Effective Hatchery Releases to Increase Adult Returns of Chum Salmon in the Ishikari River, Hokkaido, Japan

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Hatchery practices have a marked effect on the size at, and timing of, ocean entry of hatchery-reared Pacific salmon (*Oncorhynchus* spp.) (Weitkamp et al. 2015). Because both of these factors play such a crucial role in the early survival and growth of hatchery-reared and wild salmon juveniles during the period of coastal residency (Quinn 2005), hatchery practices have a direct effect on the growth and survival of hatchery-reared fish. The relationship between juvenile releases and adult returns for salmon with otolith thermal marks is expected to provide insights into the causal effects of hatchery practices on differences in salmon survival. To test this hypothesis, the effects of release parameters (e.g., release numbers, release date, and size at release) and the water temperature of the release river (near the release point; hereafter, river water temperature (RWT) and at sea (near the river mouth; hereafter sea surface temperature (SST) on adult returns to the Ishikari River were investigated in chum salmon released with thermal otolith marks.

The Ishikari River in Hokkaido, Japan, flows into the Sea of Japan. The river and its catchment area are the third longest and second largest in Japan at 268 km and 14,330 km², respectively. There is only one salmon hatchery, the Chitose Salmon Field Station (CSFS), on the Ishikari River. The CSFS produces approximately 30 million juvenile chum salmon annually for release into the river. In the 1998 brood year, a subpopulation of the hatchery-reared juveniles was subjected to otolith thermal marking; since the 2001 brood year, almost all released juveniles were marked using this method. During August to December of every year, adult chum salmon returning to the river are captured using a fish wheel installed approximately 10 km downstream from the CSFS. During the upriver migration season, a monitoring survey is conducted by CSFS staff at approximately 10-day intervals. At each survey, 100 fish are randomly selected and examined for body size, age (scales), and hatchery release group (otoliths); in this way, approximately 1,000–1,200 fish are sampled for monitoring purposes in the Ishikari River each year. Based on the findings, the number and age of hatchery-reared adults returning to the river can be estimated. In this study, release information and adult return numbers for fish aged two to five years old with 63 different otolith markings were used to compile a dataset of year class strength for each marking group over the period 2001–2014. These data were then analyzed using a general additive model (GAM) in which the adult return number for each otolith thermal marking cohort was used as a dependent variable, and the effect of brood year (as a categorical variable), release date (Julian date), size at release, RWT, and SST were treated as explanatory variables. These variables were used to examine the effects of hatchery release practices and water temperatures on adult return numbers for each thermally marked otolith cohort. In all the constructed models, the number of released juveniles was included as an offset variable, and models with different explanatory variables were ranked using Akaike's Information Criterion (AIC). To avoid problems associated with multicollinearity, since the variables of release date, RWT, and SSTs were strongly correlated with each other ($r = 0.81$ – 0.86 , $n = 63$, $p < 0.0001$), they were not used as explanatory variables in the same model runs.

Of 16 models examined in this study, the top four models with the lowest AIC scores showed small differences in the AIC (i.e., $AIC_i - AIC_{min}$, where i indicates the i -th model, and min denotes the model having the lowest AIC for the 16 models) ranging from 0 to 1.82. The model with the lowest AIC used brood year effect, size at release, and SST as explanatory variables. Although the latter two variables were assumed to have been included as smooth terms, the effect of size at release on the dependent variable was fitted as a linear function. In the second and third models, release date and RWT were selected, respectively, instead of the SST of the first model. The fourth model consisted of the brood year effect and size at release. Based on the model findings, adult returns in the Ishikari River could potentially be increased by releasing juveniles with a mass ≥ 0.73 g after March 30, or when the RWT and SST are $\geq 4.6^\circ\text{C}$ and $\geq 5.3^\circ\text{C}$, respectively.

Hatchery practices are expected to change gradually in response to the changes in river and/or coastal seawater temperatures brought about by climate change in the future. Consequently, the monitoring of fish that have been thermally marked, as demonstrated by the findings of this study, will be indispensable for developing robust and sustainable hatchery practices that will help to mitigate against future changes in the environment.

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