin through a 6.5 mm incision made approximately 25 mm below the insertion of the dorsal fin. Chinook and coho salmon received an additional Peterson disc tag, consisting of two 20 mm plastic discs secured with a surgical stainless steel pin through the dorsal flesh above the backbone, midway between the dorsal and adipose fins. Fish initially captured at the Prairie Creek weir received black disc tags, while fish initially captured at the Lost Man weir received white disc tags. Following data collection and tag application, each fish was allowed to recover in a recovery basin with positive water flow for at least 15 minutes before being released into the stream at least 20 m above the weir.

Spawning Ground Surveys

The study area of each stream was divided into several reaches of approximately 3 km each for the purposes of conducting spawning ground surveys (Figure 1). Reach size was previously determined as a distance easily surveyed in one day. Each reach was surveyed by a crew of at least two experienced surveyors approximately bi-weekly. The interval between surveys was selected based on data from previous investigations that showed an average stream residence time of approximately 17 days for adult coho salmon returning to Prairie Creek (Wright 2011).

Surveys were conducted on foot moving upstream, and surveyors recorded information for each live fish, carcass, and redd encountered during the survey. The location of each live fish, carcass, and redd was estimated to the nearest 5 m using meter marker flags attached to streamside vegetation every 50 m throughout the study reach. For each live fish encountered during a survey, surveyors recorded species (if identifiable), sex (if identifiable), whether the fish was actively digging or guarding a redd, and whether the fish bore a Peterson disc tag.

Carcasses were identified to species and sex (if possible), and condition was assessed (fresh, decayed, or skeletal/scattered remains). Carcasses were given a uniquely numbered jaw tag to facilitate identification on subsequent surveys. Each carcass and the area immediately surrounding each carcass was examined for the presence of any tags. All carcasses were scanned with a hand-held PIT tag scanner and if a tag was detected, the tag number was recorded. Additionally, surveyors estimated an average measure of visibility by measuring the maximum depth visible on a stadia rod in deep pools encountered in the reach. Weather conditions encountered during the survey were also recorded.

PIT Interrogation Array

An array of in-stream PIT interrogation stations was installed in the Prairie Creek main stem study area prior to the 2007-2008 spawning season, and was expanded to include the Lost Man Creek study area prior to the 2008-2009 spawning season. Interrogation stations were placed throughout each study area in such a manner that effectively isolated each survey reach from tributaries and other survey reaches (Figure 1). For the 2007-2008 spawning season, the number of reader systems available could isolate three of the four spawning survey reaches. As a result, only survey data from three reaches were included in the observer efficiency study for that season.

Each interrogation station consisted of a Texas Instruments Series 2000 Radio Frequency Identification (RFID) reader/controller unit (Texas Instruments Incorporated, Dallas, Texas, USA) interfaced with an Oregon RFID internal data-logger (Oregon RFID, Portland, Oregon, USA) and connected through a Texas Instruments multiplexer and a Texas Instruments tuner module to either two or four antenna loops. Antenna loops were constructed of 8-gauge, stranded copper wire and were anchored vertically perpendicular to the stream channel (pass-through style) with t-posts. The bottom lengths of each loop were buried at least 20 cm in the stream channel substrate. Antennae were tuned to maximum read range as indicated by a Texas Instruments RFID tuning indicator, and tuning was monitored and adjusted throughout the course of each season. Data recorded on the internal data logger were uploaded weekly to a Palm M130 Personal Digital

Assistant (Palm, Incorporated, Sunnyvale, California, USA) using Oregon RFID's PTLogger software.

At times, as a result of high flow events, some antenna loops blew out and required repairs. In these instances repairs were made as soon as flows receded, and affected antennae were re-tuned. During down times, affected antennae were not capable of detecting tagged fish and as a result, it became necessary to determine the overall efficiency of the antenna array. Antenna array efficiency was determined by comparing PIT interrogation detection histories to radio telemetry tracking results for PIT-tagged individuals that were also radio-tagged for another study being conducted in the survey area during the same period. Additionally, all detection histories were analyzed with a set of logical evaluations to identify potential detection errors.

Observer Efficiency

Only individuals with detection histories free of logical errors were used in the observer efficiency analyses. Two methods were used to estimate observer efficiency, and the resulting estimates were compared. The first method (subsequently referred to as the "comparison method") consisted of comparing the number of tagged fish observers recorded in the survey reach to the number of tagged fish known to be in the survey reach over the given time of the survey (derived from antenna data). The second method (subsequently referred to as the "solution method") consisted of solving for observer efficiency in the AUC escapement estimation equation. A detailed description of each method is provided below.

Comparison Method

The comparison method consisted of estimating observer efficiency as the ratio of the number of tagged fish observed during a survey to the number of tagged fish expected to be in the survey area at the time of the survey. The elements required to make this comparison were: 1) a population of fish bearing both PIT tags and external tags (in this case, Peterson disc tags), and 2) an array of in-stream PIT tag antennae to monitor movement of tagged fish into and out of survey reaches.

A source of error in the comparison method involves uncertainty in estimating the size of the population of tagged fish available to be surveyed in any given survey reach on a daily basis. Additions to the observable pool of tagged fish in any given reach were straight-forward and easy to document, since they could only occur when a tagged fish was recorded on antenna moving from a tributary or other survey reach into the survey reach in question, or, for survey reaches adjacent to weirs, when newly tagged individuals were released above the weirs. Similarly, it was straight-forward to document removals from the observable pool that occur when fish migrate out of the reach in question. However, removals that occurred as a result of mortality were more difficult to document. For example, an individual could perish in a particular reach and then be removed from the stream channel by a predator. In this situation, the antenna would not record movement out of the reach for the individual and the survey crew would not find the carcass on the next spawning survey. As a result, the individual would be incorrectly assumed to still be alive in the survey reach in which it perished. For individuals whose date of mortality was not known, date of mortality was predicted using the results of a regression analysis conducted on individuals with known survey life (the amount of time between when an individual first entered the survey area and when it died, Perrin and Irvine 1990).

Linear regression, using Akaike's information criterion to assess and select models, was used to model survey life as a function of biological and environmental variables, and residual analysis was used to determine whether model assumptions were met. The most parsimonious model was used to estimate survey life for the remaining 133 PIT- and Peterson disc-tagged coho salmon. Confidence intervals (95%) were constructed around each survey life estimate, producing a range of possible dates of mortality for each individual. These ranges were confronted with antenna detection histories and the dataset was adjusted according to the following rules: 1) if the last antenna detection of an individual occurred *before* the earliest date in the estimated range of mortality, the individual was treated as alive until the day preceding the first date in the estimated range of mortality, after which the individual was treated as being either dead or alive on each day in the estimated range of mortality; 2) if the last detection occurred *within* the estimated range of mortality, the individual was treated as alive until the date of last detection, after which the individual was treated as being either dead or alive on each remaining day in the estimated range of mortality;3) if the date of last detection occurred *on or after* the last date in the range of estimated mortality, the individual was treated as though it died on the date of last detection. Applying these rules resulted in two separate counts of individuals potentially present in survey reaches on survey dates: a 'base' count resulting from treating individuals for which state of life was unknown as dead, and a 'high' count resulting from treating those same individuals as alive. Observer efficiency was calculated separately for each count, resulting in 'base' and 'high' observer efficiency values for each survey.

Solution Method

This method utilized the AUC escapement estimation formula, which has the general form of:

$$\hat{E} = \widehat{AUC} * \widehat{rt}^{-1} * \widehat{oe}^{-1} \qquad \textit{Equation 1}$$

where $\hat{E}$ is the estimated escapement, AUC is the area under the spawner abundance curve, rt is the average residence time in the study area (a quantity also known as survey life), and oe is observer efficiency. *AUC* was estimated from the spawner survey data as:

$$\widehat{AUC} = 0.5 * \sum_{i=2}^{n}[(t_i - t_{i-1}) * (p_i + p_{i-1})] \qquad \textit{Equation 2}$$

where n is the number of surveys conducted during the season, t_i is the position of the ith survey (measured in number of days since the first survey) relative to the first survey, and p_i is the number of fish present in the survey area on the date of the ith survey (English et al. 1992). Normally, p_i is estimated by multiplying the number of fish observed on a survey by the observer efficiency, but since the goal was to solve for observer efficiency in *Equation 1*, only the numbers observed on each survey were used for values of p. The average survey life was determined using longevity information from individuals marked at the weir and subsequently recaptured as fresh carcasses. Escapement, for this procedure, was estimated using Chapman's (1951) bias-adjusted form of the 2-sample Lincoln-Petersen mark-recapture expansion

$$\widehat{N} = \frac{(M+1)(C+1)}{R+1} - 1 \qquad \textit{Equation 3}$$

where $\widehat{N}$ is the estimated escapement, *M* is the number of individuals initially caught and marked, *C* is the number of individuals secondarily caught and examined for marks, and *R* is the number of individuals tagged in the initial sample and recaptured in the second sample. Confidence intervals at the 95 percent level were constructed around the escapement estimate as two times the square root of the estimated variance of the escapement estimate, where variance was estimated according to the method described by Seber (1970). Once estimates of *AUC*, *rt*, and *E* had been produced, solving Equation 1 for $\widehat{oe}$ provided an estimate of observer efficiency. Three estimates of observer efficiency were produced this way: one based on the point estimates of survey life and escapement from the mark-recapture data, and a second and third produced by using the lower and upper 95 percent bounds on the survey life and mark-recapture escapement estimates.

