Post-release mortality of fall Chinook and Coho salmon captured in lower Columbia River seine fisheries

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DRAFT

April 16, 2017

**Background**

For generations, salmon *Oncorhynchus* spp. fisheries have been an essential part of the economic and cultural foundations of Columbia River communities. Native American tribes of the Columbia Basin have relied on salmon for subsistence and trade for thousands of years (Craig and Hacker 1940). In the mid-1800s, European settlers built entire communities around salmon fishing in the lower Columbia River (Craig and Hacker 1940). Salmon fisheries remain an integral part of the culture and economy of the Pacific Northwest, despite many salmon and steelhead *Oncorhynchus mykiss* populations being listed under the federal Endangered Species Act (ESA). In recent years sport and commercial salmon fisheries in the lower Columbia River have been estimated to generate $29.3 million annually to personal incomes (TCW 2008). Fisheries in the Columbia River are constrained by ESA impact limits established by the National Marine Fisheries Service (NMFS) for threatened or endangered stocks. Allowable ESA impacts are shared among stakeholders including Native American tribes, recreational anglers, and non-tribal commercial fishers.

For the past century, hatcheries were considered the primary solution to supplement harvest and mitigate declines in natural salmon and steelhead populations in the Pacific Northwest. In recent years, accumulating evidence suggests hatchery fish may actually be inhibiting the recovery of wild stocks. Hatchery salmonids can adversely affect wild stocks through competition at all life stages, but particularly for juvenile life stages where large numbers of hatchery fish are released into natal streams (Tatara and Berejikian 2012). Hatchery fish have also been shown to have lower fitness than wild fish (Araki et al. 2008, Christie et al. 2014). Thus, the overall fitness of wild populations can be reduced through introgression with hatchery fish (Araki et al. 2009). Growing concerns over the interactions between hatchery and wild salmonids prompted the US Congress to form the Hatchery Science Review Group (HSRG) in 2005. A system-wide review of hatchery programs in the Columbia River Basin was completed by the HSRG in 2009. The HSRG determined that achieving harvest and conservation goals for salmon and steelhead in the Columbia River basin would require both hatchery and fishery reforms. As part of these reforms, the HSRG concluded that increasing selective harvest of hatchery fish could produce conservation benefits for natural-origin salmon populations by reducing the abundance of hatchery fish that escape to spawn in natural populations. Subsequently, the state of Washington adopted policies to reform hatchery practices (WA Policy C-3619) and fisheries in the lower Columbia River (WA Policy C-3620). Developing alternative commercial fisheries is now a high priority for both fishery and hatchery reform goals in the lower Columbia River. Fisheries that allow for selective harvest of hatchery fish would simultaneously increase opportunity for the commercial fishing industry.

From the mid-twentieth century until recent years, fall Chinook *Oncorhynchus tshawytscha* and Coho salmon *Oncorhynchus kisutch* were harvested exclusively with gill nets in commercial fisheries on the lower Columbia River. In these fisheries, all Chinook and Coho captured were harvested, including stocks listed under the ESA. Purse and beach seines are being considered as alternatives to gill nets for lower Columbia River fishery reforms. These gear types may allow natural-origin fall Chinook and Coho salmon to be released with a high likelihood of survival, which would enable commercial seine fisheries to selectively harvest hatchery fish. Since 2011, WA and OR have conducted beach and purse seine fisheries on a trial basis. Full implementation of commercial seine fisheries in the lower Columbia River has been precluded largely due to uncertainty surrounding post-release mortality rates for fall Chinook and Coho salmon. Post-release mortality was estimated for steelhead using a mark-recapture study design (Rawding et al. 2016). Similar methodology was employed for a previous WDFW study of fall Chinook and Coho salmon; however, the Washington Fish and Wildlife Commission and WDFW were concerned about bias in the mortality estimates because critical assumptions of the mark-recapture approach did not appear to be met (WDFW, unpublished data). Specifically, the previous design relied on the assumption that fish released from seines (treatment) had the same recapture probability as control fish obtained from the Adult Fish Facility (AFF) at Bonneville Dam. WDFW is proposing to conduct another mortality study utilizing different methodology to address the concerns over the violation of this critical assumption in the previous study. The proposed containment study eliminates the need for assumptions about recapture probability between treatment and control fish because all mortality will be directly observed. This study is necessary to lessen remaining uncertainty about post-release mortality rates for fall Chinook and Coho salmon caught in purse and beach seines, and will build on a the body of information regarding selective commercial fishing gears in the Columbia River. Quantifying post-release mortality for fall Chinook and Coho salmon in purse and beach seines will provide fishery managers the necessary information to determine if these fisheries can selectively harvest hatchery salmon while allowing natural-origin fish to be released with a high likelihood of survival.

