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Short-term Survival of Fall Chinook and Coho Salmon Captured by Purse Seines in the Lower Columbia River, 2017: A Holding Study

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Table of Contents

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List of tables

List of figures

Abstract

Co-managers of the lower Columbia River have been exploring the viability of alternative commercial fishing gears, including beach and purse seines, to allow the selective harvest of hatchery-origin fall Chinook *Oncorhynchus tshawytscha* and Coho *Oncorhynchus kisutch* salmon. The viability of purse seines as a selective fishing gear depends on the expected survival rate of released fish. In autumn 2017, the Washington Department of Fish and Wildlife implemented a holding experiment to estimate short-term survival of Chinook and Coho salmon following capture in purse seines. Treatment fish were captured by purse seines in Columbia River Commercial Fishing Zone 5 and control fish were obtained from the Adult Fish Facility at Bonneville Dam. Paired groups of treatment and control fish were held together in net pens and their survival monitored for 48 h after capture. Mixed-effects logistic regression models were developed to explore the influence of covariates including of water temperature, body size, sort time, transport time, and reflex impairment on the probability of survival. Model selection results supported simple models and none of the covariates considered were found to significantly affect survival during this experiment. Short-term (48 h) survival for adult Chinook and Coho salmon captured in purse seines was estimated to be 97.9% (94.0 – 99.3%; 95% CL) and 98.1% (85.7–99.8%; 95% CL), respectively.

Introduction

Pacific salmon *Oncorhynchus* spp. have been a cornerstone of the economic and cultural foundation of the Pacific Northwest for generations. Native American tribes of the Columbia River have relied on salmon for subsistence and trade for thousands of years (Craig and Hacker 1940). European settlers established entire communities around salmon fisheries in the lower Columbia River beginning in the mid-19th century (Craig and Hacker 1940). Today, salmon fisheries remain an integral part of the culture and economy of the Pacific Northwest, despite many populations being listed as threatened or endangered under the federal Endangered Species Act (ESA). Fisheries in the Columbia River are allowed to operate within impact limits for threatened or endangered stocks determined by the National Marine Fisheries Service (NMFS). Fishery impacts are shared among diverse stakeholder groups including Native American tribes, non-tribal commercial fishers, recreational anglers, and guide services.

In addition to fishery impacts on threatened and endangered stocks, accumulating evidence suggests that the abundance of hatchery-origin salmon and steelhead *Oncorhynchus mykiss* produced in the Columbia River basin may be impeding the recovery of natural-origin stocks. Competition with hatchery salmonids affects natural-origin fish at all life stages, but can be particularly severe for juveniles where large numbers of hatchery fish are released into natal streams (Tatara and Berejikian 2012). Hatchery fish have also been shown to have lower reproductive fitness than wild fish in the natural environment (Araki et al. 2008; Christie et al. 2014). Thus, the overall fitness of wild populations can be reduced when natural-origin fish spawn with hatchery fish (Araki et al. 2009). The typical suite of sport and commercial fisheries implemented in the lower Columbia River has not realized the full potential to harvest hatchery stocks, which frequently results in surplus escapement to both hatcheries and natural habitats throughout the basin.

A review of the Columbia River hatchery system completed in 2009 by the congressionally appointed Hatchery Scientific Review Group (HSRG) identified increasing selective harvest of hatchery fish to promote conservation and recovery of natural-origin populations. From the mid-twentieth century until recent years, fall Chinook *Oncorhynchus tshawytscha* and Coho salmon *Oncorhynchus kisutch* were harvested exclusively using entangling methods such as gill or tangle nets in lower Columbia River commercial fisheries. All fall Chinook and Coho salmon captured in gill net fisheries were harvested, including ESA-listed stocks. Promoting selective fishing gears that allow the live-release of natural-origin fish would provide commercial fishing opportunity and directly reduce impacts to protected stocks. Beginning in 2009, the Washington and Oregon Departments of Fish and Wildlife conducted a series of studies exploring the viability of selective beach and purse seine fisheries as part of a Columbia River harvest reform initiative. Seines were considered a potential alternative to gill nets, as capturing fish in seine gear was believed to be less harmful than in gill nets. However, this hypothesis had not been evaluated for salmon and steelhead in the lower Columbia River.

Beginning in 2011, the Washington Department of Fish and Wildlife (WDFW) commenced a multi-year study to evaluate post-release survival for Chinook and Coho salmon and steelhead captured in seines using Ricker's two-release design (Seber 1982; Holowatz et al. 2014; Rawding et al. 2016). Post-release survival for summer steelhead was estimated to be 97.8% (96.4 – 99.2%; 95% CL, Rawding et al. 2016). However, survival estimates for Chinook and Coho salmon were considerably lower than for steelhead (Holowatz et al. 2014). Unbiased survival estimates under the Ricker model required the assumption that fish released from seines had an equal probability of passing Bonneville Dam as control fish obtained from the Bonneville Dam Adult Fish Facility (AFF). A radio telemetry study in 2013 found that 45% of Chinook and 47% of Coho captured in seines in the same area of the lower Columbia River never passed Bonneville Dam, but many were recovered in spawning tributaries and hatcheries downstream from Bonneville Dam (Liedtke et al. 2014). The authors concluded seines fishing downstream from Bonneville Dam captured a mixture of lower Columbia and upper Columbia stocks, thus the assumption of equal recapture probability at Bonneville Dam for treatment and control groups in the Holowatz et al. (2014) study was likely violated (Liedtke et al. 2014). Violation of this assumption would have resulted in negatively biased survival estimates (i.e., underestimated survival), as fish that survived but did not pass Bonneville were indistinguishable from mortalities. These complications resulted in uncertainty surrounding post-release mortality rates for Chinook and Coho salmon and the viability of selective seine fisheries. To date, commercial seine fisheries have not been fully adopted in the lower Columbia River due to uncertainty surrounding post-release survival rates for fall Chinook and Coho salmon.

Therefore, in 2017 we conducted an additional study to further evaluate the short-term (48 h) survival of Chinook and Coho salmon captured in purse seines. This study sought to evaluate short-term survival with a holding experiment to eliminate the critical assumption of equal recapture probability between treatment and control groups at Bonneville Dam. We utilized a study design similar to a study implemented by ODFW to estimate survival of Coho salmon captured in tangle nets (TAC, 2018 memorandum to US v. Oregon Policy Committee, on recommended revisions to release mortality rates for fall non-treaty commercial fisheries). The primary objectives of this study were to provide unbiased estimates of short-term, post-release survival for Chinook and Coho salmon captured in purse seines and to explore variables that could affect short-term survival for salmon captured in purse seines. Unbiased estimates of post-release survival are essential for fishery managers to determine the viability of selective commercial purse-seine fisheries in the lower Columbia River.

Methods

Study design

A holding study was implemented to observe survival of Chinook and Coho salmon captured in purse seines. Fish captured in purse seines (the treatment group) in Columbia River Commercial Fishing Zone 5 were held in net pens with fish obtained at the Bonneville Dam AFF (the control group) for 48 h to assess short-term survival. Control fish provided a means of estimating the effects of handling, tagging, transport, and confinement on survival that would otherwise be confounded with being captured in purse seines (Pollock and Pine 2007). Beach seines were not included as part of this study due to limited funding. A 48-h holding period was chosen at the recommendation of the US v. Oregon Technical Advisory Committee (TAC). Unpublished data from the Oregon Department of Fish and Wildlife (ODFW) showed that most (~70%) of the observed mortality among Coho captured in tangle nets and held for 8 days occurred within the first 24 h after capture (TAC, 2018 memorandum to US v. Oregon Policy Committee, on recommended revisions to release mortality rates for fall non-treaty commercial fisheries). Furthermore, field and laboratory studies have shown that indicators of physiological stress in anadromous salmonids exposed to capture (or simulated capture), such as heart rate and blood chemistry metrics, often recover to pre-capture levels within 24 h (Anderson et al. 1998; Gale et al. 2014; Raby et al. 2015a). In previous WDFW research in the Columbia River, median travel time from the Commercial Fishing Zone 5 fishery to Bonneville Dam was approximately two days for Chinook, Coho, and steelhead (Holowatz et al. 2014; Rawding et al. 2016). A radio telemetry study by the U.S. Geological Survey (USGS) in 2013 reported Chinook and Coho salmon captured with seines in the same area of the lower Columbia River reached Bonneville Dam in 32 – 47 h on average (Liedtke et al. 2014). It seemed reasonable to assume that most mortality in seine-caught Chinook and Coho salmon would be due to acute stress or injury and would occur within a relatively short window after capture. The 48-h holding period also covered a comparable time frame as the short-term survival estimates in Holowatz et al. (2014), Rawding et al. (2016) and Rawding et al. (*In prep.*).

