Appendix

Estimating Northern Rock Sole recruitment in the last (most recent) 6 years of the assessment using environmental covariates

Dan Cooper, Lauren Rodgers and Tom Wilderbuer

Difficulties exist in estimating northern rock sole recruitment at young ages since they do not appear in BSAI survey catches until age 3 and not in survey age sampling until age 4 or 5. They are estimated to be 25 and 40% selected by the survey trawl (males and females respectively) at age 3 and 95 and 98% selected at age 5. The age 4 and 5 fish that do end up in the age samples are quite rare, typically only 7 fish out of 500 on an annual basis. Therefore there is not a lot of information to inform the stock assessment model estimates of year class strength for the last (most recent) 6 years. Some assessments provide estimates for the last 3 years by using an average of the estimated values to provide more credible values of year class strength. Here we propose to use two environmental covariates in regression modeling to estimate the unknown recruitment, and then compare those estimates with future estimates derived from fitting full age composition data in the stock assessment model.

Studies on the influence of environmental variables on BSAI northern rock sole recruitment have shown that both on-shelf springtime winds (Wilderbuer et al. 2002, Wilderbuer et al. 2013) and above average water-temperatures in nursery areas (Cooper et al. 2014, Cooper and Nichol 2016) are positively correlated with northern rock sole recruitment. Spring wind direction was obtained from the Ocean Surface Current Simulation Model (OSCURS) and was classified as either on- or across-shelf or off-shelf, depending on the ending longitude position after 90 days of drift starting from a locale in a known spawning area. Water temperature effects were calculated from the percent of the known northern rock sole nursery area that is in the cold pool each year from survey temperature data. Both indexes extend back to 1982 for this analysis. Estimates of female spawning stock biomass were also included in the analysis for model runs when recruitment was estimated from a Ricker stock-recruitment model with environmental variables.

The analysis seeks to answer the following questions using multiple models.

Question: Do onshore winds and the size of the cold pool (as a percentage of the nursery area) affect recruitment of Northern Rock Sole?

Question: Does the effect of the cold pool on recruitment depend on the presence of favorable winds? (i.e. is there a significant interaction?)

Question: Does including wind and cold pool covariates in the stock-recruitment model improve predictions of age-4 recruitment?

How: Compare models by including single and multiple covariates in Ricker stock-recruitment models. To be parsimonious, it is worth comparing these to models without an assumed Ricker relationship, as well as more simple forecasting models. Test for an interaction between temperature and winds, because temperature may only matter if winds were onshore (i.e. the fish had to get there in the first place). Assess model performance using standard model-selection tools (e.g. AIC) as well as by using out-of-sample predictions and one-year-ahead forecasts.

We assess 13 models.

1) Ricker model
2) Ricker model with % cold pool covariate
3) Ricker model with wind covariate
4) Ricker model with % cold pool covariate + wind covariate
5) Ricker model with an interaction between % cold pool and wind (hypothesis is that the thermal conditions on the nursery grounds only matter if winds are favorable).
6) Same as above, but cold pool slope set to 0 if unfavorable winds.
7) Regression model with % cold pool
8) Regression model with wind
9) Regression model with % cold pool + wind
10) Regression model with interaction between % cold pool and wind.
11) Same as above, but cold pool slope set to 0 if unfavorable winds.
12) Previous year recruitment (t-1)
13) Running mean recruitment (t:(t-1))

We also considered GAMs, but they had overall poor predictive performance and were likely over-parameterized.

