**METHODS**

*Study area*. – The Upper Columbia River (UCR) steelhead Distinct Population Segment (DPS) is comprised of four steelhead populations and extends upstream from the confluence of the Yakima River to the border with Canada. Steelhead status and trend monitoring for this DPS has been occurring at Priest Rapids Dam since 1986 (Brown 1995).

*PIT tag data collection.* – PIT tagging of juvenile steelhead occurs in Columbia River tributaries and hatcheries to estimate smolt abundance, assess juvenile and adult survival, travel time, migration patterns and to address other research or management questions (e.g., Haeseker et al. 2012). In addition, adult summer steelhead were sampled at Priest Rapids Dam (PDR) at Columbia River rkm 639 during their adult migration in return years 2010 to 2017 (Figure 1, Waterhouse et al. 2020). We collected biological data, scale samples, and PIT tagged adult hatchery and wild steelhead at the PRD trap using an annual sample rate of ~ 15%. Adult steelhead PIT tag data were uploaded into the regional PIT Tag Information System database (PTAGIS, Tenney et al. 2017). The PTAGIS database (<https://www.ptagis.org/>) was subsequently queried to obtain PIT tag detections at mainstem dams on the Snake/Columbia Rivers and instream PIT tag detection sites from the adults PIT tagged at PRD. These data were formatted for analysis to estimate adult overshoot return abundance at PRD as described below.

*Overshoot fallback abundance*.– We used a Bayesian nested Patch Occupancy Model (POM) to estimate overshoot return abundance (Waterhouse et al. 2020). The model estimates transition probabilities past various detection points while accounting for imperfect detection at those sites, essentially a multi-state variation of a spatial Cormack-Jolly-Seber model. Detection probabilities are estimated using double arrays at some sites, as well as detections from sites upstream of a particular site (Figure 1). After each detection point, *j*, (including the initial one at Priest Rapids), the true location of fish *i*, *zi,j+1*, is drawn from a multinomial distribution with transition probabilities ,

and the detection of that fish at each array *k* at site *j*, *yi,j,k*, is modeled as a Bernoulli distribution with detection probability *pj,k*.

The overall probability of a fish moving past a particular detection site is the multiplication of all the subsequent downstream transition probabilities along that path. The detection probabilities, , are estimated using detections from both hatchery and wild fish but transition probabilities, , are different for hatchery and wild fish. These overall transition probabilities are multiplied by an estimate of total abundance, by origin, at Priest Rapids Dam, providing estimates of escapement past that detection site.

Escapement estimates of the four steelhead populations that comprise the UCR DPS have been estimated using the POM beginning in return year 2011 (Waterhouse et al. 2020). Some adult steelhead PIT tagged at PRD overshoot their natal stream, fallback, and ascend their presumed natal stream to spawn where they are detected (i.e., overshoot return). To account for this behavior the original model structure was extended to estimate overshoot return abundance at interrogation sites downstream of Priest Rapids Dam. Specifically, overshoot return abundances in the MCR DPS were estimated for the Yakima River at rkm 76 (Prosser Dam [PRO]), Walla Walla River at rkm 9 [PRV]), Umatilla River at rkm 5 (Three Mile Falls Dam [TMF]), the John Day River at rkm 35 (McDonald Ferry site [JD1]), and the SR DPS at Ice Harbor Dam at rkm 16 [IHA].

The PTAGIS database was queried to obtain a list of wild adult steelhead that were PIT tagged as juveniles in the Middle Columbia River (MCR) Distinct Population Segments (DPS) detected as adults at PRD and subsequently detected at other PTAGIS sites in the Upper Columbia River (UCR), MRC, and Snake River (SR) DPSs (Figure 1). These data are referred to as observed known origin steelhead and were used to estimate MCR stray percentages by population detected in the UCR and SR DPSs, overshoot abundance, stray and overshoot return survival, and migration timing.