Ancillary variables

Ancillary variables measured for inclusion as explanatory variables in the statistical analyses include five environmental variables measured within the study area and four descriptive variables derived from weir data and/or survey data. Environmental variables measured included stream discharge, stream turbidity, water temperature, air temperature, and light intensity in the riparian zone. Descriptive variables derived from weir data included date of initial arrival at the weir, as well as gender of each individual included in the analysis. Descriptive variables derived from surveys included date of survey and surveyor set (a categorical variable representing the pairs of surveyors that conducted each survey).

Data analysis

Linear regression was used to determine what relationship, if any, existed between the calculated observer efficiencies and the ancillary variables. A preliminary residual analysis was conducted on the full linear model (the model with all explanatory variables included) to determine whether the model met the error structure and independence assumptions of linear regression. This analysis included an assessment of normality and independence of model residuals. When necessary, non-linear variables were transformed so that model assumptions were met. If assumptions were still violated, nonlinear model structures were explored. Once an appropriate model structure was identified, analysis was conducted according to the *a priori* concept (Burnham and Anderson 2002), whereby further analysis was constrained to a parsimonious set of candidate models. Model selection was accomplished based on corrected Akaike Information Criterion (AIC_c) scores.

RESULTS

2007-2008 Spawning Season

The Prairie Creek weir was operated from 22 October 2007 through 6 April 2008. High flows rendered the weir inoperable on four occasions, resulting in a total of 163 days of effective trapping. Coho salmon first arrived at the weir on 13 November 2007 and continued to arrive in a protracted, pulsed pattern until 5 February 2008 (Figure 2). Chinook salmon arrivals were fewer and less protracted than coho salmon, beginning on 18 November 2007 and continuing until 8 January 2008. Steelhead first arrived at the weir on 5 January 2007 and continued until 25 March 2008.

During the 2007-2008 trapping season, stream discharge ranged from a minimum of 0.49 m^3s^{-1} on 5 November 2007 to a maximum of 28.27 m^3s^{-1} on 31January 2008 (median =1.02 m^3s^{-1}). Stream turbidity ranged from a minimum of 0 FNU (Formazin Nephelometric Units) on 17 December 2007 to a maximum of 485 FNU on 4 January 2008 (median = 4 FNU). Stream discharge and turbidity data were collected by the National Park Service (NPS) at the NPS gauging station located at the Wolf Creek bridge, approximately 350 m upstream of the weir site.

Light intensity data were only collected through 22 November 2007, when a malfunction rendered the light meter inoperable for the duration of the season. Data from the meter were compared with data from the same period of time from three other light meters in the region. Data from the nearest solar intensity meter located at 42.2233^o N, 124.0525^o W, approximately 14.5 km from Prairie Creek study area, was used due to its proximity to the study site and relatively strong correlation to the Prairie Creek light meter data (Prairie, West Side correlation = 0.554), strongest correlation of three sites examined.

A total of 176 coho salmon, 14 Chinook salmon, and 28 steelhead were caught during the 2007-2008 trapping season (Table 1). Additionally, 21 coastal cutthroat trout, one chum salmon, and one Sacramento sucker were trapped. PIT tags were applied to 167 coho salmon and 13 Chinook salmon. Of the PIT-tagged fish, 152 coho salmon and 11 Chinook salmon also received Peterson disc tags. Additionally, 15 PIT-tagged coho salmon and two PIT-tagged Chinook salmon received radio tags.

During the 2007-2008 spawning season, a total of 24 spawning surveys were conducted in the Prairie Creek study area (six surveys on each of four survey reaches). The average interval between surveys on a reach was 21.8 days (standard deviation = 6.7 days). A total of 163 observations of live coho salmon (43 observations of tagged individuals, 46 of untagged individuals, and 74 of individuals whose tag status could not be determined by the surveyors) and seven observations of untagged Chinook salmon were made over the course of the spawning season (Table 2).

The in-stream PIT-tag interrogation array recorded movement information for 156 tagged coho salmon, all 13 tagged Chinook salmon, and 31 tagged steelhead. Eleven PIT-tagged coho salmon and one PIT-tagged steelhead were never detected by any of the in-stream PIT antennae. Five steelhead detected by the array were repeat spawners that had been tagged in the previous year as part of another study. Only one of these returning individuals was trapped at the weir during the 2007-2008 trapping season; the other four apparently entered the study area while the weir was topped over during a high flow event.

The interrogation array functioned at high efficiency, except when antenna loops were blown out due to high flows. A comparison of movement data from 12 coho salmon that received both radio-telemetry and PIT tags yielded a PIT tag detection efficiency of 90.8%. Errors in individual tracking histories that occurred as a result of reader malfunction or loop blow-outs were identified with logical analyses of the detection data. Logical errors were detected in 31 individuals (28 coho salmon and 3 steelhead). Only one coho salmon was removed from the analysis due to irreconcilable errors in the antenna data; the remaining 27 coho salmon with errors in the antenna data were included because their reach of residence was known with certainty on all relevant survey dates. A total of 166 PIT- and Peterson-tagged coho salmon were used in the observer efficiency analysis.

<u>2008-2009 Spawning Season</u>

Sampling during the 2008-2009 season was interrupted mid-season as a combined result of a funding freeze and a large winter storm. The Prairie Creek and Lost Man Creek weirs were operated with full funding from 1 November 2008 until 27 December 2008,when funding for the project was suspended. This required the discontinuation of sampling in the Lost Man Creek study area, while sampling continued on Prairie Creek on a volunteer basis. A severe winter storm caused extremely high flows on Prairie Creek on 28 December 2008, and the Prairie Creek weir was topped over until early on 4

January 2009. Trapping resumed on 4 January 2009 and continued uninterrupted until the weir sustained heavy damage during another large flow event on 16 March 2009.

From 1 November through 27 December 2008, a total of 80 coho salmon, 45 Chinook salmon, and two steelhead were caught at the Prairie Creek weir (Figure 3), and 12 coho salmon, 30 Chinook salmon, and 1 steelhead were caught at the Lost Man Creek weir (Figure 4). After sampling resumed, only seven coho salmon, nine Chinook salmon, and five steelhead were caught at the Prairie Creek weir during the remainder of the trapping season. Additionally, throughout the 2008-2009 trapping season, a total of 11 cutthroat trout and one Sacramento sucker were trapped at the Prairie Creek weir, and four cutthroat trout were trapped at the Lost Man Creek weir. At the Prairie Creek weir, PIT and Peterson disc tags were applied to 78 coho salmon, 36 Chinook salmon, and 6 steelhead, while radio tags were applied to two coho salmon and three Chinook salmon (Table 1). All coho and Chinook salmon trapped at the Lost Man Creek weir received PIT and Peterson disc tags, while the only steelhead encountered there received a PIT tag only. No radio-tags were applied to fish trapped at the Lost Man Creek weir.

A total of six surveys were conducted on the Prairie Creek and Lost Man Creek reaches (one survey on each of the four Prairie Creek reaches, and one survey on each of the two Lost Man Creek reaches) before project funding was cut. Thereafter, nine surveys were conducted, primarily on the Prairie Creek reaches. Surveys on the Lost Man Creek reaches yielded no observations of tagged coho or Chinook salmon, and a total of six observations of untagged coho salmon and two observations of untagged Chinook salmon (Table 3). Surveys on Prairie Creek resulted in a total of 18 observations of tagged coho salmon, five observations of tagged Chinook salmon, 32 observations of untagged coho salmon, and 14 observations of untagged Chinook salmon. Also, 14 coho salmon and one Chinook salmon whose tag status surveyors were unable to determine were observed on Prairie Creek.