Study area

All work occurred in the Columbia River Commercial Fishing Zone 5, which extends from RKM 208 to RKM 234 (Figure 1). Purse seine fishing was conducted near Rooster Rock State Park, OR (RKM 208) and the net-pen array was located near Skamania Landing, WA (RMK 225; Figure 1). Skamania Landing was chosen as the net-pen site because it met several criteria necessary to execute this study design. This site was within a relatively short drive of Bonneville Dam, and near a boat launch to facilitate transferring control fish from the tanker truck to the net pens. The site was also deep enough to accommodate the pens and had adequate flow to maintain consistent dissolved oxygen and temperature, but not enough flow to damage or dislodge the pens. In addition, this site had derelict pilings from which to anchor the net-pen array, and was out of the main shipping channel.

Net pens measured 6.1 m by 6.1 m and were fitted with 3.0 m-deep mesh bag. Net pen bags were constructed of 3.2 cm stretch mesh and weighted at the corners to maintain their shape in the current. The net pen array was surrounded with a 24.4 m by 18.3 m by 3.7 m Kevlar net and covered in 5 cm stretch mesh bird netting to deter predators. Pens were located in an off-channel site with a back eddy current (i.e., opposite the prevailing main-channel current). Depth and flow at the net pen site varied over the course of the study, due mainly to operations at Bonneville Dam. Care was taken to ensure fish were placed in net pens suspended in greater than 3.0 m depth to provide the full volume of the pen during holding. Two digital temperature loggers (HOBO Water Temp Pro v2) affixed to the net pen array recorded water temperature at the holding site for the duration of the study.

Fish capture and handling

Two commercial fishers were contracted to fish for Chinook and Coho salmon with purse seines. Fishing occurred from 14 September to 25 October 2017. Logistical constraints, including closure of the Columbia River to all boat traffic due to a wildfire, precluded fishing until after the peak daily passage of fall Chinook at Bonneville Dam (Figure 2). While the fishery location and methods were similar, purse seine gear differed slightly between the two fishers. One fisher employed a 365.8 m-long (200 fathom) by 16.5 m-deep (9 fathom) seine, constructed of 8.3 cm (3.25 in) stretch mesh, with a 18.3 m (10 fathom) bundt; the other used a 274.3 m-long (150 fathom) by 10.4 m-deep (5.7 fathom) seine, constructed of 8.9 cm (3.5 in) stretch mesh, with a 9.1 m (5 fathom) bundt. Bundts on both seines were constructed with 2.5 cm (1 in) mesh. Fish captured in the purse seine were dip netted out of the seine individually and placed into a tote of fresh river water. Fishing time for individual seine hauls (i.e., sets) varied from 10 to 26 minutes, with a mean of 18 minutes. Fishers kept the seine pursed loosely while sorting catch to minimize crowding of captured fish. Non-target species (e.g., steelhead and White Sturgeon *Acipenser transmontanus*) were released. Before release, steelhead were scanned for PIT tags, measured to the nearest cm FL, and a piece of caudal fin tissue was collected for genetic analysis at the request of Idaho Department of Fish and Game.

The condition of each Chinook and Coho salmon was classified at capture using the 1 – 5 scale described by Ashbrook (2008) and the degree of scale loss was recorded (i.e., <5 % of body, 5 – 30% of body, >30% of body). Additionally, five reflex actions were evaluated to calculate a reflex action mortality predictor (RAMP) score (Davis 2010). Reflex actions included: tail grab, eye roll, body flex, head complex, and orientation as defined in Raby et al. (2012) and Cook et al. (2018b). The RAMP score of each fish was calculated as the proportion of the reflex actions that were observed to be impaired, higher RAMP scores indicate greater impairment. After processing, fish were placed into tanks onboard the fishing vessel with river water pumped continuously through tanks in a flow-through system. Upon reaching the net pens, fish were dipped from tanks and placed directly into net pens.

During the first two days of the study oxygen was not supplied in the transport tanks and nearly 50% of the fish from the seine died between the fishing site and the net pens. When DO was measured in the tanks at the end of transport, it had been depleted to 45-50% saturation while the river was approximately 100% saturated. For the remainder of the study, oxygen was supplied to the transport tanks and DO was monitored throughout transport to the net pens using a handheld meter (YSI Pro2030). Oxygen concentration was measured in the river each fishing day, and oxygen concentration in the transport tank was maintained at a similar level, to emulate conditions that fish would have encountered had they been released directly into the river after capture. Additionally, after the first two days of the study, a maximum target sample size of 15 fish was established to minimize the potential for crowding effects in the transport tanks. When seines captured more than the target sample size, surplus fish were enumerated by species and released directly into the river.

On each fishing day, control fish were obtained from the AFF at Bonneville Dam, with the exception of the first two days of the study, when the river was too warm to operate the AFF. United States Army Corps of Engineers (USACE) protocol requires the river temperature be ≤ 69.9°F at Bonneville Dam for research activities at the AFF. The AFF collects fish volitionally by diverting them from the Washington shore fish ladder through a series of picket leads into the collection facility. Each fish handled at the AFF was anesthetized using Aqui-S 20E (Aqua Tactics, INAD Number 11-741-17-240F). Ideally the control group would have been subjected to the same handling as seine-caught fish, and handled without being anesthetized. However, USACE requires all fish sampled at the AFF to be anesthetized. We did not anesthetize seine-caught fish because we were unsure how anesthetic would affect survival and fish captured during typical commercial fisheries would not be anesthetized. Capture condition and RAMP metrics were not recorded for the control group because fish were anesthetized. Any Chinook and Coho salmon captured with PIT tags present were allowed to recover from the anesthetic and returned directly to the fish ladder (USACE 2016 Fish Passage Plan; Appendix G). After recording biological data and tag information, Chinook and Coho salmon retained for the study were placed in a 950 L tank to recover, with river water flowing through continuously. Oxygen was supplied through an air stone inside the holding tank. Oxygen levels in the transport tank were measured using a handheld DO probe and adjusted to match river oxygen concentrations. Once sampling was completed at the AFF, the tank containing the control fish was loaded into the bed of a pickup truck and transported to the net pen site at Skamania Landing. Although dissolved oxygen was supplied to the control fish during collection and transport, mortalities continued to occur during transport until 2 October when it was discovered that the probe was not measuring DO accurately. Control fish captured prior to 2 October were not considered in survival analyses. Once at the net-pen site, control fish were dip netted out of the transport tank and placed in a 680 L-tank filled with fresh river water onboard a small vessel and driven approximately 100 m to the net pens. Fish were then dip netted individually into the net pen from the transport boat.

Handling and tagging protocols were as consistent as possible between treatment and control fish. To minimize loss of scales and protective mucous, all fish were handled without gloves and dip nets used to move fish were constructed of knotless rubber bags. Chinook and Coho retained for the study were measured to the nearest cm FL, examined for adipose fin clip status and incidence of net marks or other injuries. Target species captured with a PIT tag present were not included in the study and were released. Chinook and Coho retained for the study were implanted with 12.5 mm 134.2 kHz full duplex PIT tags using a MK-25 Rapid Implant Gun (Biomark, Boise, ID) to enable individual fish to be identified from capture to release. Tags were injected into the peritoneal cavity using standard Columbia River protocols (CBFWA 1999). Data were recorded digitally using custom data collection forms on Apple iPad tablets with Biomark PIT-tag readers connected via Bluetooth. Data for all PIT-tagged fish, including recaptures, were uploaded to the Columbia Basin PIT Tag Information System (PTAGIS) database. Detections of fish released after the 48-h holding period were queried from the PTAGIS database to examine the relative passage of the treatment and control groups at Bonneville Dam.

