Ecological Predictors of Marine Survival for Coho Salmon in Washington State

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Annual marine survival rates of coho salmon can vary by an order of magnitude, resulting in a challenge for fishery management in the Pacific Northwest. In Washington State, run size forecasts rely on predictions of marine survival. Hatchery coho run sizes are predicted from recent-year average marine survival rates, and wild coho salmon run sizes have been predicted from historical average ratios of jack (age-2) to adult (age-3) returns. A framework is needed to expand wild coho salmon marine survival predictions to non-monitored systems where jack returns are unknown. In addition, the correlation between jack and adult returns has degraded in recent years requiring further exploration of factors useful for predicting coho salmon marine survival.

The goal of this study is to improve understanding of the marine ecological factors that explain coho salmon marine survival. Our approach considers the marine environment to be heterogeneous at different scales. For example, previous studies suggest that the combination of coastwide (Hare et al. 1999), regional (Beetz 2009), and local (Babson et al. 2006; Moore et al. 2008) scales should contribute to the marine ecology of salmon in general. In this study, we first identify the appropriate spatial scale for explaining trends in Washington State coho salmon stocks and then ask what ecological indicators and scale are the best predictors of marine survival.

We included a total of 17 hatchery and 8 wild coho salmon stocks. Stocks were geographically representative of three major regions in Washington State–Puget Sound, Coastal Washington, and the Lower Columbia River. Marine survival (pre-fishing) was estimated from releases and recoveries of coded-wire tagged hatchery and wild coho salmon for the 1983 to 2011 return years. Hatchery and wild coho survival in the same basin were considered separately because, although they were generally correlated, correlations differed from a slope of one suggesting that wild coho salmon were better able to take advantage of good marine conditions.

A correlation matrix of stock-specific marine survival supported the regional distinctiveness of Puget Sound, Coastal Washington, and Lower Columbia stocks, which was consistent with a previous study that included a subset of these stocks (Beetz 2009). Within the Puget Sound region, marine survival was not synchronous across the oceanographic sub-basins for either hatchery or wild coho salmon. We considered Puget Sound sub-basins (North Sound, Whidbey Basin, Central Sound, South Sound, Hood Canal, and Juan de Fuca) to be the appropriate scale to investigate factors contributing to marine survival. Within the Coastal Washington region, marine survival was not synchronous between north-coast and south-coast stocks. We concluded that the appropriate scale for coho salmon stocks on the Washington Coast was a division between the south coast (Grays Harbor to Willapa River) and the north coast (Quillayute River to Quinault River). Within the Lower Columbia region, coho salmon marine survival was well correlated among stocks and we considered a single average marine survival to be representative of fish from this region.

We selected indicators at three spatial scales. Atmospheric indicators were representative of global climate of the North Pacific. Regional indicators represented marine productivity in the areas of interest (coastal shelf for Lower Columbia and Washington Coast and Strait of Juan de Fuca for Puget Sound). Local indicators were associated with the smolt transition between freshwater and the immediate marine environment. Ecological indicator data were provided by a number of long-term monitoring studies (see Acknowledgments). Multiple linear regression was used to test the contribution of each indicator variable to coho salmon marine survival. An Akaike information criterion (AIC) model selection process was used to determine which combination of indicators best explained the marine survival data. The relative weight was calculated for each indicator using models with a cumulative AIC weight of 0.95.

The best models explained between 12 and 83% of the variation in coho salmon marine survival. The selected indicators did not significantly predict survival in two areas (Central Sound wild- and South Sound hatchery-origin fish). These results should improve forecasts over current methods; however, predictions of marine survival for some stocks still involve considerable uncertainty. Ecological indicators from all spatial scales were included in the best-fit models. Results for the Lower Columbia indicated regional and local indicators had higher relative weights than atmospheric indicators, and indicators for hatchery and wild coho salmon differed from each other. In the coastal Washington model, atmospheric indicators had a high relative weight for the wild coho, whereas regional indicators had the highest relative weight for hatchery coho salmon. Indicators also differed between north- and south-coast hatchery coho salmon that was consistent

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with the survival trends between these areas. In the model for Puget Sound, regional and local indicators had higher relative weights than atmospheric indicators across all sub-basins, with the exception that the regional indicators selected were not good predictors of North Sound hatchery coho salmon survival. Prediction of North Sound coho salmon survival might be improved by selecting a regional productivity indicator from the Strait of Georgia. The relative weights of the selected indicators differed among Puget Sound sub-basins and between wild and hatchery coho salmon from the same sub-basin, which was consistent with the different survival trends observed by area and origin.

In conclusion, marine survival of coho salmon stocks in Washington State is best understood by variation at a fairly localized scale (river mouth distances 50 to 140 km), which suggests that local factors (either freshwater or marine) are making a substantial contribution to cumulative marine survival over the 18-month ocean residency of coho salmon.

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