The array of PIT antennae on Prairie Creek was operated from 14 November 2008 until 1 April 2009. All antennae in the Prairie Creek array were damaged by high flows on 28 December 2008, and were inoperable until repairs were completed on 2 January 2009. The array of PIT antennae on Lost Man Creek was operated from 18 December 2008 until funding was frozen on 27 December 2008, at which time antennae operations on Lost Man Creek were halted.

A total of 69 tagged coho salmon, 23 tagged Chinook salmon, and seven tagged steelhead were detected by the Prairie Creek array during the 2008-2009 season. Three of the seven steelhead detected by the array were individuals that were tagged as adults during the 2007-2008 spawning season. Logical errors were identified in 46 percent of coho salmon detection histories, 43 percent of Chinook salmon detection histories, and 71 percent of steelhead detection histories. Due to a combination of high error rates in detection histories and the low number of observations made on spawning surveys, it was not possible to complete the observer efficiency analysis for the 2008-2009 spawning season.

Observer Efficiency

Comparison Method

During the 2007-2008 spawning season, individual survey life for 33 PIT-tagged coho salmon decreased linearly over time (Figure 5), and was best modeled as a linear function of the date of arrival at the weir, condition upon arrival, and sex (Table 4). A residual analysis of the top model (Figure 6, Figure 7) did not reveal any significant lack of model fit to the data. In comparing the estimated survey life ranges with the detection histories, the first rule was applied to the majority of tagged individuals (71 percent, 94 individuals), while the second rule applied to 28 individuals (21 percent), and the third rule was applied to 11 individuals (8 percent).

Only spawning surveys conducted on days when tagged fish were known to be present in the surveyed reach (i.e., had been observed with the PIT tag interrogation system) could be used for the observer efficiency analysis; 11 of the 24 surveys conducted during the season satisfied this condition. Observer efficiency for these surveys, calculated from the base number of tagged individuals present ranged from zero to one with a median of 0.167 (first quartile = 0.036, third quartile = 0.268; Table 5), and increased over time. Observer efficiency values based on the ‘high’ number of tagged individuals ranged from zero to 0.533 with a median of 0.114 (first quartile = 0.036, third quartile = 0.231), and also increased over time. Unfortunately, the observer efficiency data was too sparse to model with respect to environmental covariates.

Solution Method

The solution method was applied only to data for coho salmon during the 2007-2008 spawning season; lack of information on survey life and limited observations precluded analysis for Chinook salmon and steelhead. Using information from the spawner surveys, the area-under-the-curve (AUC) for coho salmon spawners for the 2007-2008 spawning season was estimated to be 2239 fish-days for coho salmon. The average survey life for coho salmon during the 2007-2008 season was approximately 25 days, with lower and upper 95% confidence bounds at approximately 20 and 30 days, respectively. The mark-recapture estimate for coho salmon escapement for the season was 401 ± 173 individuals (estimate ± 95% confidence interval). The mark-recapture escapement estimate of 401 individuals and the 95 percent lower and upper bounds on that estimate (228 and 574 individuals, respectively) were each substituted into the general AUC escapement estimation formula along with the estimates of AUC and survey life to produce three estimates of observer efficiency. The resulting estimates of observer efficiency, based on the lower bounds on the mark-recapture and survey life estimates, mark recapture and survey life estimate, and upper bounds on the mark-recapture and survey life estimates, respectively, were 0.491, 0.223, and 0.130 (Table 6).

DISCUSSION

To estimate a range of dates over which tagged coho salmon may have died, I modeled survey life of coho and found that the survey life of coho salmon was negatively correlated with date of arrival at the weir. Survey life was best modeled as a function of date of arrival at the weir, condition upon arriving at the weir, and sex. These findings are similar to results found in the literature; several studies have shown survey life of adult anadromous salmonids to decrease throughout the duration of a spawning season (Neilson and Geen 1981; Bocking et al. 1988; Perrin and Irvine 1990; English et al. 1992; Su et al. 2001; Korman et al. 2002; Szerlong and Rundio 2008; Goin 2009), and that sex has an influence on survey life (van Den Berghe and Gross 1986; Korman et al. 2002). One might suppose that condition upon arrival at the weir would be correlated with date of arrival. However, the data did not support this and both the term date of arrival at the weir and the term condition upon arriving at the weir lost significance when an interaction term between the two was added to the top model.

Observer efficiency calculations were only possible for coho salmon in the 2007-2008 spawning season, and these values were too few to effectively model with environmental covariates (a main objective of this study). A funding freeze coincided with a large flow event during the peak of 2008-2009 season, resulting in a lack of useable data from that season. Because of this, another study objective of comparing observer efficiency values between streams within year and within streams between years was not possible.

Observer efficiency estimates generated by the comparison method from the 2007-2008 season were highly variable (ranging from 0 to 1) and increased over time. Regarding observer efficiency values of zero, it should be noted that on two of the three surveys that produced these zero estimates, only one tagged individual was in the reach to be observed and no untagged individuals were observed. In these instances - with extremely low numbers of tagged fished, and low numbers of fish in the reach overall - an efficiency of zero is understandable. However, the third survey that produced an efficiency estimate of zero - 3 January 2008 on Prairie Creek Reach 3 - is different in that between 7 and 13 tagged fish were present to be observed, and surveyors observed none of them while observing 6 untagged individuals. Here, the observer efficiency obviously is not zero since the surveyors observed fish. The probability of this outcome - an observation of 0 out of a minimum of 7 tagged fish and a maximum of 13 tagged fish - can be calculated if we assume a binomial distribution of possible counts of tagged fish with 'n' available tagged fish (minimum n=7, maximum n=13) and 'p' equal to the median value of all observer efficiency estimates (base count observer efficiency=0.167, maximum count observer efficiency=0.114). Assuming this, we find that the probability of observing 0 tagged fish on this survey was between 0.09 (n=13, efficiency=0.167) and 0.43 (n=7, efficiency=0.114).

The nature of the increase in observer efficiency over time (i.e. gradually increasing as the season progressed, until the end of the season when the increase became pronounced) could be due to several causes. These include increasing observer skill over time and decreasing hiding behavior of spawning adults over time. The former is not likely, as experienced surveyors that had conducted surveys for more than one season were present on every survey. The latter, however, is more probable given the physiological and behavioral changes that occur in semelparous Pacific salmonids over the course of the spawning season.

Upon entry to freshwater, individuals focus energy on migration rather than feeding (Synkova 1951; Prakash 1962; Higgs et al. 1995), and thus reach the spawning grounds with a dwindling supply of energy that is used for location of mates and for spawning. After spawning has been completed, males may search for more mates or die, while females tend to guard redds and then die (Shapovalov and Taft 1954; Moyle 2002; Goin 2009). In the pre-spawning, and to some degree during the spawning phase, individuals tend to hide in pools or undercut banks, decreasing their chance of being detected by surveyors (M. Sparkman, CDFG, Arcata, CA, personal communication). However, during spawning and post-spawning phases, individuals are either pre-occupied by the act of spawning or lack the energy to hide, thus increasing the chance of being detected by observers. I am unaware of any published data on the relationship between spawning phase and observability. Unfortunately, with only one year of useable observer efficiency data I cannot infer that the trend over time the data show is not a random occurrence.

The solution method produced estimates of observer efficiency with greater magnitude and variability than those generated using the comparison method: the solution estimate based on the lower 95 percent bounds on the survey life and mark-recapture escapement estimates was 0.491, while the median of the comparison method estimates generated from the base number of tagged individuals present was 0.167. The solution method estimate based on the upper bounds on the mark-recapture and survey life estimates was 0.130, while the median of the comparison method estimates based on the maximum number of tagged individuals present was 0.114. The increased variability observed in the solution method estimates is due to error propagation resulting from incorporating variability around the survey life and escapement estimates, and illustrates how sensitive this method is to variation in those components. The mean comparison method observer efficiency values (0.252 from the base number of tagged individuals present, and 0.159 from the maximum number of tagged individuals present) are more similar to the solution method values, but the mean values may not accurately reflect the central tendency of the non-normal observer efficiency distributions.

In general, most values of observer efficiency observed in this study are similar in magnitude to those identified in other small coastal streams in Northern California. Using the solution method, observer efficiencies of approximately 0.25 have been estimated from Freshwater Creek, Humboldt County, California (S. Ricker, CDFG, Arcata, CA, personal communication). Szerlong and Rundio (2009) report observer efficiency estimates of approximately 0.22 from surveys on the South Fork Noyo River. These estimates are similar to the mean comparison method observer efficiency calculated from the base number of tagged individuals (0.252), as well as the solution method observer efficiency based on the point estimates of survey life and escapement (0.223). However, the variability in this study's observer efficiency estimates (Results

Table 6) suggests that observer efficiency may vary between stream reaches and over time within reaches.