Though the goal for each replicate was to include equal numbers of control and treatment fish of each species, the unpredictable nature of capturing fish in the purse seines and at the AFF precluded balanced samples. Ideally, transport time would have been similar for control and treatment fish within each replicate as well. While the average transport time for the control group was slightly lower than for fish captured in the seine, sporadic recruitment of control fish into the AFF resulted in more variable transport times for individuals in the control group. Average transport time (i.e., time from tagging to release into the net pen) was 2.2 h (SD = 0.58) and 2.1 h (SD = 0.57) for Chinook and Coho captured in the purse seine, respectively. Average transport time for fish from the AFF was 1.3 h (SD = 0.58) and 2.2 h (SD = 1.07) for Chinook and Coho, respectively. Despite the differences in transport time between the treatment and control group, the crew onboard the seine vessel coordinated daily with personnel at the AFF to ensure the control group arrived at the net pens at approximately the same time as the treatment fish.

Net pens were checked every 24 h to remove mortalities, document the presence of predators (e.g., otters or sea lions) in the area, and ensure the pens were intact. Fish were scanned for PIT tags prior to release following each 48-h holding period. The fate (live or dead) of each fish and any injuries that occurred during the holding period were recorded before release. Both treatment and control fish were released directly from the net pens into the Columbia River after the holding period was complete.

Data analysis

To determine if the control group represented a similar length distribution as the treatment group, we compared the relative length-frequency distributions from the respective samples. Graphical comparison indicated considerable overlap in the length-frequency distributions of the control and treatment groups for both species, but the seines captured some larger Chinook salmon than the AFF (Figure 3). A k-sample Anderson-Darling test showed no significant difference between the length-frequency distributions for the treatment and control groups of each species (Figure 1, $P > 0.1$ for Chinook, $P > 0.5$ for Coho). The k-samples Anderson-Darling test was selected because it is sensitive to differences between samples in the tails of empirical distributions (Scholz and Stevens 1987). Anderson-Darling tests were conducted using the kSamples package in R version 3.4.2 (Scholz and Zhu 2017; R core development Team 2017).

Mixed-effects logistic regressions were fit to model 48-h survival as a function of several individual covariates and one environmental variable. A set-level (i.e., each purse seine set) random effect was included to model survival as a function of individual covariates while accounting for clustering in the data (i.e., individuals captured and held together may not be strictly independent). Individual covariates to control for effects of the experimental design included transport time and a pen effect (i.e., the effect of the specific pen used to hold fish). However, the pen effect was assumed negligible because 100% of the control fish survived in all pens and it was not included in candidate models. Variables related to capture in purse seine gear included the time individuals spent in the pursed seine (i.e., from closing the seine to removal for tagging), reflex impairment scores (RAMP) at capture and the size of individual fish. Size was considered a factor with two levels for Chinook salmon (i.e., life stage, either jack or adult) but was modeled as a continuous individual covariate (i.e., FL) for Coho salmon because only two Coho jacks were captured during the study. Water temperature was hypothesized to be an important environmental covariate affecting survival of Chinook and Coho salmon captured in purse seines. Data from the control group were excluded from regression analysis because zero mortalities occurred in the control group, precluding estimating a treatment effect as a contrast to the control group under the maximum likelihood framework. Logistic regression models were of the form:

$$logit(p_i) = \beta_0 + X_{\boldsymbol{i}} \cdot \beta + \varepsilon_s ,$$

where $logit(p_i)$ is the log-odds of 48-h survival for individual i, β_0 is the intercept, $X_{\boldsymbol{i}}$ is a vector of the predictor variable data for individual i, β is a vector of regression coefficients for the predictor variables, and ε_s is the set-level random effect. Continuous covariates were centered and scaled to mean 0 and variance 1 prior to model fitting. The candidate model set was developed to include all univariate models, as well as a subset of plausible multivariate models. The most complex model included all of variables described above. No interactions among the variables were included in the candidate set because we were primarily interested in the main effects of the variables considered. Pairwise scatterplots of predictor variables were examined to determine if any variables exhibited collinearity. Scatterplots did not indicate substantial correlation among any pairs of the predictor variables.

Candidate models were ranked using the small-sample adjusted Akaike information criterion (AIC_c). Multimodel inference was used to estimate model-averaged regression parameters and predicted survival of Chinook and Coho salmon using AIC_c weights to calculate a weighted average over the model set (Burnham and Anderson 2002). Regression coefficients for predictor variables were model-averaged over the set of models that included each effect. Survival was estimated by predicting survival probability from each model in the candidate set with continuous predictor variables set to their sample means, and calculating a weighted average of the predictions using AIC_c weights. Survival was predicted for adult and jack Chinook salmon and adult Coho salmon. Data analyses were conducted in R version 3.4.2 (R core development Team 2017). Mixed-effects models were fit using the lme4 package (Bates et al. 2015). The AICcmodavg package was used to calculate AIC_c scores and weights for candidate models as well model-averaged regression coefficients, model-averaged survival estimates, and confidence intervals for both regression coefficients and survival estimates (Mazerolle 2017).

Results

Fish capture and condition

Contracted fishers conducted 39 purse seine drifts from 14 September 2017 to 25 October 2017, and captured a total of 315 Chinook and 102 Coho salmon. Fifty-four Chinook and six Coho from the purse seine treatment group were censored from 14 September and 18 September due to depleted DO levels during transport to the net pens. Seventy-eight Chinook and nineteen Coho were released over the course of the study when the seine captured more than the daily target sample size of 15 fish. Four previously PIT-tagged Chinook and one Coho were released immediately from the purse seine. One Chinook and one Coho were released after completing one set when sampling was called off due to the weather. One Chinook that escaped before being placed into the net pens was omitted because its fate over the 48-h holding period could not be determined. Two Chinook that were partially eaten and found dead in the pens were excluded because we could not be certain if the mortality was caused by capture in the seine or by the injuries inflicted by predators during the holding period. Ultimately, 175 Chinook and 72 Coho captured in purse seines between 19 September and 25 October were included in the regression analysis (Table 1). Of the fish considered in the survival analysis, only four Chinook (3 adults, 1 jack) and two Coho (adults) captured in the purse seine died during the study.

For the control group, 149 Chinook and 103 Coho were handled at the AFF from 18 September to 25 October 2017. Thirty-six Chinook and 38 Coho captured at the AFF prior to October 2nd were censored due to severely depleted DO during transport. Six Chinook that escaped into the river before being placed in net pens, or were missing from the net pens at the time of release were omitted because their fates over the 48-h holding period could not be determined. One Chinook with a PIT tag present at capture was released immediately. In total, 106 Chinook and 65 Coho salmon from the control group were considered part of the experiment (Table 1). Zero mortalities were observed among the control fish after DO saturation issues during transport were resolved.

Fish captured in the seine were generally in good condition, although some injuries were observed. Approximately 74% of Chinook and 88% of Coho salmon were classified as vigorous at capture (condition 1 or 2) and 26% were classified as lethargic (condition 3 or 4). No immediate mortalities (i.e., fish that were dead at capture) occurred for either species during the study. Of the four Chinook salmon that died during the experiment, two were classified as condition 1 (vigorous, not bleeding), one was classified as condition 3 (lethargic, not bleeding), and one was classified as condition 4 (lethargic, bleeding). The Chinook salmon classified as condition 4 that died was noted to have an open pinniped wound at the time of capture. One of the Coho that died during the experiment was classified as condition 1 (vigorous, not bleeding) and one was classified as condition 3 (lethargic, not bleeding), however both had elevated RAMP scores. Net marks on the body were the most common injuries observed and they occurred at comparable rates for both Chinook and Coho salmon (Figure 4), but only 6 Chinook (five jacks, one adult) were noted to be entangled or gilled in the purse seine. Most net marks observed were likely the result of encounters with gillnets in either Select Area Fisheries downstream of the study site or in the commercial gillnet fishery in Columbia River Commercial Zones 4 – 5 that occurred concurrently with this study. Gill nets are more likely to wrap or entangle fish, leaving net marks on fish that escape capture. In contrast, seines corral fish in a mesh too small to entangle most adult salmonids. Minor scale loss (5 – 30% of the body) was observed at similar rates for Chinook and Coho salmon; however, a small percentage of Coho salmon had severe scale loss (greater than 30% of the body; Figure 5). Injuries attributed to pinnipeds were observed on 15.4% of Chinook and 12.5 % of Coho. Sport-hooking injuries were noted on approximately equal proportions of Chinook and Coho (2.9% and 2.8%, respectively).