**Study Design**

*Methods*

A short-term containment study will provide valuable information to address uncertainty regarding post-release mortality of fall Chinook and Coho salmon captured in purse seines. Key points for containment-type studies to estimate post-release mortality are: 1) the assumption that the mortality due to being caught in the gear occurs during the holding period, and 2) the use of a control group to account for handling and containment effects (Pollock and Pine 2007). Without including a control group, post-release mortality estimates may be biased high because mortality due to handling cannot be quantified independently from mortality due to capture in the gear. This approach requires assuming that the handling and containment effects are equal for treatment and control fish.

Commercial fishers will be contracted to conduct purse seine sampling in the Columbia River downstream of Bonneville Dam from September through October 2017. Both Chinook and Coho salmon captured in the seine gear will be held for 48 hours to monitor survival. Any steelhead captured in seines will be measured for stock (i.e., total length greater or less than 78 cm), have a DNA sample taken and then be released immediately. A 48 hour holding period was chosen because similar holding studies by the Oregon Department of Fish and Wildlife (ODFW) have shown that Coho salmon captured by tangle nets and held for up to eight days experience most mortality within 48 hours (ODFW, unpublished data). Immediately upon capture, fish will be scanned and if they already contain a Passive Integrated Transponder (PIT) tag fish will be released and not included in the study. All treatment fish will be anesthetized with AQUI-S, tagged in the pelvic girdle with a PIT tag and sampled for biological data. Biological data including fork length, visual stock identification (i.e., tule fall Chinook or bright fall Chinook), and reflex assessment mortality predictor (RAMP) metrics (Davis 2010) will be recorded in digital data collection forms by WDFW staff. Rubber dip nets will be used to remove fish from the seines to reduce loss of scales and protective mucous during handling After sampling is complete, fish will be moved to covered totes with circulating water to recover from anesthesia and be transported by boat to the net pen site. Equal numbers of control fish will be obtained from the Adult Fish Facility at Bonneville Dam and mixed with treatment fish in net pens. Identical tagging and biological sampling protocols will be applied to control fish collected at Bonneville Dam. Control fish will be transported from Bonneville Dam to the net pen site in hatchery tanker trucks, then transferred to the transport boat and taken to the net pens. Individuals handling the fish will be rotated among the treatment and control groups daily to standardize effects that could result from variation in handling technique.

Large net pens (6m × 6m × 3m) will be used for holding fish in the Columbia River. The net pens will be located at a low flow (<0.5 m/s) site and attached to pilings and/or anchored to the riverbed to keep them in place. Pens will be covered to deter predators from entering the pen and to prevent fish from escaping; pens will also include protective framing surrounding the netting to deter predators from accessing the pens from below. The holding capacity of each net pen will be restricted to a maximum of 30 fish to minimize crowding stress. After the holding period, the PIT tag numbers and disposition of all individuals in the net pens will be recorded and the fish released directly into the river. If the mortality rate for both treatment and control fish during the holding period exceeds 50%, the study will be discontinued until the source of the mortality is discovered and addressed. A digital thermograph will be affixed to the net pens to record water temperatures for the duration of the study. Ideally, net pens will be located at sites that minimize transport time for both control and treatment fish.

It is important to note that the AFF can be shut down by the Bonneville Dam Fish Passage Operation and Maintenance group (FPOM) if water temperatures exceed 21°C (70°F). Temperature restrictions have shut down sampling at the AFF for an average of 3.0 days during the first week of September and 1.9 days during the second week of September over the previous 10 years. Including control fish is essential in this study design to estimate post-release mortality due to seine capture. If control fish cannot be obtained from any source, it is our intention to conduct the study using seine-caught fish only. The resulting mortality estimates would likely be positively biased using only seine-caught fish because any mortality due to handling cannot be estimated separately from mortality due to being captured in the seine.

Seine fishers will be contracted to sample three times per week (e.g., Monday, Wednesday, and Friday). One replicate of this experiment will be considered a paired release of treatment and control fish into the net pens. If one or more replicates can be completed on each day of sampling, and the season extends for eight weeks, the experiment could include more than 24 replicates. With four net pens and a goal of holding 30 fish per net pen, a total of 120 fish can be held for each 48-hour period. Provided target sample sizes for treatment and control groups can be achieved, up to 360 fish could be included each week. By the end of the study period, up to 2,880 fish could be included in the experiment. However, it is unlikely that target sample sizes will be achieved every day, particularly in weeks before and after the peak of the run.