It should be noted that, as performed in this study, the solution method for estimating observer efficiency cannot address the temporal variability that may exist in true observer efficiency. Szerlong and Rundio (2008) have devised a methodology that allows, when available, multiple observer efficiency calculations to be incorporated into the estimation process. Utilizing the Szerlong-Rundio method would allow a higher level of accuracy and better assessments of error in estimation; these are highly desirable traits of escapement estimation methods in the context of stock assessment, management, and rehabilitation.

LITERATURE CITED

Adams, P. B., L. B. Boydstun, S. P. Gallagher, M. K. Lacy, T. McDonald, and K. E. Shaffer. 2011. California coastal salmonid population monitoring: strategy, design, and methods. Fish Bulletin 180, California Department of Fish and Game, Sacramento.

Ames, J. and Phinney, D. E. 1977. 1977 Puget Sound summer-fall Chinook methodology: escapement goals, run size forecasts, and in-season run size updates. Washington Department of Fisheries Technical Report No. 29.

Bocking, R. C., J. R. Irvine, K. K. English, and M. Labelle. 1988. Evaluation of random and indexing sampling designs for estimating coho salmon (*Oncorhynchus kisutch*) escapement to three Vancouver Island streams. Canadian Technical Report of Fisheries and Aquatic Sciences 1639.

Bue, B. G., S. M. Fried, S. Sharr, D. G. Sharp, J. A. Wilcock, and H. J. Geiger. 1998. Estimating salmon escapement using area-under-the-curve, aerial observer efficiency, and stream-life estimates: the Prince William Sound pink salmon example. North Pacific Anadromous Fisheries Committee Bulletin 1: 240-250.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach. 2nd Edition. Springer-Verlag, New York, New York, USA. 488 pp.

Cashman, S. M., H. M. Kelsey, and D. R. Harden. 1995. Geology of the Redwood Creek Basin, Humboldt County, California. Pages B1-B13 *in* K.M. Nolan, H.M. Kelsey, and D.C. Marron, editors. Geomorphic processes and aquatic habitat in the Redwood Creek basin, Northwestern California. Professional Paper 1454, United States Geological Survey, Denver, Colorado.

Chapman, D. G. 1951. Some properties of the hypergeometric distribution with application to zoological censuses. University of California Publications in Statistics 1: 131-160.

English, K. K., R. C. Bocking, and J. R. Irvine. 1992. A robust procedure for estimating salmon escapement based on the area-under-the-curve method. Canadian Journal of Fisheries and Aquatic Sciences 49: 1982-1989.

Goin, J. J. 2009. Spawning migration dynamics of ocean-returning salmonids (*Oncorhynchus* spp.) in Freshwater Creek, California. Master's Thesis. Department of Fisheries Biology, Humboldt State University, Arcata, California.

Higgs, D. A., J. S. Macdonald, C. D. Levings, and B. S. Dosanjh. Nutrition and feeding habits in relation to life history stage. Pages 161-315 *in* C. Groot, L. Margolis and W.C. Clarke (eds). Physiological Ecology of Pacific Salmon. UBC Press, Vancouver, Canada.

Hilborn, R., B. G. Bue, and S. Sharr. 1999. Estimating spawning escapements from periodic counts: a comparison of methods. Canadian Journal of Fisheries and Aquatic Sciences 56: 888-896.

Korman, J. R., M. N. Ahrens, P. S. Higgins, C. J. Walters. 2002. Effects of observer efficiency, arrival timing, and survey life on estimates of escapement for steelhead trout (*Oncorhynchus mykiss*) derived from repeat mark-recapture experiments. Canadian Journal of Fisheries and Aquatic Sciences 59: 1116-1131.

Moyle, P. B. 2002. Inland fishes of California – revised and expanded. University of California Press, Berkeley, CA. 502 pp.

National Oceanic and Atmospheric Administration. 1997. Threatened status for southern Oregon/northern California coastal ESU of coho salmon. Federal Register 62(87): 24588-24609.

National Oceanic and Atmospheric Administration. 1999. Threatened status for two Chinook salmon ESUs in California. Federal Register 64(179): 50393-50415.

National Oceanic and Atmospheric Administration. 2000. Threatened status for one steelhead ESU in California. Federal Register 65(110): 36074-36094.

Nehlsen, W., J. E. Williams, and J. A. Lichatowich. 1991. Pacific Salmon at the crossroads: stocks at risk from California, Oregon, Idaho, and Washington. Fisheries. Bethesda, Maryland, USA. 14: 237-261.

Neilson, J. D. and G. H. Geen. 1981. Enumeration of spawning salmon from spawner residence time and aerial counts. Transactions of the American Fisheries Society 110: 554-556.

Perrin, C. J. and J. R. Irvine. 1990. A review of survey life estimates as they apply to the area-under-the-curve method of estimating the spawning escapement of Pacific Salmon. Canadian Technical Report of Fisheries and Aquatic Sciences 1733.

Prakash, A. 1962. Seasonal changes in feeding of coho and chinook (spring) salmon in southern British Columbia waters. Journal of the Fisheries Research Board of Canada 19: 851-865.

Seber, G. A. 1970. The effects of trap response on tag-recapture estimates. Biometrika 26: 13-22.

Shapovalov, L. and A. C. Taft. 1954. The life histories of the steelhead rainbow trout (*Salmo gairdneri gairdneri*) and silver salmon (*Oncorhynchus kisutch*) with special reference to Waddell Creek, California, and recommendations for their management. California Department of Fish and Game Bulletin 34.

Shardlow, T., R. Hilborn, and D. Lightly. 1987. Components analysis of instream escapement methods for Pacific salmon. Canadian Journal of Fisheries and Aquatic Sciences 44: 1031-1037.

Solazzi, M. F. 1984. Relationships between visual counts of coho salmon (*Oncorhynchus kisutch*) from spawning fish surveys and the actual number of fish present. Pages 175-186 *in* P. E. K. Symons and M. Waldichuk, editors. Proceedings of the workshop on stream indexing for salmon escapement estimation. Canadian Technical Report of Fisheries and Aquatic Sciences 1326.

Su, Z., M. D. Adkison, and B. W. Van Alen. 2001. A hierarchical Bayesian model for estimating historical salmon escapement and escapement timing. Canadian Journal of Fisheries and Aquatic Sciences 58: 1648-1662.

Synkova, A. I. 1951. Food of young salmon in Kamchatka waters. Proceedings of the Pacific Research Institute of Fisheries and Oceanography 34: 105-121.

Szerlong, R. G. and D. E. Rundio. 2008. A statistical modeling method for estimating mortality and abundance of spawning salmon from a time series of counts. Canadian Journal of Fisheries and Aquatic Sciences 65: 17-26.

Tobin, J.H. 1994. Construction and performance of a portable resistance board weir for counting migrating adult salmon in rivers. U.S. Fish and Wildlife Service, Kenai Fishery Resource Office, Alaska Fisheries Technical Report Number 22, Kenai, Alaska.

Van Den Berghe, E. P. and M. R. Gross. 1986. Length of breeding life of coho salmon (*Oncorhynchus kisutch*). Canadian Journal of Zoology 64: 1482-1486.

Wright, K. A. 2011. Escapement, migration timing, and spatial distribution of adult Chinook and coho salmon in Prairie Creek, California. Master's Thesis. Department of Fisheries Biology, Humboldt State University, Arcata, California.

PERSONAL COMMUNICATIONS

Ricker, S. 2007. Personal Communication. California Department of Fish and Game, 50 Ericson Court, Arcata, CA 95521.

Sparkman, M. 2009. Personal Communication. California Department of Fish and Game, 50 Ericson Court, Arcata, CA 95521.