Survival estimates and factors affecting survival

Short-term (48 h) survival was predicted to be 97.9% (94.0 – 99.3%; 95% CI) for adult Chinook salmon and 97.6% (91.6 – 99.4% 95% CL) for Chinook salmon jacks, averaging over the suite of models at the mean of the predictor variables (Table 2). Model selection results of mixed-effects logistic regressions favored the intercept-only model for Chinook salmon (Table 3). Coefficients for all variables were small (near zero) and their confidence intervals included zero in all cases, indicating temperature, life stage, time-in-net, and transport time had little effect on Chinook salmon survival during this experiment (Table 4). Although temperature occurred in the top univariate model and top four bivariate models, the effect on survival was small over the range of temperatures that occurred during this study (Table 4). The estimated temperature effect indicated the odds of survival for Chinook salmon would decrease with increasing temperature, but the model-averaged survival predictions only varied from 98.2% (90.6 – 99.7%, 95% CL) at the minimum temperature (12.7 °C) to 97.2% (90.6 – 99.3%, 95% CL) at the maximum temperature (19 °C). The life-stage variable indicated lower odds of survival for jacks, but the difference in predicted survival between adults and jacks was negligible (Table 2). The time-in-net and transport time variables were both estimated to have a weak positive effect on survival, which was counter to our expectations. The set-level random effect was included in all models to reflect the experimental design, but the random effect variance was estimated as zero in all candidate models.

Averaging over the suite of models at the mean of the predictor variables, short-term survival of Coho salmon was estimated to be 98.2% (84.9 – 99.9%, 95% CL). The univariate model including RAMP score had marginally greater support than the intercept-only model (Table 5). Models with $\Delta AIC_c < 2$ relative to the RAMP model included the intercept only, temperature, time-in-net and FL models. The coefficient for RAMP score was negative as expected, indicating increasing reflex impairment correlated negatively with the log-odds of survival. Although the model-averaged effect of RAMP score on the log-odds of survival was relatively large (-7.98), it was not estimated precisely (95% CL: -16.5 – 0.55; Table 6). Fork length had a weakly positive effect on survival for Coho salmon (i.e., larger fish had higher survival) and both time-in-net and transport time variables had small negative effects on the odds of survival. Although the estimated regression coefficients for all variables affected survival of Coho salmon in the expected direction, confidence intervals of the estimated coefficients all included zero, indicating these variables did not significantly affect survival in this experiment (Table 6). The estimated random effect variance was effectively zero in models fit to the Coho salmon data as well.

Discussion

Short-term survival

Short-term survival was high for adult Chinook (97.9%) and Coho (98.2%) salmon captured in purse seines in this study. These survival rates are comparable to short-term survival estimates for summer steelhead captured with purse seines in the same area of the Columbia

River in Rawding et al. (2016; 97.8%) and for adult fall Chinook salmon captured in purse seines that were PIT tagged as juveniles in basins upstream of Bonneville Dam and (Rawding et al. *In prep.*, 97.5%). In addition, Rawding et al. (*In prep.*) re-analyzed the radio telemetry data from Liedtke et al. (2014) using a known fates model (Kaplan and Meier 1958). Based on the Kaplan-Meier model, survival for Chinook salmon released from purse seines between Commercial Fishing Zone 5 and Bonneville Dam was estimated to be approximately 95%. The Ricker-Two-Release design employed in Holowatz et al. (2014), Rawding et al. (2016) and Rawding et al. (*In prep.*) required the assumption of equal passage probability for treatment and control groups at Bonneville Dam. This assumption was more likely to be met for summer steelhead and fall Chinook salmon PIT tagged as juveniles in tributaries upstream of Bonneville Dam. The study by Rawding et al. (2016) was conducted in August and September in 2011-2013, during the timeframe when most summer steelhead migrating through the lower Columbia River are bound for rivers upstream of Bonneville Dam (Robards and Quinn 2002). Similarly, all fall Chinook salmon PIT tagged as juveniles in basins upstream of Bonneville Dam would be expected to pass Bonneville Dam as returning adults (Rawding et al. *In prep.*). The estimates of short-term survival in Rawding et al. (2016), Rawding et al. (*In prep.*) and this study were similar among the three species studied.

The short-term post-release survival estimates for Chinook and Coho salmon published in Holowatz et al. (2014) were substantially lower than the estimates in Rawding et al. (2016), Rawding et al. (*In prep.*), and our study. Our study provided further evidence that the assumption of equal probability of passage at Bonneville Dam was likely violated for Chinook and Coho salmon in Holowatz et al. (2014). Of the Chinook salmon PIT tagged and released after the 48-h holding period during this study, notably more individuals from the control (64%; n=141) were detected at or above Bonneville Dam than the treatment group (37%; n=198). Chinook from the control group were 1.7 (1.4 – 2.1; 95% CL) times as likely to pass Bonneville as fish captured in the purse seine. The Coho control group (n=100) was 1.2 (1.0 – 1.5; 95% CL) times as likely to be detected upstream of Bonneville after release relative to the treatment group (n=76). The radio-telemetry study by Liedtke et al. (2014) reported both Chinook and Coho salmon that were detected in the Washington shore ladder were more likely to pass Bonneville relative to all Chinook and Coho captured in seines. In addition, Liedkte et al. (2014) found that many surviving fish migrated downstream out of the study area after release. If a hypothetical Ricker

Two-Release model were applied to the PIT tag detections for fish released from our study, survival between the net-pen site and Bonneville Dam would be estimated at approximately 57% and 81% for Chinook and Coho salmon, respectively. It seems unlikely that survival would suddenly decrease to these levels after greater than 95% of both species survived for 48 h after capture. After 48 h, fish that did not die from acute stress or injury would likely be recovering to pre-capture physiological condition (Raby et al. 2015a; Gale et al. 2014; Farrell et al. 2000; Anderson et al. 1998). However, recent research indicates that dermal injury plays a significant role in delayed mortality for salmon captured in seines (Cook et al. 2018a, 2018b). The low incidence of severe dermal injury in both species during this study seems insufficient to explain the difference in PIT tag detections between treatment and control fish at Bonneville Dam (Figure 5). It seems more plausible that Chinook and Coho salmon captured at the AFF are more likely to pass Bonneville Dam than fish captured by seines in Columbia River Commercial Zone 5. Given the results of this study and Liedtke et al. (2014), the Ricker Two-Release design employed in Holowatz et al. (2014) would have overestimated short-term mortality for Chinook and Coho salmon.

Although including the control group enabled us to quantify mortality due to handling, transport and containment, handling mortality appeared to be negligible over the range of conditions realized during this study. Once DO levels were maintained at levels similar to the river during transport, there were no mortalities among the control fish. However, the control group may have under-represented handling mortality because USACE protocol requires fish handled at the AFF to be anaesthetized. Anaesthetizing the control fish could have reduced the stress response to handling and tagging in contrast with fish captured in the purse seine that were not anesthetized (Strange and Schreck 1978). If survival of the control group were positively biased by anesthetization, the survival estimates for seine-caught fish in this study would be underestimates, reflecting a minimum short-term (48 h) survival rate.

Factors affecting survival

High survival and modest sample sizes limited our ability to make inferences about the effects of variables affecting short-term survival of Chinook and Coho salmon captured in purse seines. Model selection results favored an intercept-only model for Chinook salmon. Although there appeared to be substantial support ($\Delta AIC_c < 2$) for several univariate models for Chinook salmon that included temperature, life stage (i.e., jack/adult), and time-in-net variables, these model likelihoods were not substantially different from the intercept-only model (Table 5). As a heuristic for model selection, Burnham and Anderson (2002) suggest models within 2 AIC_c of the top model (i.e., smallest AIC_c) have considerable support in the data, while models within 4-7 AIC_c of the top model have weak support in the data, and models with AIC_c >7 relative to the top model are highly unlikely. A model's AIC is defined as $2p - 2ln(\hat{L})$, where p is the number of parameters in the model and $\hat{L}$ is the maximized model likelihood (AIC_c adds an additional penalty for small sample sizes). Models with one additional parameter relative to the top model which do not substantially improve the model likelihood must be within 2 AIC of the top model, by definition. Overall, model log-likelihoods varied little among the candidate set for Chinook salmon, the variation in AIC_c was likely due to the penalty on the number of parameters in each model. Among the Coho models, the RAMP model was the only model with (marginally) greater support than the intercept-only model (Table 6). However, the estimated RAMP effect was likely biased because only two mortalities were observed, one of which was assigned an elevated RAMP score.