One approach to estimate wild steelhead overshoot abundance at PDR is to use the methods of Richins and Skalski (2018) to estimate the known percentage of overshoots and expand by the population specific juvenile PIT tag rate. However, due to the complex rearing strategies of interior Columbia River steelhead juveniles, and the shift of various program objectives through time, the population specific tag rates are unknown (reference). Therefore, we developed a general relationship between the known origin overshoot tags that are detected at PRD and detected successfully falling back and entering downstream area *j* which is part of the POM in year *i* (*si,j*) and POM estimates of total overshoot return abundance (fish that crossed PRD, then fell back and entered a downstream tributary) in year *i* (*Fi*). First, we expanded the number of observed overshoot return tags by the site’s detection probability as estimated by the POM, , and then we summed the expanded estimate of overshoot return tags for that year (*ti*).

To improve the homogeneity of the variances and meet the linear regression assumptions, we log-transformed total abundance and estimated overshoot tags and then fit a linear model.

We then used that linear model to predict the total overshoot abundance that arrived at PRD (*Oi*), based on the number of known overshoot tags that were detected at PRD each year (*Ti*).

Finally, we calculated the overshoot return survival rate () by dividing the estimate of total overshoot return abundance by the total overshoot abundance at PRD, accounting for uncertainty in the overshoot return abundance from the POM.

We implemented this model within a Bayesian framework, using R (R Core Team 2019) and JAGS software (Plummer 2019). We focused on natural-origin fish, because adipose fin clipped hatchery steelhead may be harvested and harvest rates both upstream and downstream of Priest Rapids Dam are variable and unknown, making it more problematic to find a relationship between overshoot detections at PRD and overshoot return abundance downstream.

*Overshoot migration success*. – We examined the PTAGIS detection histories of steelhead tagged as juveniles in the Yakima river that were detected crossing McNary dam, the last dam downstream of the Yakima river. Fish detected within the Yakima river (e.g. at Prosser dam) were categorized as successful migrants. To evaluate the impact of dam crossings on overshoot return success, we grouped fish based on the number of dams they were observed to cross, from zero (moved straight from McNary into the Yakima river) up to five (Wells dam). Most dams have no way to detect adult fish moving downstream, except for the juvenile bypass at Rocky Reach Dam which closes August 31. Therefore, we focused on the furthest upstream dam fish were detected at during their upstream migration and pooled this data across years due to low sample size. For each group, the overshoot return success rate was calculated as the proportion of successful migrants within each group of fish. For comparison purposes only, because overshoot steelhead that were only detected at Priest Rapids Dam may have also migrated upstream of Wanapum Dam (only 31 km upstream with no PIT tag interrogation), the overshoot return rate was attributed to both dams (i.e., N = 2), while the square root of the two dam overshoot return rate was attributed to Priest Rapids Dam (i.e., N = 1). While this approach may be biased, it does provide some distinction in overshoot returns rates for steelhead that migrated upstream over one or two dams.

*Overshoot timing.* – The influence of overshoot and fallback on run timing into their natural tributary was examined at Prosser Dam by expanding steelhead PIT tag detections from Priest Rapids, at a monthly time scale, using an average tag rate of 15% (WDFW, unpublished data). The estimated monthly abundance of overshoot steelhead was compared to non-overshoot steelhead using a Kolmogorov-Smirnov (KS) test. Mean monthly water temperature in the lower Yakima River were queried from the U.S, Bureau of Reclamation Hydromet station at Kiona ([https://www.usbr.gov/pn/hydromet/yakima/yakwebarcread.html](https://www.usbr.gov/pn/hydromet/yakima/yakwebarcread.html%20)) and Columbia River from the tailrace of Priest Rapids Dam Data Access Real time (DART) website [(http://www.cbr.washington.edu/dart/query/river\_daily](file:///C:\Users\murdoarm\AppData\Roaming\Microsoft\Word\(http:\www.cbr.washington.edu\dart\query\river_daily)) in 2015.