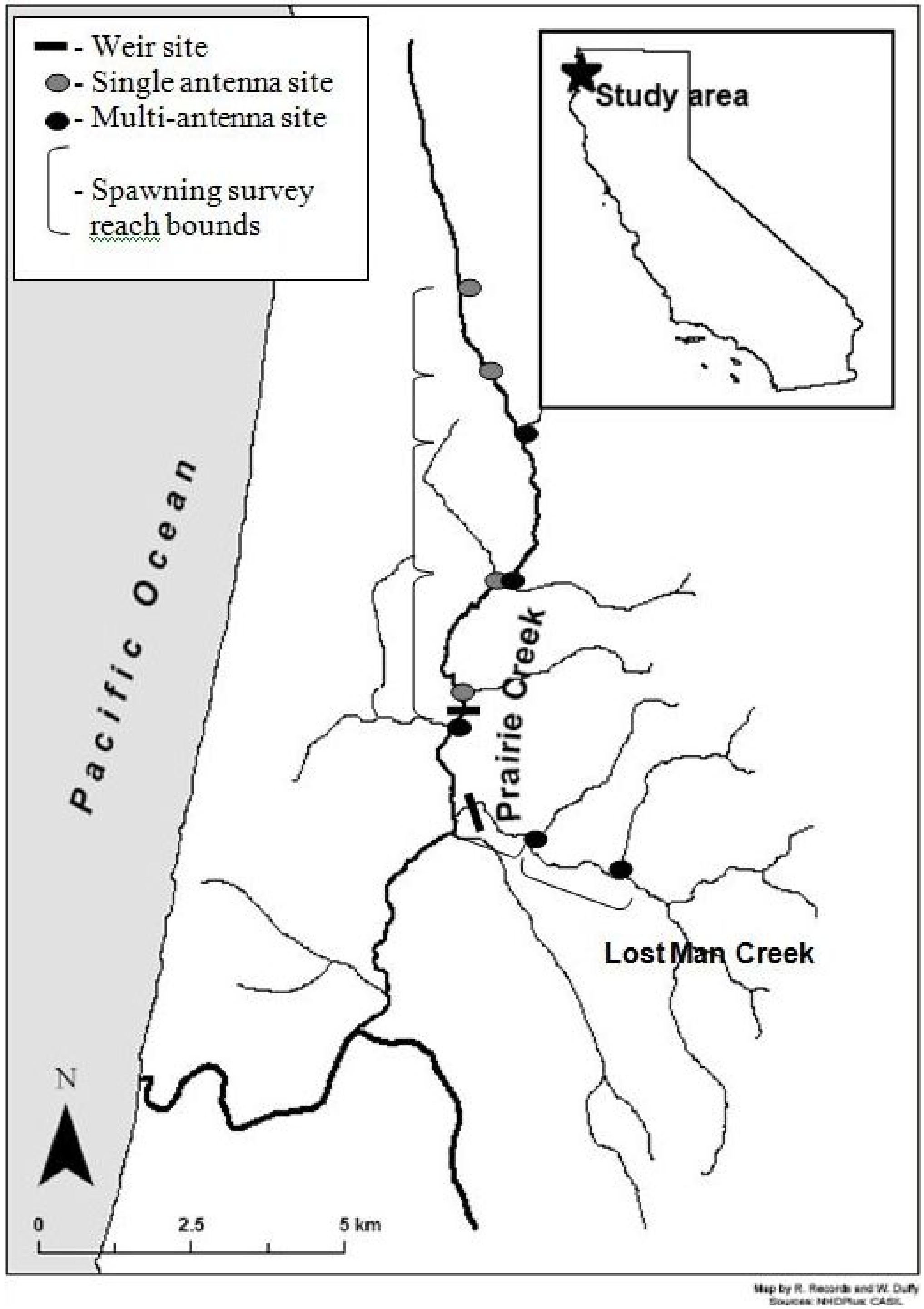

Figure 1. The Prairie Creek drainage, its respective location in Humboldt County, California and the locations of study points of interest. Multi-antenna sites refer to sites where the PIT antennae spanned two streams just above their confluence.

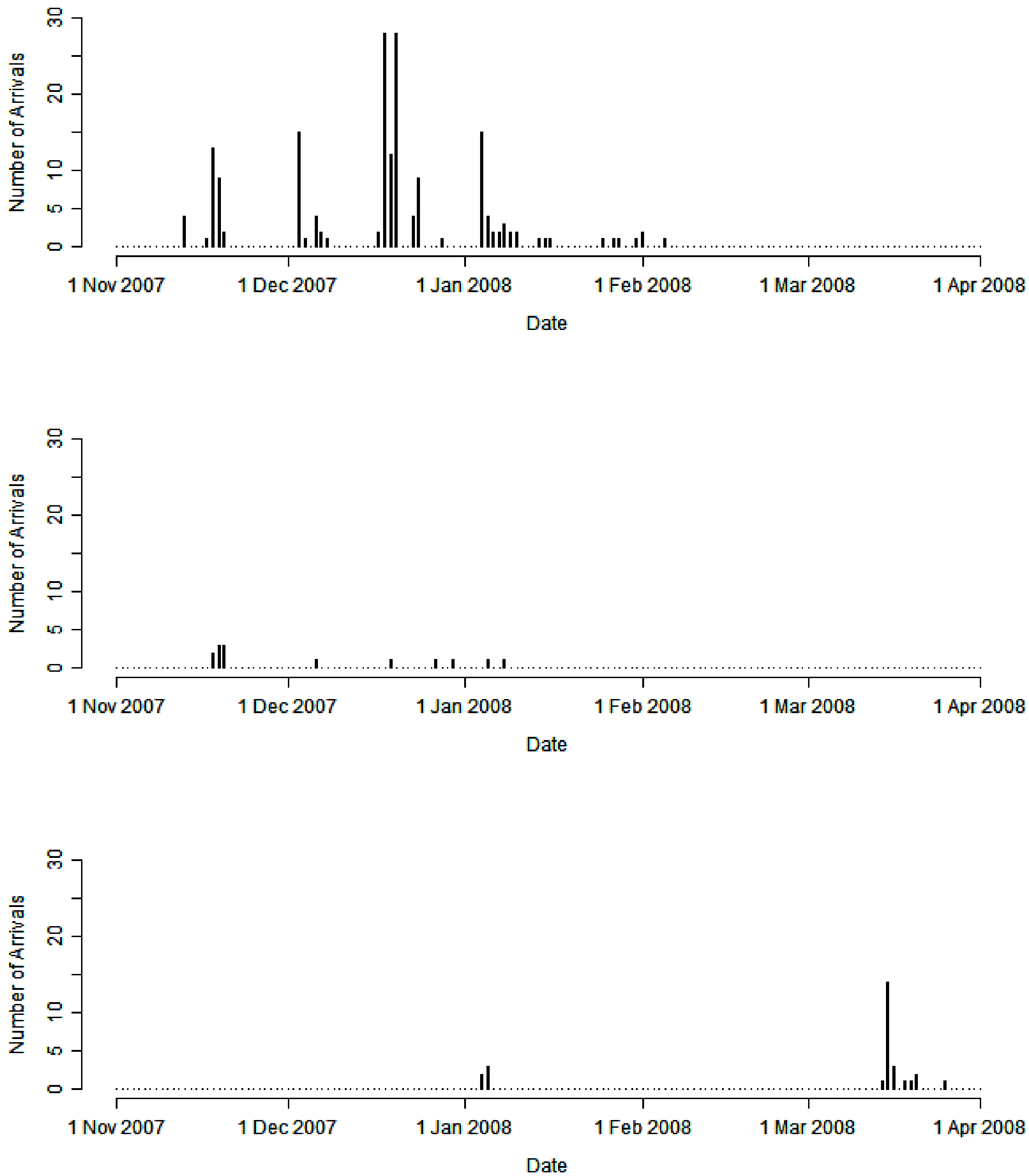

Figure 2. Daily counts of coho salmon (top), Chinook salmon (middle), and steelhead (bottom) at the Prairie Creek weir during the 2007-2008 trapping season.

Table 1. Summary of the numbers of coho salmon, Chinook salmon and steelhead trapped and tagged at the Prairie Creek weir during the 2007-2008 and 2008-2009 trapping seasons, and at the Lost Man Creek weir during the 2008-2009 trapping season.

			2007-2008			2008-2009		
Stream	Species	Sex	Caught	PIT-tagged	Radio-tagged	Caught	PIT-tagged	Radio-tagged
Prairie Creek	Coho	Male	109	103	1	50	45	0
		Female	67	64	14	37	33	2
		Total	176	167	15	87	78	2
	Chinook	Male	11	10	0	36	22	0
		Female	3	3	2	18	14	3
		Total	14	13	2	54	36	3
	Steelhead	Male	17	17	0	4	4	0
		Female	11	11	0	3	2	0
		Total	28	28	0	7	6	0
Lost Man Creek	Coho	Male	--	--	--	9	9	0
		Female	--	--	--	3	3	0
		Total	--	--	--	12	12	0
	Chinook	Male	--	--	--	16	16	0
		Female	--	--	--	14	14	0
		Total	--	--	--	30	30	0
	Steelhead	Male	--	--	--	1	1	0
		Female	--	--	--	0	0	0
		Total	--	--	--	1	1	0

Table 2. Numbers of observations of live coho and Chinook salmon made over the course of 24 spawning surveys conducted in the Prairie Creek, California study area during the 2007-2008 spawning season.