Both fixed and random effects estimates may be biased in logistic regression when one outcome is rare (King and Zeng 2001; Moineddin et al. 2007). Given that we observed only four Chinook salmon and two Coho salmon mortalities during this study, it is unlikely that these data provided sufficient statistical power for unbiased effects estimates. For example, the effects of the time-in-net, transport time, and RAMP score variables for Chinook salmon were all estimated having a positive effect on the odds of survival, which was counter to our *a priori* hypotheses. These effects estimates were likely spurious correlations, a result of the modest sample size achieved and having observed few mortalities. In addition to small-sample bias, the effects estimates for both Chinook and Coho salmon had relatively wide confidence intervals, all of which included zero (Table 3 and Table 4). Thus, none of the variables considered appeared to have a significant influence on survival during this study. In addition, little variation in survival among the seine sets and small samples within each set likely provided insufficient information to estimate the set-to-set random effect (Li et al. 2011). Likelihood ratio tests between mixed models and equivalent fixed effects models (i.e., comparing the same model without the random effect) indicated including the set random effect did not significantly improve the models.

Comparison with other research

Research examining post-release survival for Chinook and Coho salmon captured in purse seines has generally employed either telemetry or holding studies and focused on marine purse-seine fisheries. Two holding studies by Ruggerone and June (1996; 1997) reported high survival (pooled results: 95.3% survival) for Chinook salmon captured with purse seines in coastal waters of southeast Alaska. These studies utilized similar seine gear and net pens to our study, but allowed fishers to sort their catch on the seine vessel's deck. Ruggerone and June (1996) reported 98% survival for Chinook Salmon held for two days and Ruggerone and June (1997) found slightly lower survival (90.8%) over a longer holding period (3 – 5 days). Post-release survival estimates for Chinook and Coho salmon captured in ocean purse-seine fisheries were considerably lower in several telemetry studies. Survival of Chinook Salmon captured in purse seines in Johnstone Strait, British Columbia was estimated to be 77% (95% CL: 62 – 87%) over a 24-h period (Candy et al. 1996). Raby et al. (2015b) estimated post-release survival of Coho Salmon captured by purse seines off the coast of British Columbia to be 79% after a 24-h holding period. The same study concurrently estimated 80% post-release survival over a 48 – 96-h period for 50 Coho released with acoustic tags. A more robust telemetry study by Cook et al. (2018b) found injury and impairment were significant predictors of short-term, post-release survival over approximately 4.6 days. Short-term survival was estimated be 64% for Coho Salmon with average injury and impairment scores, but model-predicted survival varied from 86% for uninjured and unimpaired fish to 25% for fish with severe scale loss and reflex impairment (Cook et al. 2018b).

Higher short-term survival in our study relative to Candy et al. (1996), Raby et al. (2015b) and Cook et al. (2018b) could be partly be explained by differences in fish handling techniques. In Candy et al. (1996) most fish were hauled onto the vessel's deck over the stern to mimic commercial fishing techniques in the Johnstone Strait, British Columbia Sockeye *Oncorhynchus nerka* fishery. Stern hauling catch resulted in significantly higher incidence of visible injury relative to side hauling (Candy et al. 1996). Purse seine fisheries in British Columbia allow salmon to be brailed onto vessel decks for sorting (Raby et al. 2015b; Cook et al. 2018b). Lifting batches of fish in brail nets could cause injury due to crushing, and sorting fish on deck would result in air exposure (Raby et al. 2015b; Cook et al. 2018c). Fishery regulations in the Columbia River prohibit purse-seine fishers from brailing catch onto vessel decks and require fish to remain in the water during sorting. We aimed to approximate fish handling requirements in Columbia River purse seine fisheries by sorting fish from the seine by hand.

Although post-release survival estimates based on telemetry provide more comprehensive estimates relative to holding studies (Raby et al. 2014), salmon captured in marine fisheries may experience reduced post-release survival relative to salmon captured in freshwater. Salmon in the marine environment are more susceptible to dermal injury and scale loss than salmon closer to spawning (Raby et al. 2013; Cook et al. 2018d). Dermal injury and scale loss have been shown to be significant predictors of post-release survival (Cook et al. 2018b). Adult salmon released from marine purse seine fisheries would also be vulnerable to predators including pinnipeds, killer whales *Orcinus orca*, and sharks that are either not present or less abundant in river systems.

Study limitations

The fishing conditions during this study may not fully represent commercial seine fisheries in the lower Columbia River for several reasons. First, catches were relatively low during this study. This is likely because fall Chinook and early-stock Coho passage at Bonneville Dam had peaked before we were able to begin sampling (Figure 2). Mean catch-per-set was only 8.0 for Chinook and 2.6 for Coho during this study, with maximum catch-per-set of 52 Chinook and 12 Coho. Small catches resulted in quick sort times and low densities of fish pursed in the seine. The median sort time was 31 min (min=14 min, max=97 min) during this study. If mark-selective seine fisheries in the Columbia River were implemented during the peak of the fall Chinook or Coho salmon migration, fishers could potentially capture hundreds of fish at a time. Larger catches and increased sort times in actual fisheries could exacerbate the stress response in captured fish and lead to greater incidence of injury, which in turn could reduce post-release survival (Candy et al. 1996, Raby et al. 2015a, Cook et al. 2018d). However, Rawding et al. (*In prep.*) estimated a similar post-release survival rate as this study for upriver-origin Chinook salmon captured in Holowatz et al. (2014) despite larger catches and increased sort times during that study.

In addition, the location that this study was conducted may not represent all commercial purse seine fisheries on the lower Columbia River. Our study occurred in Columbia River Commercial Fishing Zone 5 (RKM 207.6 – 235.0), while most commercial seine fisheries are likely to be executed in Commercial Fishing Zones 2 – 4 (RKM 29.0 – 207.6). Transitioning from the ocean to freshwater is physiologically stressful for anadromous fish, and likely a time of elevated natural mortality (Cooke et al. 2006; Cooperman et al. 2010). Fish that are physiologically stressed may be more sensitive to additional stressors, like being captured by sport or commercial fishing gears (Cooperman et al. 2010). Furthermore, dermal injury sustained in a river estuary could impair osmoregulatory function and increase the likelihood of mortality during the transition to freshwater (Cooke et al. 2006; Cook et al. 2018a). This study may not accurately represent post-release survival for Chinook and Coho salmon captured in the Columbia River estuary. Published research indicates that anadromous salmon become more resilient to capture or injury after fully transitioning to freshwater (Vincent-Lang et al. 1993; Brobbel et al. 1996; Raby et al. 2013; Cooke et al. 2018d). This study may best represent fisheries in Columbia River Commercial Zones 3 – 5, where adult Chinook and Coho salmon have fully acclimated to freshwater. During low-flow periods in the late summer and autumn, saltwater can flow up to 50 km upstream into the Columbia River estuary (Jay and Smith 1990; Wei 2016), which covers all of Commercial Fishing Zone 1 and a portion of zone 2. Seine fisheries operating in Columbia River Commercial Zones 1 and 2 have the potential to capture fish still transitioning to freshwater, which could result in lower post-release survival.

The range of water temperatures that occurred during this study may not be fully representative of a commercial purse seine fishery on the lower Columbia River. Seine fisheries are likely to operate during the warmest water temperatures of the year. Although we were unable to detect a significant effect of temperature on survival over the range of conditions we observed, elevated river temperatures could reduce post-release survival in purse seine fisheries (Gale et al. 2011; Gale et al. 2013). Commercial seine fisheries in the Columbia River in 2014 and 2015 occurred from late August through the end of September. In those years, river temperatures varied from 23° to 17 °C when fisheries occurred. River temperatures only varied from 20° to 13 °C over the course of our study. With climate change expected to reduce mean flow and increase mean water temperatures throughout the Columbia River basin during summer months, peak summer river temperatures approaching the lethal limit for Chinook (25°C) and Coho salmon (23°C) could become common (Mote et al. 2003; Richter and Kolmes 2005). Fisheries managers will require more information on post-release survival for fisheries operating near the upper thermal tolerances for adult Chinook and Coho salmon. However, USACE water temperature restrictions at the AFF could preclude collecting control fish in future studies at the upper range of typical autumn Columbia River temperatures.

