07-08
Project Title: Incorporation of ocean environmental variation in the Klamath River fall
Chinook (KRFC) salmon stock assessment

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Goals:
We aim to improve the current KRFC ocean stock abundance forecast model by incorporating
environmental variables. This could constitute a significant improvement in the Pacific Fisheries
Management Council's (PFMC) ability to manage KRFC salmon harvest, and will improve the
justification for highly restrictive ocean salmon fishery regulations off the coasts of California
and Oregon, when required based on the KRFC abundance forecast. We also have the goal of
determining the vital rates that are most dramatically affecting variability around the current
forecast models.

Approach:
Environmental data included three-month averaged seasonal estimates of sea surface
temperature, sea level height, curl, upwelling, wind stresses, spring transition date, and Klamath
River flow obtained from the Northern California region (Cape Mendocino, CA to Cape Blanco,
OR). Salmon abundance data was obtained from annual reports of the PFMC and maturation rate
data was obtained from the California Department of Fish and Game.

Path analysis- Path analysis was used to determine the direct, indirect, and total effects of a suite
of environmental variables on ocean abundance. A path analysis begins with the variables of
interest arranged in a hierarchical fashion representing the demonstrated causative relationships
between variables (e.g. wind stresses drive, in part, upwelling) and/or accumulated variance (e.g.
sea level height represents the accumulated variance of many factors including upwelling and
wind stresses). Given an *a priori* defined path structure, successive stepwise regressions are then
used to test the significance of the relationships between the variables and, hence, the paths. It is
important to note that while path analysis quantifies the degree of colinearity between variables,
it does not correct for it.

Partial least squares regression (PLS)- PLS is an extension of multiple regression that is
appropriate for identifying a relationship between a dependent variable and a large set of
independent variables When an ordinary multiple regression analysis includes many
independent variables, colinearity among them often becomes a problem. PLS regression
circumvents this problem by finding orthogonal sets of linear combinations of independent
variables in the order of decreasing correlation with the dependent variable and retaining the
significant linear combinations (latent variables) in the model. In this analysis, we used the
residuals from the ordinary linear regression current forecasting model as a dependent variable
and the significant environmental variables selected in the path analysis as independent
variables.

Generalized Additive Models (GAMS)- As an alternative to the path and partial least squares regression analysis, we evaluated GAMS. GAMS are attractive in that the original environmental variables, as opposed to linear combinations of the variables, are preserved in fitted models, and this facilitates interpretation of the results.

The combination of these three approaches allowed us to build predictive models that allowed for mechanistic interpretation of the links between salmon dynamics and the environment. We also repeated the above methodologies to determine the likelihood that the environment relates to early or late maturity of males which would directly impact the sibling model regressive approach (i.e., variability in the maturation rate would translate to variability in the relationship between ocean abundance estimates and age 2 returns).

Work Completed:
The primary focus of the Fisheries and the Environment program is to promote research that can be directly used to incorporate environmental variation into fishery stock assessments and management. We have demonstrated that by incorporating a multivariate environmental factor into the current age 3 ocean abundance forecast model that there is a moderate improvement in model fit (improvement from $R^2 = 0.44$ to $R^2 = 0.78$) for the 1993–2007 period. Figure 1 demonstrates the effectiveness of this new hybrid model.
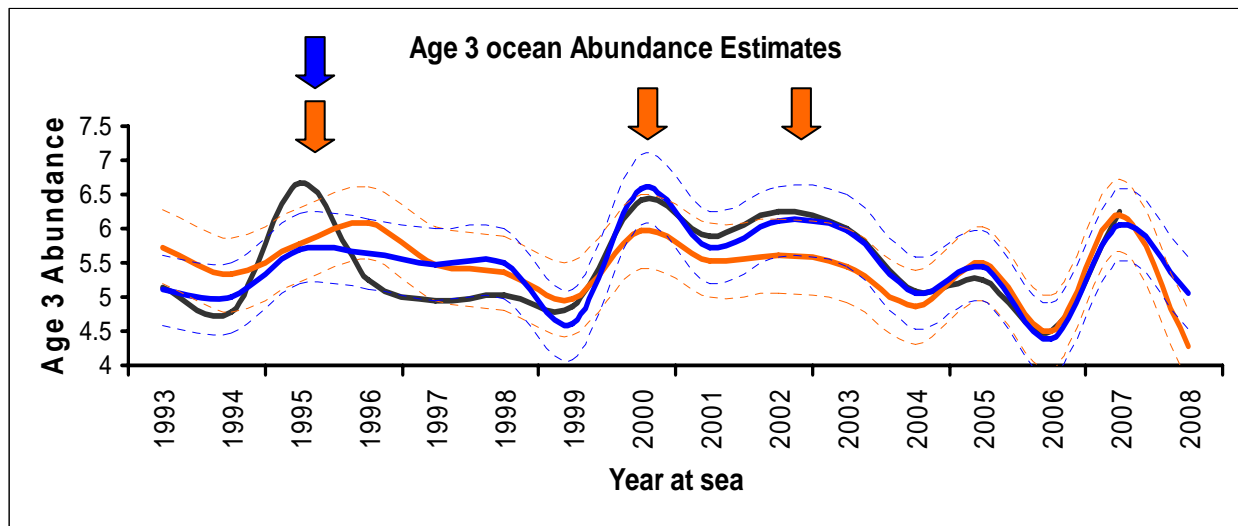