Survey Reach	Survey Date	Coho Salmon			Chinook Salmon		
		Tagged	Untagged	Unsure	Tagged	Untagged	Unsure
1	23 Oct	0	0	0	0	0	0
	23 Nov	2	0	2	0	0	0
	13 Dec	2	6	3	0	4	0
	2 Jan	4	8	15	0	2	0
	16 Jan	8	3	3	0	0	0
	12 Feb	0	0	0	0	0	0
2	24 Oct	0	0	0	0	0	0
	24 Nov	0	0	0	0	0	0
	10 Dec	4	3	2	0	0	0
	2 Jan	5	0	20	0	0	0
	14 Jan	2	4	4	0	1	0
	10 Feb	0	0	1	0	0	0
3	25 Oct	0	0	0	0	0	0
	25 Nov	0	0	0	0	0	0
	11 Dec	0	0	0	0	0	0
	3 Jan	0	6	2	0	0	0
	15 Jan	6	11	15	0	0	0
	9 Feb	0	0	0	0	0	0
4	26 Oct	0	0	0	0	0	0
	27 Nov	0	0	0	0	0	0
	12 Dec	0	0	0	0	0	0
	27 Dec	4	4	4	0	0	0
	17 Jan	6	1	3	0	0	0
	11 Feb	0	0	0	0	0	0

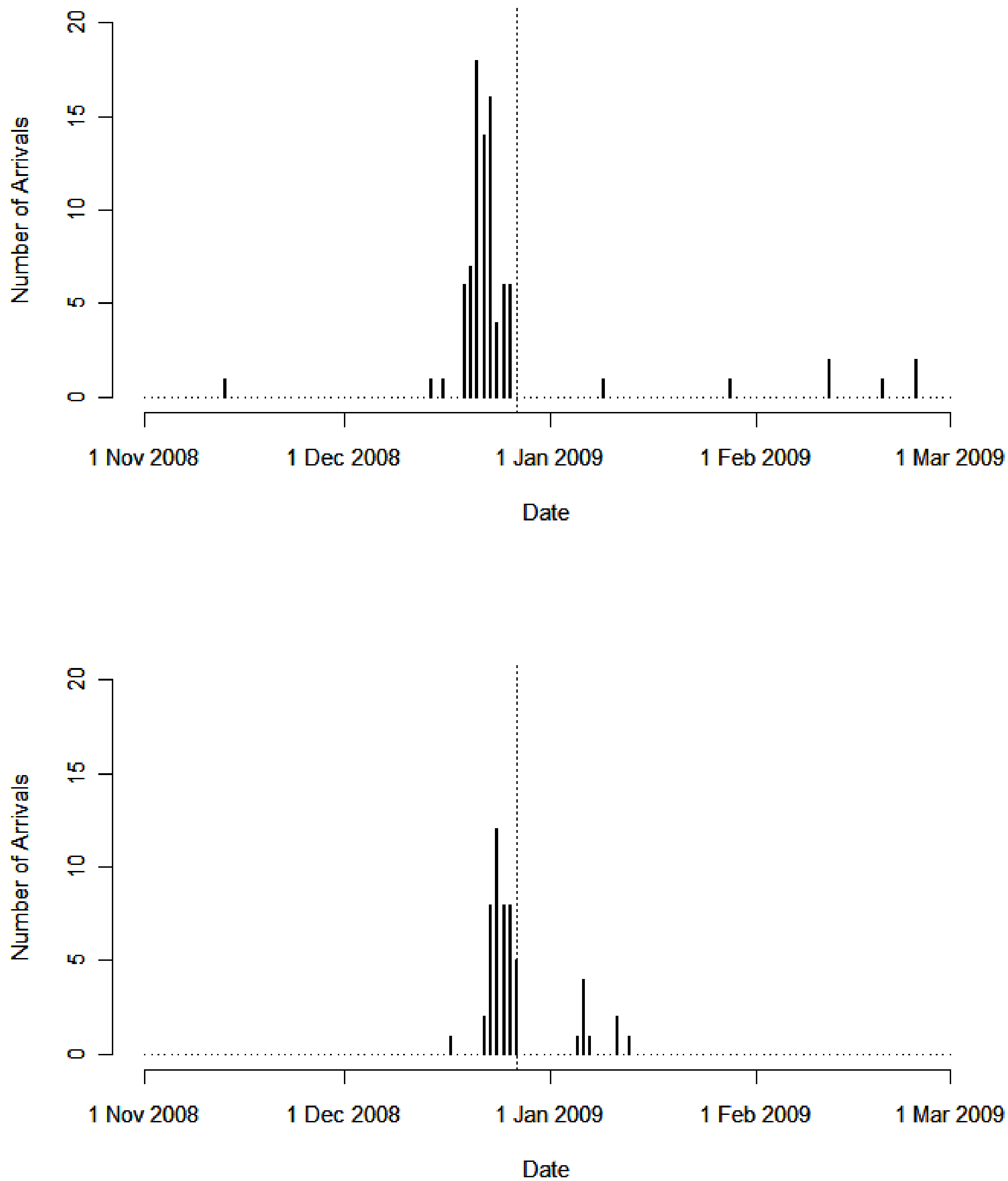

Figure 3. Daily counts of coho (top) and Chinook salmon (bottom) arriving at the Prairie Creek weir during the 2008-2009 trapping season. Dotted vertical line indicates the location of 27 Dec 2008, when project funding was frozen.