Another potentially important limitation of our study is that fish held in net pens are not subject to predation after release. In actual fisheries, released fish that are injured or disoriented may be more vulnerable to opportunistic predators (Raby et al. 2014). Post-release survival may be overestimated for fish held in net pens after capture in fishing gear because study animals are not vulnerable to predation (Raby et al. 2014). Predation by marine mammals including Steller sea lions *Eumetopias jubatus* and California sea lions *Zalophus californicus* on adult salmon in the lower Columbia River has been increasing in recent years. Although most of the observed predation occurs during the spring, the USACE has observed increasing numbers of Steller sea lions in the lower Columbia River during the autumn (Madson et al. 2017). Few pinnipeds were observed in the fishing area during this study, but injuries attributed to pinnipeds were noted on a portion of the captured fish. Quantifying the precise contribution of predation risk to post-release survival would be difficult, but telemetry or mark-recapture studies (where fundamental assumptions can be met) would provide more comprehensive estimates of post-release survival than holding studies (Raby et al. 2014). Considering that post-release survival estimates from previous mark-recapture and telemetry studies in the lower Columbia River were comparable to our study, elevated risk of predation for released fish may not substantially affect short-term post-release survival in Columbia River fisheries in the autumn (Rawding et al. 2016; Rawding et al. *In prep.*).

Summary

Short-term, post-release survival for both Chinook and Coho salmon was high (~98%) over the range of conditions in this study, and comparable to estimates for summer steelhead in Rawding et al. (2016), and Chinook salmon PIT tagged as juveniles in Rawding et al. (*In prep.*). Research in Commercial Zone 5 on the lower Columbia River indicates that short-term post-release survival for anadromous salmonids captured in purse seines is higher than in existing mark-selective tangle net fisheries for spring Chinook salmon in the same reach (84%; Ashbrook 2008), and Coho salmon near the Columbia River estuary (80.3%; Takata and Johnson 2018). Careful fish handling can ensure the highest possible short-term survival for Chinook and Coho salmon released from purse seines. Best-practices for maximizing post-release survival in seine fisheries include keeping the pursed seine loose during sorting, minimizing the potential for crushing fish when lifting them from the water, and minimizing air exposure for fish intended to be released (Cook et al. 2018c; 2018d).

Although the Ricker-Two-Release model has been successfully applied to both spring Chinook and summer steelhead (Vander Haegen et al. 2004; Ashbrook 2008; Rawding et al. 2016), the assumptions required may not be appropriate for mark recapture studies in the Columbia River during the autumn (Takata and Johnson 2018). While nearly all spring Chinook and summer steelhead present in Commercial Zone 5 originate from upper Columbia or Snake River tributaries, there are fall Chinook and Coho salmon populations occurring in tributaries and the mainstem Columbia River throughout Commercial Zone 5. This study corroborates findings in Liedtke et al. (2014) that Chinook and Coho salmon captured at the AFF in the autumn are more likely to pass Bonneville Dam than fish captured in seines in Commercial Fishing Zone 5. Short-term post-release survival in Holowatz et al. (2014) would have been underestimated by violating this assumption. However, long-term survival estimates (from Bonneville Dam to McNary Dam) in Holowatz et al. (2014) may be unbiased estimates of delayed mortality. Researchers could better meet the assumption of equal detection probability for treatment and control groups by ensuring some probability of detecting PIT tags in all potential escapement tributaries (either using antennas or escapement surveys). However, considering the scale of the Columbia River basin, it would likely be cost-prohibitive to do so.

It is important to note the results of this study may not generalize to all commercial purse-seine fisheries in the lower Columbia River. Important questions remain regarding the influence of temperature, catch density and sort time, and the osmoregulatory state of fish on post-release survival. Further research could better emulate the spatial and temporal distribution of expected commercial seine fisheries in the lower Columbia River by fishing at higher temperatures, fishing during peak migration, and fishing in river sections where seine fisheries will be implemented. However, developing a study to imitate fisheries occurring further downstream and at higher temperatures would be challenging because of difficulty in obtaining a representative control group. Conducting a study lower in the Columbia River could make transport of control fish from the AFF prohibitive due to long transport times. Furthermore, current USACE sampling restrictions at the AFF would preclude obtaining control fish during periods of higher temperatures than were encountered in 2017. In the absence of a control group, it would be impossible to determine the effects of handling and gear-related impacts on post-release survival (Pollock and Pine 2007). Without quantifying the effects of handling, post-release survival would be underestimated in studies where no suitable control group can be obtained (Pollock and Pine 2007).

Table 1. Daily sample sizes of fish held in net pens for 48 h during 2017 survival study. Fish in control group were censored from 9-19 through 9-29 due to severe DO depletion during transport.

	Species			
	Chinook		Coho	
Date	Control	Treatment	Control	Treatment
19-Sep		6		3
20-Sep		13		2
25-Sep		8		2
26-Sep		8		3
27-Sep		3		1
29-Sep		8		7
2-Oct	6	4	8	11
4-Oct	6	4	9	6
5-Oct	13	13	2	2
9-Oct	12	14	7	7
10-Oct	10	17	2	3
11-Oct	2	7	5	5
12-Oct	8	10	5	4
16-Oct	7	5	4	2
17-Oct	12	13	2	2
18-Oct	9	9	2	1
19-Oct	11	11	4	4
23-Oct	6	11	4	4
25-Oct	4	11	11	3
Total	106	175	65	72

Table 2. Model-averaged predicted survival rates for Chinook and Coho salmon with 95% CL at the average of each continuous covariate (see Table 4 and Table 6 for covariate definitions).

Species	Life stage	N	Survival (%)	95% CL
Chinook	Adult	148	97.9	94.0 – 99.3
Chinook	Jack	27	97.6	91.6 – 99.4
Coho	Adult	70	98.2	84.0 – 99.9

Table 3. Model selection results for mixed-effects logistic regression models of Chinook survival during 2017 holding study.

Model	No. parameters	AICc	ΔAICc	AICc wt.	Log - likelihood	Cumulative Wt.
Intercept only	2	42.21	0.00	0.22	-19.07	0.22
Temperature	3	43.44	1.24	0.12	-18.65	0.34
Transport time	3	43.97	1.76	0.09	-18.91	0.43
Life stage	3	44.02	1.82	0.09	-18.94	0.51
Time in net	3	44.24	2.03	0.08	-19.05	0.59
RAMP	3	44.27	2.07	0.08	-19.07	0.67
Life stage+Temp.	4	45.25	3.05	0.05	-18.51	0.72
Temp.+Time in net	4	45.42	3.22	0.04	-18.59	0.76
Temp.+Transport time	4	45.48	3.28	0.04	-18.62	0.80
Temp.+RAMP	4	45.50	3.29	0.04	-18.63	0.84
Time in net+Transport time	4	46.00	3.79	0.03	-18.88	0.88
RAMP+Transport time	4	46.06	3.85	0.03	-18.91	0.91
RAMP+Time in net	4	46.33	4.12	0.03	-19.05	0.94
Life stage+Temp.+Time in net	5	47.25	5.04	0.02	-18.45	0.95
Life stage+Temp.+RAMP	5	47.32	5.12	0.02	-18.48	0.97
Temp.+RAMP+Time in net	5	47.49	5.29	0.02	-18.57	0.99
Life stage+ Temp.+ Time in net+Transport time	6	49.35	7.14	0.01	-18.43	0.99
Temp.+ RAMP+Time in net+ Transport time	6	49.57	7.36	0.01	-18.53	1.00
Life stage+Temp.+Time in net+Transport time+RAMP	7	51.46	9.25	0.00	-18.39	1.00

Table 4. Variable definitions and model-averaged regression parameters from mixed-effects logistic regression models for Chinook salmon captured during the 2017 seine mortality study.