Recent studies have held salmon captured in sport or commercial gears for short periods (24 h) to quantify post-release mortality (Donaldson et al. 2011; Raby et al. 2015). In these studies, the authors noted that holding fish in net pens increased stress levels that likely contributed to long-term mortality. Sockeye salmon in Donaldson et al. (2011) were held at a density of 0.72 fish per m3 and Coho salmon in Raby et al. (2015) were held at densities ranging from 4.96 – 7.14 fish per m3. Although neither of these studies utilized a control group, each compared the relative survival of fish held in net pens to fish immediately released with acoustic tags. These studies were also based on smaller sample sizes and fewer replicates than proposed in this study; Donaldson et al. (2011) conducted only one replicate with 36 fish and Raby et al. (2015) conducted four replicates with sample size varying from 25-36 fish. This study will be using large net pens and limit the density of fish in the pens to a maximum of 0.5 fish per m3 in an attempt to minimize confinement stress. In addition, seine sampling will be conducted over 24 days, which should yield at least 24 replicates.

*Expected Sample Sizes and Precision of Estimates*

To estimate the number of Chinook, Coho and steelhead that might be caught in seines in 2017, CPUE for each species was modeled as a negative binomial distribution. Negative binomial distributions were fit to CPUE data from the pilot seine fisheries that occurred in the same river section from 2011 – 2013 as vector generalized linear models (VGLM; Ye 2015, Ye 2017). Parameters for negative binomial CPUE distributions were modeled as functions of statistical week and run size to account for run timing and the abundance of the target species. The expected CPUE distribution for each week of the study period in 2017 was predicted with the fitted VGLM models for each species given their respective 2017 run forecasts. Catch data were then simulated 1000 times from the predicted CPUE distributions to model expected sample sizes by week. Each catch simulation consisted of twelve simulated sets (2 boats conducting 2 sets each per day, 3 days per week) for an 8 week period.

Results of the CPUE simulations showed that approximately 670 fall Chinook (575-760; 95% CL) and 290 Coho (200-380; 95% CL) could be captured over the course of this study in 2017. Although steelhead are not a focal species in this study, ESA impact limits could potentially limit both lower Columbia River fisheries and research in 2017. Steelhead catch models indicated approximately 190 (120-270; 95%CL) steelhead could be handled during this study in 2017. Given the forecasted proportion of the Snake River B-run stock, approximately 2 of the 190 steelhead encountered could be wild Snake River B-run (the most limiting ESA-listed stock). Assuming steelhead stocks are captured in proportion to their abundance and a 2% post-release mortality rate for steelhead captured in purse seines (Rawding et al. 2016); our expected impacts for this research could be 0.04 (0.02 – 0.05; 95% CL) wild B-steelhead mortalities.

Simulated catch data were used to conduct a power analysis to determine the level of precision that could be expected for post-release mortality estimates derived from this study. Simulated catch data and several “best-guess” survival rates for the treatment and control groups were used to simulate live/dead data from a binomial distribution to model the survival part of the study. Simple logistic regression models were fit to the simulated survival data with only a fixed categorical treatment effect. Predicted probabilities of survival for the treatment and control groups and their confidence limits from logistic regression models were used to derive estimates of post-release mortality as the mortality of the treatment fish relative to the control group (Pollock and Pine 2007). At the expected sample sizes, survival study simulations regression simulations suggest the half-width of the 95% confidence intervals for seine post-release mortality estimates could be approximately 1.5% for Chinook and 3% for Coho.

*Data Analysis*

Mixed-effects logistic regression models will be developed to predict survival probabilities of the treatment groups and to test for individual or environmental covariates that influence survival. Covariates including handling and transport time will be considered to model the effects of handling. Temperature during capture and holding could be an important environmental covariate affecting survival of both treatment and control fish. The size of individuals or density of fish captured in each seine set could also affect survival in the seine treatment. A random effect may be included to account for replicate-to-replicate variation and to treat groups of fish caught together as the experimental unit rather than individuals (i.e., individuals captured in a seine set and held together are not statistically independent). Candidate models can be ranked using the small-sample adjusted Akaike’s Information Criterion (AICc) or another similar information criterion in the Bayesian framework. If multiple models are supported by the data, survival for treatment and control groups will be estimated using a multimodel inference approach (Burnham and Anderson 2002). Post-release mortality for seine caught fish will be estimated relative to the control group using the predicted survival probabilities from logistic regression models (Pollock and Pine 2007). Considering total instantaneous mortality (*Z*) for each of the experimental groups as the sum of handling and capture mortality, and given the assumptions: 1) mortality due to handling is equal for the treatment and control groups, and 2) that mortality due to capture of the control group is zero, mortality due to capture in the seine can be calculated as:

$M\_{seine}=1-\frac{e^{-(Z\_{seine})}}{e^{-(Z\_{control })}}$ ,

where *e-(Z)* is the finite survival rate (S) of the treatment groups (Pollock and Pine 2007). Precision of the derived seine mortality estimate can be calculated using either a delta method approximation, bootstrapping, or alternatively by conducting the analysis in a Bayesian framework.

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