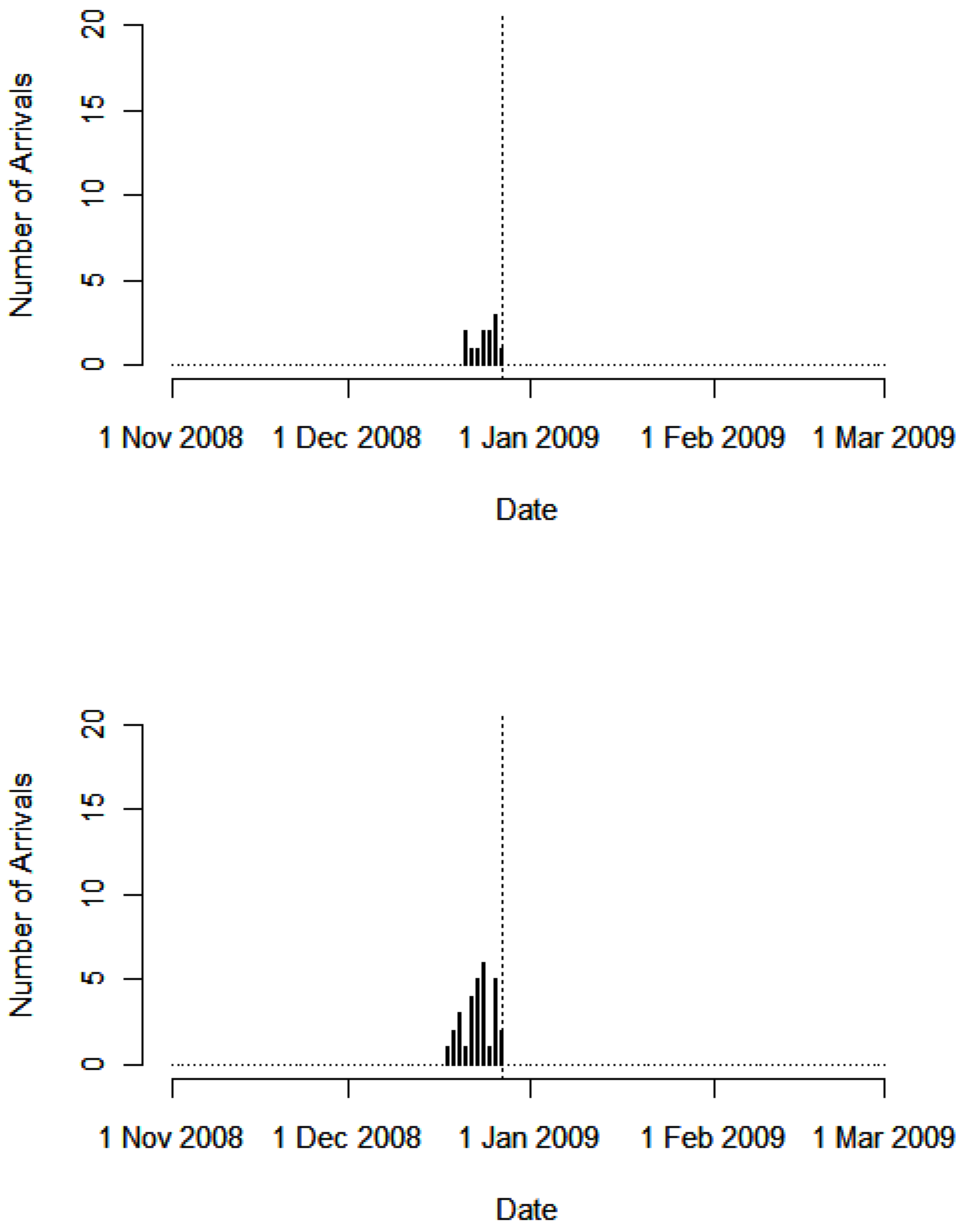

Figure 4. Daily counts of coho (top) and Chinook (bottom) salmon arriving at the Lost Man Creek weir during the 2008-2009 trapping season. Dotted vertical line indicates the location of 27 Dec 2008, when project funding was frozen.

Table 3. Numbers of observations of live coho and Chinook salmon made over the course of 15 spawning surveys conducted in the Prairie Creek and Lost Man Creek study areas during the 2008-2009 spawning season.

Stream	Reach	Date	Coho Salmon			Chinook Salmon		
			Tagged	Untagged	Unsure	Tagged	Untagged	Unsure
Lost Man	1	21 Dec	0	1	0	0	1	0
		21 Jan	0	1	0	0	1	0
	2	21 Dec	0	0	0	0	0	0
		21 Jan	0	4	0	0	0	0
Prairie	1	15 Nov	0	0	0	0	0	0
		13 Jan	2	5	0	1	5	0
		23 Jan	1	5	7	0	0	0
	2	16 Nov	0	0	0	0	0	0
		13 Jan	5	5	7	3	2	0
		23 Jan	2	2	0	0	0	0
	3	17 Nov	0	0	0	0	0	0
		12 Jan	4	9	1	0	3	1
		19 Jan	0	1	0	0	2	0
	4	18 Nov	0	0	0	0	0	0
		9 Jan	4	5	0	1	2	0

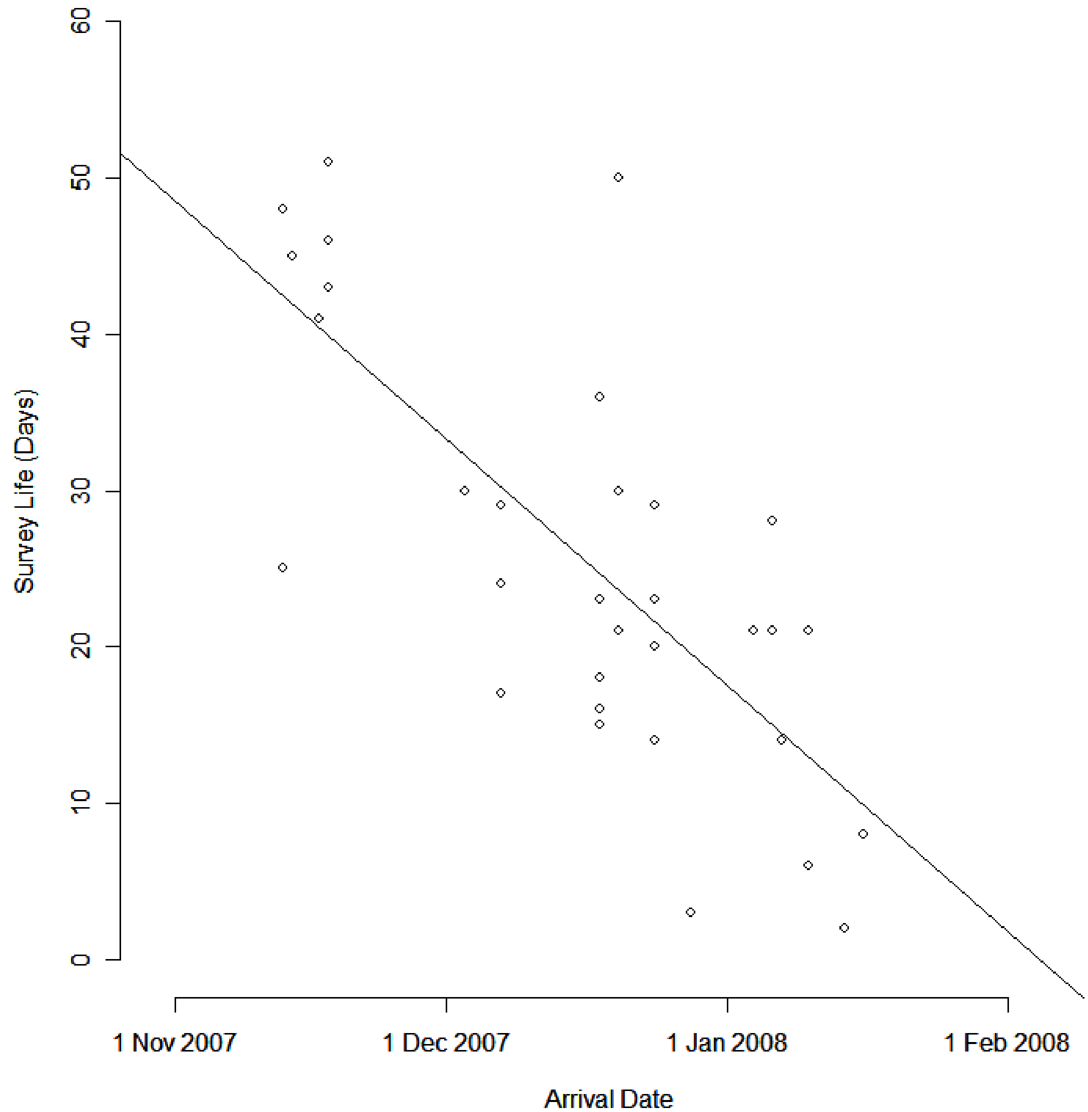

Figure 5. Survey life as a function of date of arrival (at the weir) of 33 coho salmon tagged at the Prairie Creek weir during the 2007-2008 spawning season.

Table 4. Model selection results for the multiple linear regression analysis of post-tagging coho salmon longevity in Prairie Creek during the 2007-08 spawning season. The ‘condition’ covariate refers to the condition of fish upon arrival at the weir.

Model #	Covariates	AIC_c	ΔAIC_c	Weight
4	arrival date, sex, condition	233.581	0	0.824
3	arrival date, condition	236.735	3.154	0.170
1	arrival date	244.696	11.115	0.003
2	arrival date, sex	245.523	11.942	0.002
5	sex, condition	257.919	24.338	< 0.001
6	null (intercept only)	268.245	34.664	< 0.001