FIGURE 1: Grey line represents age 3 ocean abundances 1993 - 2007. Orange line represents estimates from the current sibling model and blue line represents estimates from the hybrid model developed in this project. Dashed lines represent the mean square errors of prediction. Orange and blue arrows point to years when the sibling and hybrid models failed to fit the observed ocean abundance, respectively.

Examination of the GAMS used to develop these models indicate that error around the current sibling model can be attributed to variability in vital rates during the second year at sea; the year of the age 2 return on which the age 3 ocean abundance forecast is based. Specifically, second year spring and summer values of sea level height, sea surface temperature, and curl were negatively correlated to error around the sibling model. When sea level height, sea surface temperature and curl increased, as is indicative of poorly productive conditions, age 3 ocean abundance was overforecast. However, as upwelling during the second year spring and summer improved the sibling model underforecast age 3 ocean abundance.

Variability in the sibling model is due to variability in the age 2 maturation rate and variability in age 3 natural mortality. That second year environment is the most highly correlated factor to residual variability about the sibling model leads us to suspect that the vital rate most altered by the environment in later life (that after the first year mortality) is early maturation of males. Specifically, an environment representative of poor ocean production in the second winter and spring (i.e., decreased upwelling, increased river flow, and later transition to an upwelling season) leads to a higher maturation rate of age 2 males. This is supported by results of cohort reconstruction analyses of coded-wire tagged fish from Iron Gate and Trinity River hatcheries.

It is worth noting that we attempted these approaches to improve age 4 abundance estimates with limited success. Little was gained toward improving forecasting by including environmental variables into the model.

Applications:
The forecast model we have developed for the ocean abundance of KRFC age 3 salmon is promising for application in that the model appears to fit the historical data better than the current sibling-only forecast model that is currently used for the KRFC stock assessment. Whether this model offers improved predictive power over the current forecast model, however, remains to be determined. We have used this same modeling approach to model the abundance of Central Valley Chinook salmon and these results, although preliminary, also appear promising and are currently being considered by a NMFS interagency workgroup that is examining the potential causes for the recent decline of certain west coast salmon stocks.

Publications/Presentations/Webpages:

Wells, B.K., J. Field, M. Fujiwara, C. Grimes, B. MacFarlane, M. Mohr, and M. O'Farrell. 2008. Examination of the effects of environmental variability on cohort dynamics of Central Valley and Klamath River, California Chinook salmon. Salmon Ocean Ecology Symposium, Nanaimo, CAN.

Wells, B.K. 2008. Effects of climate change in marine environment on salmonid populations. Invited presentation to the Protected Resources Division Workshop.

Wells, B.K. 2008. Untangling the relationships between variability in the marine environment, populations dynamics, and community structure. Invited seminar to NOAA Fisheries Ecology Division.

Wells, B.K. 2008. California Current large marine ecosystem recent conditions, trend, and forecasting: Southern CA Current. Interagency Salmon Decline Working Group.