Variable	Definition	Estimated β	95% CL
Temp	Surface river temperature at time of capture (°C).	-0.23	-0.73 – 0.27
Life stage	Adult or Jack, adults defined as >56 cm FL.	-0.64	-2.95 – 1.67
Time in net	Minutes in pursed seine before tagging.	0.01	-0.10 – 0.13
Transport time	Time (h) in holding tank on seine vessel after tagging to release in the net pen.	0.46	-1.58 – 2.51
RAMP	Reflex Action Mortality Predictor score, observed at the time of tagging.	0.41	-6.32 – 7.14

Table 5. Model selection results for mixed-effects logistic regression models of Coho survival during 2017 holding study.

Model	No. parameters	AIC_c	ΔAIC_c	AIC_c wt.	Log - likelihood	Cumulative Wt.
RAMP	3	21.35	0.00	0.17	-7.49	0.17
Intercept only	2	22.34	0.99	0.10	-9.08	0.27
RAMP + Time in net	4	22.35	1.00	0.10	-6.87	0.37
RAMP + FL	4	22.43	1.08	0.10	-6.90	0.46
Temp. + RAMP	4	22.57	1.22	0.09	-6.98	0.55
Temp.	3	23.22	1.87	0.07	-8.43	0.62
RAMP + Transport time	4	23.59	2.24	0.05	-7.49	0.67
Temp. + RAMP + FL	5	23.74	2.39	0.05	-6.40	0.72
Temp. + RAMP+ Time in net	5	24.18	2.83	0.04	-6.62	0.76
Time in net	3	24.35	3.00	0.04	-8.99	0.80
FL	3	24.41	3.06	0.04	-9.02	0.84
Transport time	3	24.52	3.17	0.03	-9.08	0.87
Temp.+ Transport time	4	25.06	3.71	0.03	-8.22	0.90
Temp. + FL	4	25.35	4.00	0.02	-8.36	0.92
Temp. + Time in net	4	25.44	4.09	0.02	-8.41	0.94
Time in net + FL	4	26.53	5.18	0.01	-8.96	0.95
Temp. + RAMP +Time in net+ Transport time	6	26.54	5.19	0.01	-6.60	0.96
Time in net + Transport time	4	26.55	5.20	0.01	-8.97	0.98
Transport time + FL	4	26.66	5.31	0.01	-9.02	0.99
Temp. + Time in net + FL	5	27.66	6.31	0.01	-8.36	0.99
Temp. + RAMP + Time in net + Transport time + FL	7	28.27	6.92	0.01	-6.23	1.00

Table 6. Variable definitions and model-averaged parameter estimates from mixed-effects logistic regression models for Coho salmon captured during the 2017 seine mortality study.

Variable	Definition	Estimated β	95% CL
Temp	Surface river temperature at time of capture (°C).	-0.50	-1.64 – 0.63
FL	Fork length (cm)	0.10	-0.17 – 0.38
Time in net	Minutes in pursed seine before tagging.	-0.07	-0.29 – 0.14
Transport time	Time (h) in holding tank on seine vessel after tagging to release in the net pen.	-0.31	-3.19 – 2.57
RAMP	Reflex Action Mortality Predictor score, observed at the time of tagging.	-7.98	-16.5 – 0.55

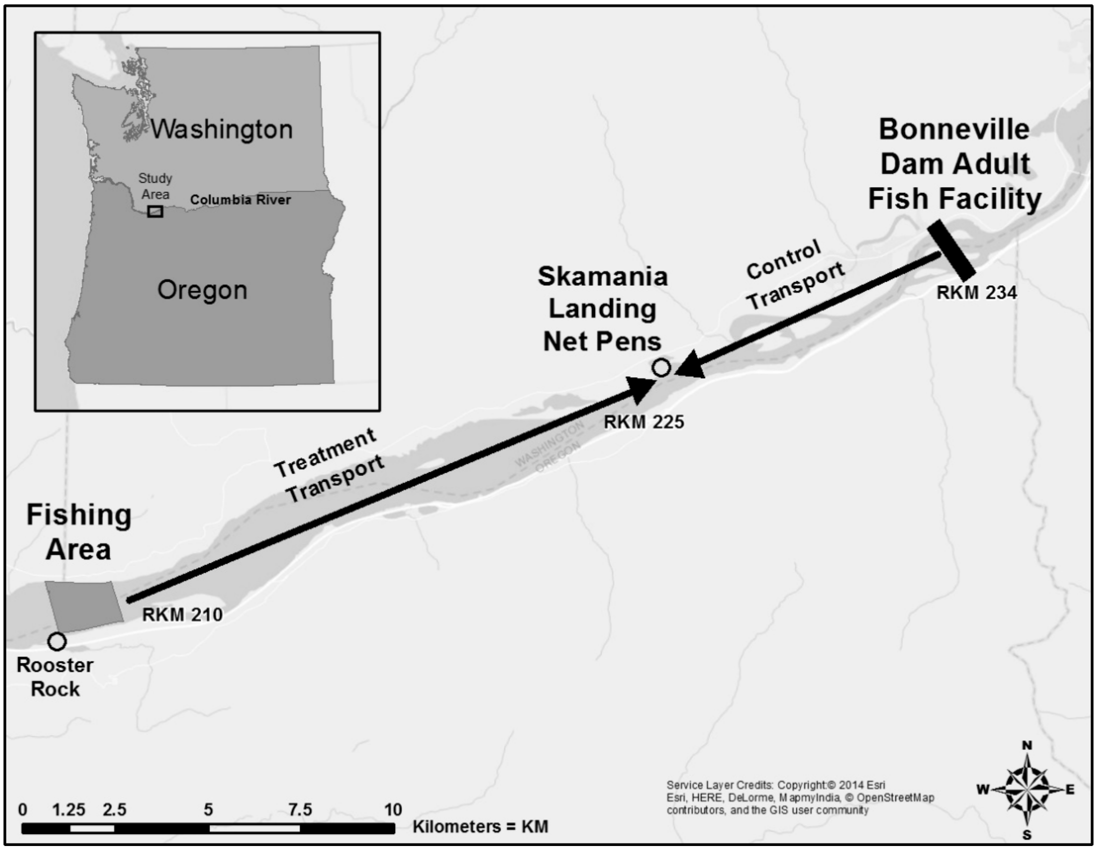

Figure 1. Map of study area, coinciding with Columbia River Commercial Fishing Zone 5.

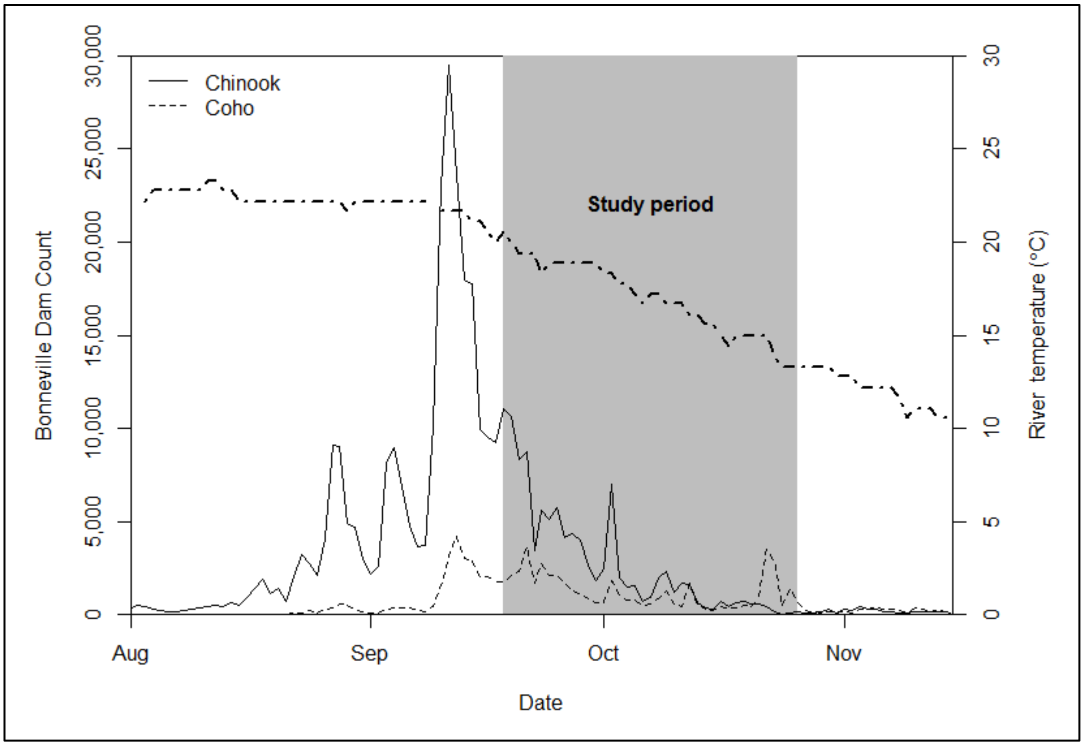

Figure 2. Daily passage of fall Chinook and Coho salmon at Bonneville Dam in 2017 with river temperature on right axis.