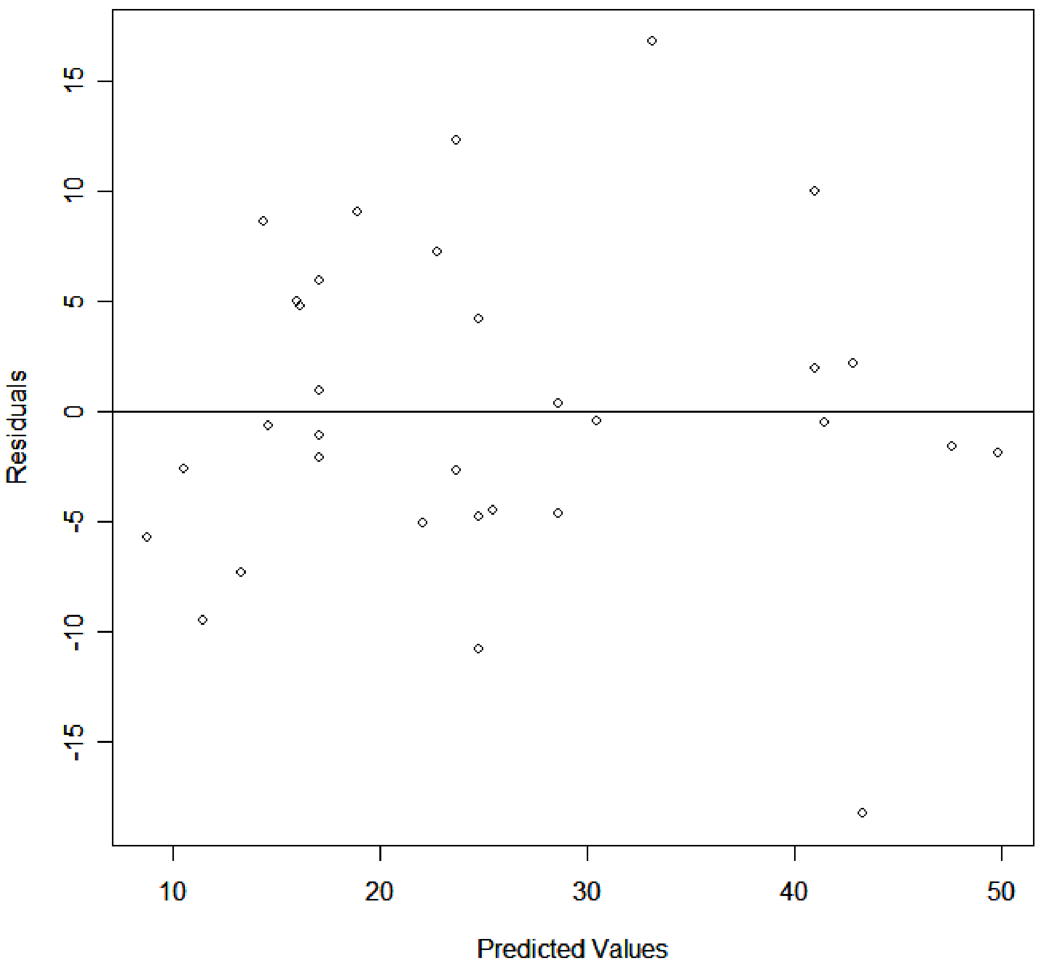

Figure 6. Plot of model residuals against predicted values for Model 4, which included date of arrival, sex, and condition upon arrival, and best described survey life of tagged coho salmon in Prairie Creek, California, during the 2007-2008 spawning season.

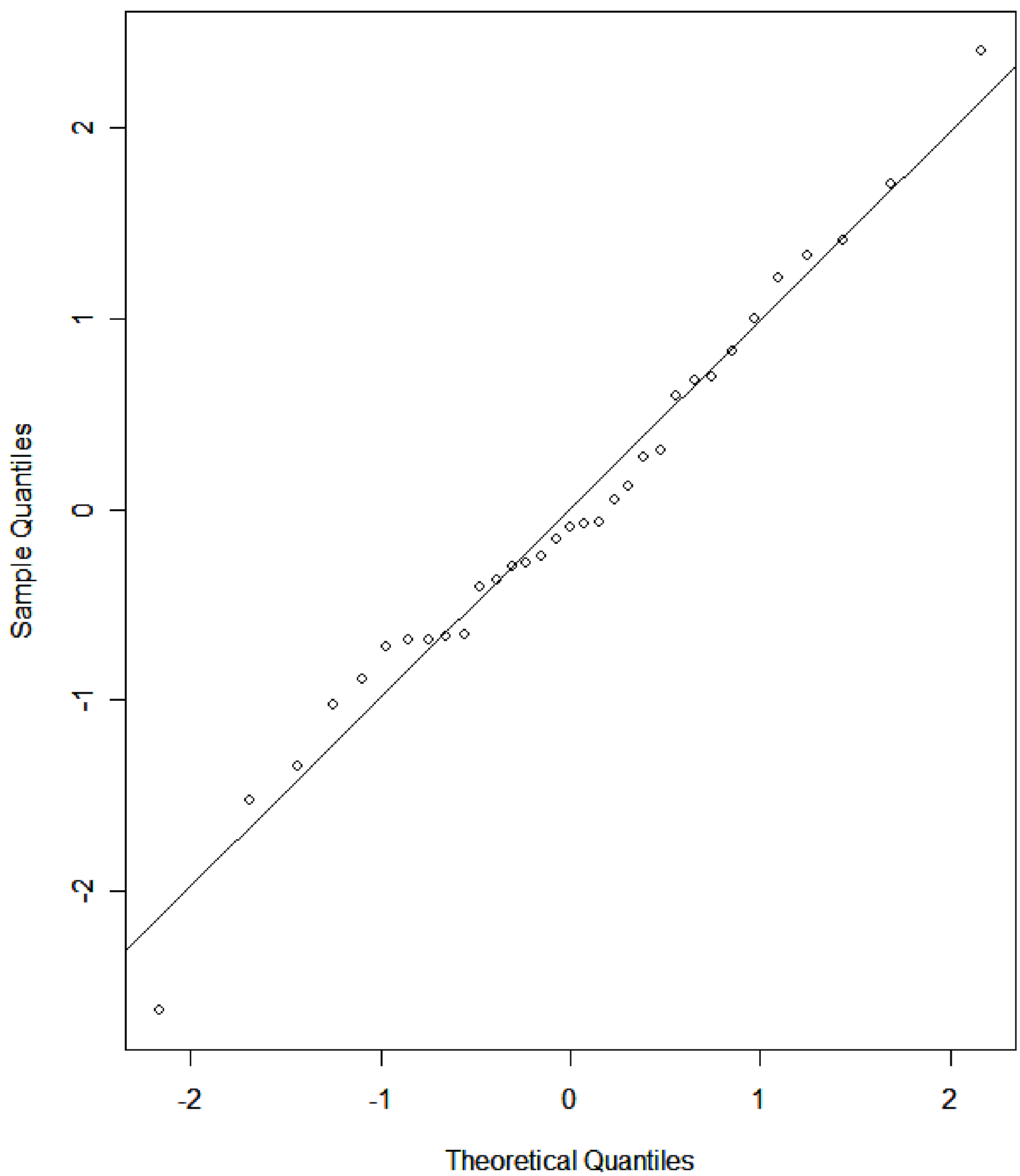

Figure 7. Normal probability plot of standardized residuals for Model 4, which included date of arrival, sex, and condition upon arrival, and best described survey life of tagged coho salmon in Prairie Creek, California, during the 2007-2008 spawning season.

Table 5. Calculated observer efficiency for all surveys in Prairie Creek during the 2007-2008 spawning season where tagged coho salmon were known to be present in the reach surveyed. 'Base Present' refers to the base number of tagged individuals estimated to be present in the survey reach on the survey date, while 'Maximum Present' refers to the maximum number of tagged individuals estimated to be present in the survey reach on the survey date. Estimates of the number of tagged individuals present come from the lower and upper bounds on the survey life estimates, respectively.

		Observer Efficiency based on:	
Survey Reach	Survey Date	Base Present	Maximum Present
1	23 Nov	0.100	0.100
	13 Dec	0.071	0.071
	2 Jan	0.167	0.114
	16 Jan	0.667	0.533
2	24 Nov	0.000	0.000
	10 Dec	0.235	0.235
	2 Jan	0.250	0.227
	14 Jan	0.286	0.167
3	11 Dec	0.000	0.000
	3 Jan	0.000	0.000
	15 Jan	1.000	0.300

Table 6. Estimates of observer efficiency for live coho salmon in Prairie Creek during the 2007-2008 spawning season, as calculated from the comparison method and solution method. The comparison method generated observer efficiency values by comparing the number of tagged individuals estimated to be in a survey reach on a survey date to the number of tagged individuals observed during that survey. The solution method consisted of solving for coho salmon observer efficiency in the general form of the AUC escapement estimation formula after plugging estimates of survey life, AUC, and the mark-recapture escapement estimate into the formula.

		Observer Efficiency, based on		
Method	Value[a]	Lower[b]	Estimate[b]	Upper[b]
Comparison	Median	0.167	NA	0.114
	Mean	0.252	NA	0.159
Solution	Estimate	0.491	0.223	0.130

[a] The comparison method generated an observer efficiency value for each survey. These values were summarized in this table by mean and median values. Median values are presented because the observer efficiency values are not distributed normally. The solution method generated only a single value for each escapement estimate value plugged into the AUC escapement estimation formula.

[b] “Lower” and “Upper” refer to the source of the values used to generate the observer efficiency estimates. For the comparison method, these terms refer to the lower and upper estimates of the number of fish present in the survey reach on the survey date; “lower” refers to the base number of fish known to be present. For the solution method, these terms refer to estimates based on the lower and upper 95% confidence bounds on the survey life and mark-recapture escapement estimates, while “Estimate” refers to the estimate based on the survey life and mark-recapture estimates.