DECISION SUPPORT MODELING FOR OUTPLANTING ADULT CHINOOK SALMON IN THE SANTIAM RIVER BASIN

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Trap-and-haul outplanting of adult spring-run Chinook salmon is an ongoing fish management strategy in the Santiam River basin and in other Willamette River tributaries. Understanding the productivity of outplanted adults and their contribution to subsequent adult returns (i.e., cohort replacement) is critical to evaluating the efficacy of the outplant programs. However, empirical estimates of replacement are difficult to generate due to the life history complexity and variable survival of juveniles and the presence of multiple adult age classes per cohort. Currently, the most reliable method to estimate cohort replacement is the use of genetic pedigree or parentage analysis, where returning adults are genetically matched to outplanted parents. In this study, our goal was to develop a statistical model-based method for estimating the relative success of outplanted cohorts.

The productivity of outplanted adults and their contribution to subsequent adult returns varies annually as a function of environmental and operational factors that affect life history pathways and stage- and reach-specific survival rates. Consequently, there is considerable uncertainty about the overall efficacy of the two Santiam River adult outplant programs. Outplanting is nonetheless expected to continue as an interim management strategy while work progresses to improve fish passage and adult salmon management plans evolve at dams in the North and South Santiam basins. Successful progeny of fish outplanted above Detroit and Foster dams do return to the Minto and Foster adult facilities and are considered natural-origin (NOR) adults. However, the genetic pedigree evaluations in several Willamette Basin Chinook salmon populations outplanted above dams have shown that adult returns rates have been below replacement and have even approached zero in some years, including in the McKenzie River, South Santiam River, North Santiam River, and Fall Creek. Optimizing the effectiveness of the outplant program in the Santiam River basin therefore requires information on the relative risks and benefits of outplanting adult Chinook salmon at different times and locations. We addressed four general objectives in our study:

1) summarize available information on adult Chinook salmon outplanting and prespawn mortality, and juvenile Chinook salmon life history pathways in the Santiam River basin;
2) construct models of cohort replacement rate (CRR) parameterized using life history pathway information and stage-specific survival data from a variety of Willamette River research sources;
3) parameterize the models to evaluate Chinook salmon CRR in the Santiam basin under a variety of management and operational scenarios; and
4) build interactive, web-based Shiny apps that allow model users to explore how user-defined parameters values affect CRR.

Methods. Our approach was to build models of cohort replacement rate (CRR) for each Santiam River sub-basin using reach- and stage-specific salmon survival parameters and life history (LH)

transition probabilities nested within a framework of juvenile LH pathways. Given the spatial complexity and juvenile Chinook salmon life history diversity in both sub-basins, we built separate models for adults outplanted from the Minto (North Santiam) and Foster (South Santiam) adult facilities. Model parameter values were derived from a mix of sources, including the Willamette River life cycle model for Chinook salmon SLAM (Species Life-cycle Analysis Modules), the U.S. Army Corps of Engineers' Fish Benefits Workbook (FBW), Hatchery and Genetic Management Plans (HGMPs), and a variety of monitoring and research programs (i.e., prespawn mortality surveys, screw trap sampling, juvenile telemetry studies, etc.)

We developed three primary metrics to compare results across CRR model scenarios. These were: cohort replacement rate (CRR), fractional CRR to quantify the contribution of each LH pathway, and compound survival from egg to adult for each LH pathway. CRR is the number of future adult females produced by a single cohort of outplanted females divided by the number originally outplanted. The fractional CRRs for each population are additive across LH pathways and allow visualization of the contribution of each LH pathway to the total CRR given alternative outplant scenarios and LH pathway composition within a cohort. Compound survivals provided a complimentary metric of expected *per capita* performance under a given scenario independent of LH pathway composition or relative abundance. To help model users further explore how key parameters affect results, we created Shiny apps for the North and South Santiam CRR models that create graphical summaries of results and parameter sensitivity surfaces based on user-selected parameter values.

Results In our baseline models, predicted CRR values were broadly comparable to empirical estimates of CRR from genetic pedigree studies and to recent smolt-to-adult (SAR) estimates in the North and South Santiam basins. This congruence demonstrates that the models reasonably approximated the overall patterns of productivity and survival in the populations. The average CRR simulations in the North Santiam model were well below replacement at 0.686 for adults outplanted below Big Cliff Dam and 0.199 for adults outplanted above Detroit reservoir. In the South Santiam, the average was 0.410 for adults outplanted above Foster reservoir and was 0.020 for adults outplanted above Green Peter reservoir. Fractional CRR values showed that some juvenile LH pathways were much more successful than others. Across models, it was evident that some survival and life history parameters need better empirical support, especially for early life history stages (i.e., fry and subyearlings).

The North and South Santiam Shiny apps were published on the Shiny server and are available to users at: https://mete-yuksel.shinyapps.io/NSAN_model/ and https://mete-yuksel.shinyapps.io/SSAN_model/. In addition to providing CRR estimates and fractional CRR, the app provides plots of outputs across all values of key parameters as response surfaces, allowing trade-offs and optima to be visualized.

Management Implications. One of our primary conclusions for the North and South Santiam River outplant programs is that the baseline CRR simulations, as well as several competing management scenarios with modified parameter estimates, generally produced mean and median CRR values <1.00 in both sub-basins. This may indicate that the assumed LH pathways poorly represent reality or that model parameter values are too conservative. We relied heavily on the

parameters documented in the 2015 SLAM and FBW documentation, around which there is remaining uncertainty and year-to-year variability that we did not attempt to model. In our opinion, parameter estimates for the younger juvenile age classes have the least empirical support. Parameters that could be most improved by additional field research and monitoring include 1) egg-to-fry survival, 2) fry and subyearling survival in reservoirs, 3) survival of all juvenile age classes in the Santiam rivers downstream from Big Cliff and Foster dams, and 4) survival of all juvenile age classes in the Willamette River and Columbia River Estuary. The CRR models do demonstrate that some juvenile LH pathways are more successful than others, suggesting there may be opportunities to increase adult returns through operations that affect specific juvenile age classes and/or survival at dams, in reservoirs, or in downstream reaches.