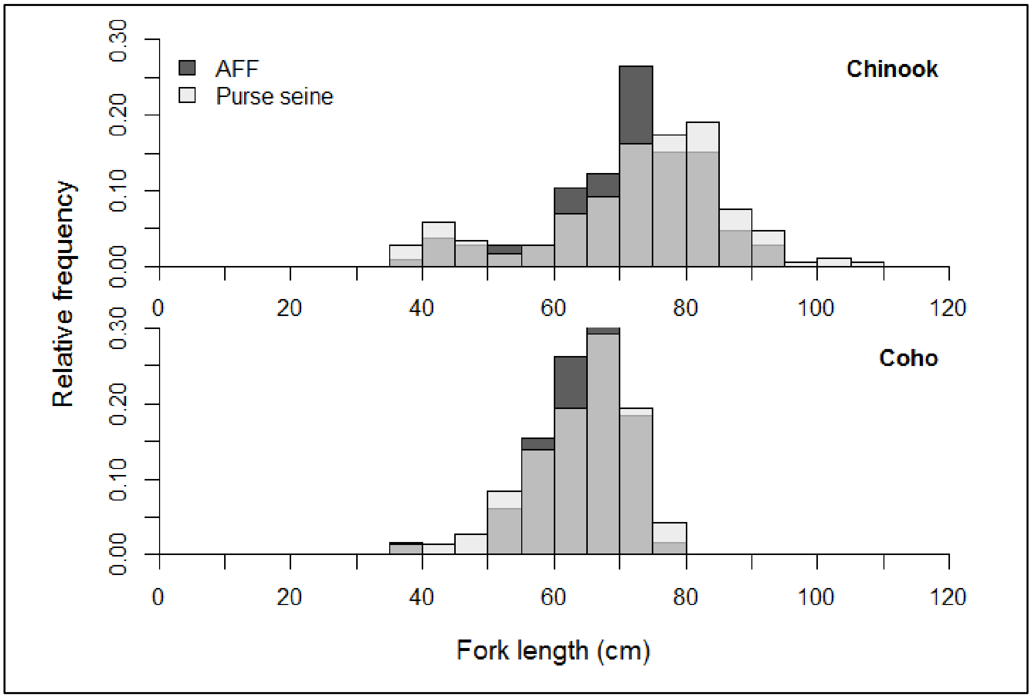

Figure 3. Relative length-frequency distributions for Chinook and Coho salmon captured in purse seines (treatment, dark gray bars) and at the AFF (controls, light gray bars). Bars are displayed with transparent fill; portions of bars with the intermediate gray shade indicates overlap between the experimental groups.

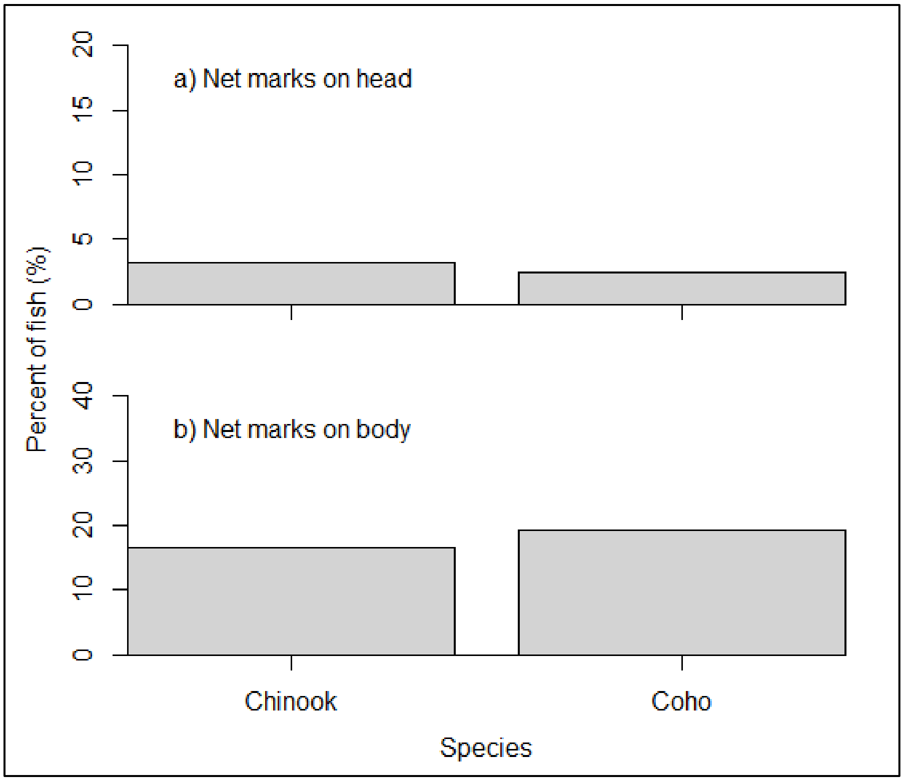

Figure 4. Percent of Chinook and Coho salmon observed with net marks at capture in purse seines, fall 2017.

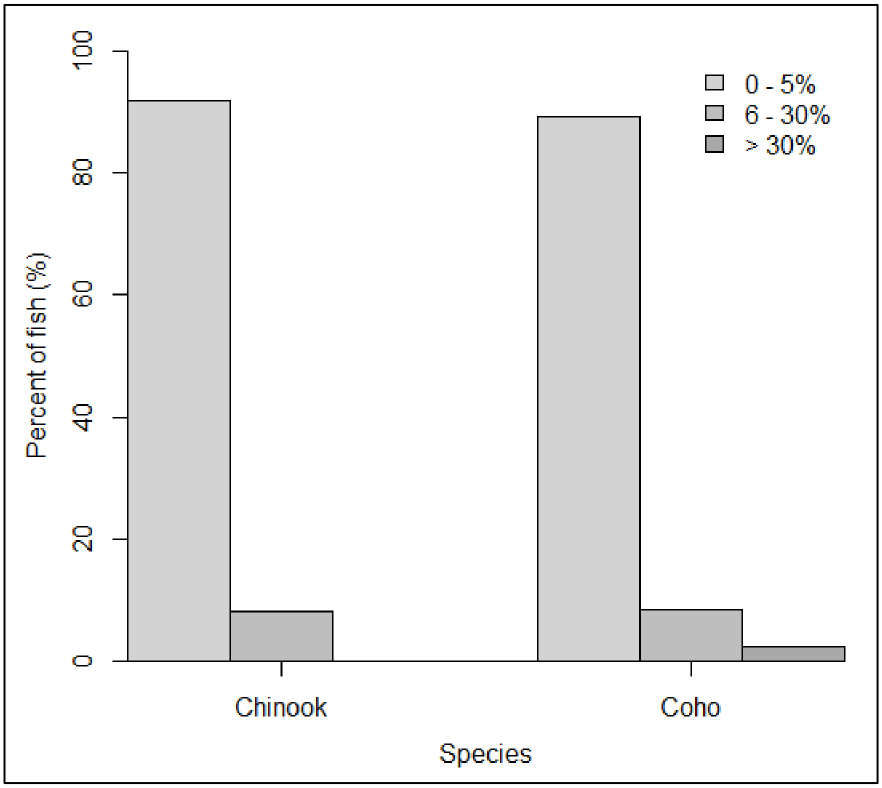

Figure 5. Percent of Chinook and Coho salmon captured in purse seines with three levels of scale loss over the body (0 – 5%, 6 – 30%, and > 30%), fall 2017.

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