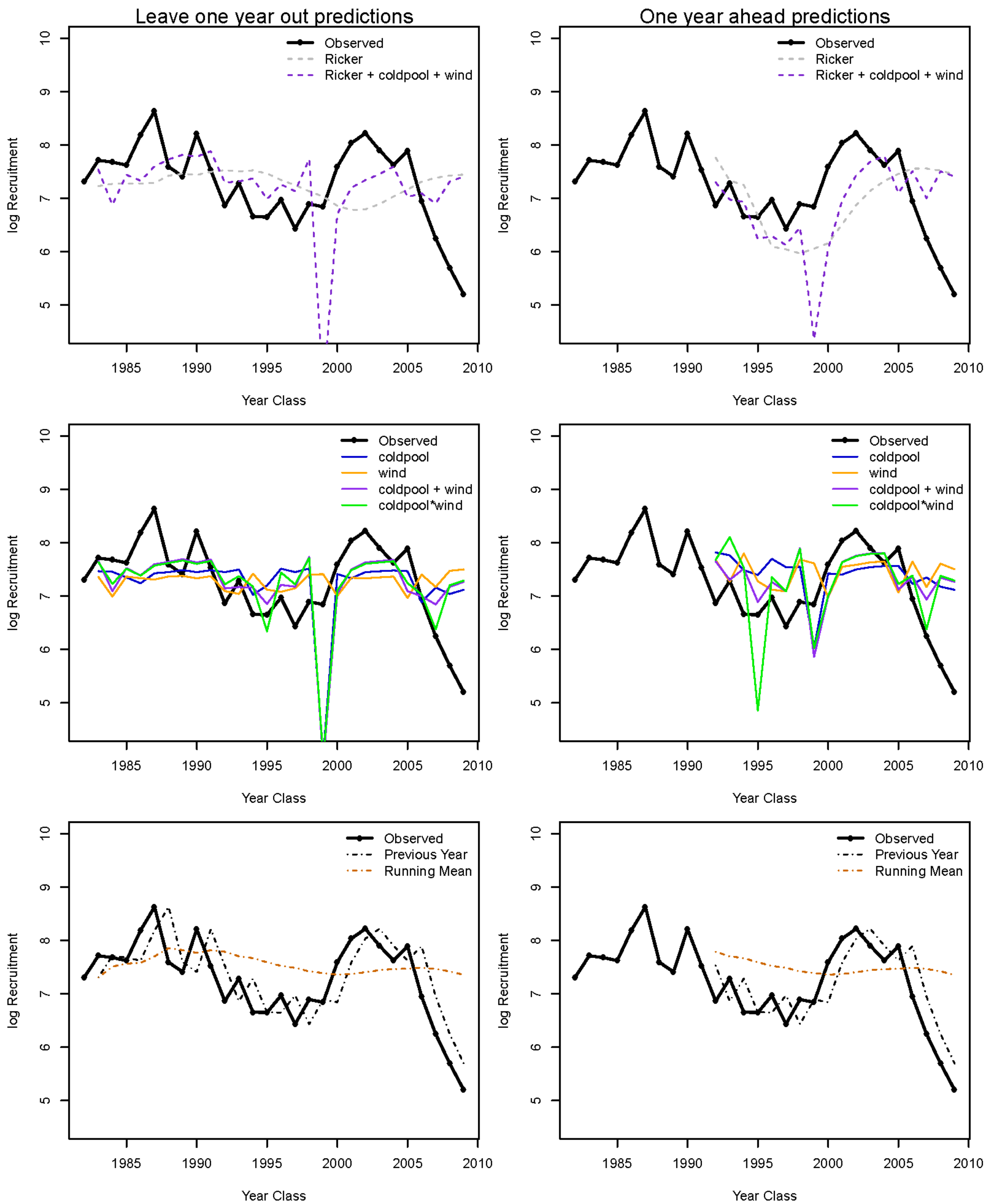
We compare model performance using traditional statistical methodology on all data (AIC), as well as by using two prediction methods. First we do a leave-one-year out analysis: we leave out one year of data, fit the model to the remaining 27 years of data, and then compare the prediction for the left-out year to the observed value. Second, we do a one-step-ahead forecast: beginning with year 11 (1992), we use the data collected up to that year to fit the model, and then compare the prediction for that year with the observation. We repeat for all remaining years. In the case of the final two models, the prediction methods will be identical.

We calculated the mean squared error for each prediction: (Observed – Predicted)^2. Because the models were fit using log(recruitment) as the response, the mean squared error is for the difference between the observed and predicted log(Recruitment). However, if the absolute difference between observed and expected recruitment is more relevant to management, the mean squared error can also be calculated based on the predicted recruitment on the real scale. In this case, Duan's smearing estimate for the log-normal re-transformation bias is used to adjust the mean of the exponentiated log-Recruitment to be equal to the mean recruitment. Both results are given in the table below.

[The assessment mentions wanting forecasts of recruitment more than 1 year in advance (up to 4 years if possible). This would change the way the model predictions are done. What would be most useful from an assessment perspective?]

Table: Mean squared error (MSE) is the mean of the squared prediction errors for each model. LOYO = Leave one year out. Lower values for MSE indicate lower prediction errors.

Model	df	AIC	MSE (LOYO, log-scale)	MSE (1 step ahead, log-scale)	MSE (LOYO, real scale)	MSE (1 step ahead, real scale)
Ricker	3	75.1	0.82	1.17	2,069,732	1,795,617
Ricker + coldpool	4	72.4	1.06	1.33	1,783,790	1,372,482
Ricker + wind	4	76.0	0.84	1.16	2,018,072	1,849,097
Ricker + coldpool + wind	5	71.3	1.04	1.19	1,547,723	1,160,685
Ricker + coldpool*wind	6	72.0	1.01	1.43	1,567,966	1,173,292
Ricker + coldpool*wind (slope=0)	5	72.9	1.08	1.25	1,639,531	1,276,978
coldpool	3	**64.8**	0.80	**0.76**	1,360,140	1,246,889
wind	3	70.0	**0.68**	0.90	1,623,021	1,510,268
coldpool + wind	4	**63.7**	0.80	**0.72**	**1,180,171**	**980,932**
coldpool*wind	5	**64.5**	**0.77**	0.90	**1,191,203**	1,219,212
coldpool*wind (slope=0)	4	**65.5**	0.83	**0.76**	**1,254,250**	**1,075,218**
Previous Year	NA	NA	**0.28**	**0.26**	1,371,833	**525,885**
Running Mean	NA	NA	**0.66**	0.89	1,531,793	1,299,166



Leave one year out predictions
One year ahead predictions
Observed
Ricker
Ricker + coldpool + wind
coldpool
wind
coldpool + wind
coldpool*wind
Previous Year
Running Mean
log Recruitment
Year Class
10
9
8
7
6
5
1985
1990
1995
2000
2005
2010

Cooper, D.W. and Nicol, D. 2016. Juvenile Northern Rock Sole spatial distribution and abundance are correlated in the eastern Bering Sea: spatially-dependent production linked to temperature. Marine Ecology Progress Series.

Cooper D, Duffy-Anderson J.T., Norcross B.L., Holladay B.A., Stabeno P.J. 2014. Northern rock sole (*Lepidopsetta polyxystra*) juvenile nursery areas in the eastern Bering Sea in relation to hydrography and thermal regimes. ICES Journal of Marine Science **72**, 515-527.

Wilderbuer, T., A., Hollowed, A., Ingraham, J., Spencer, P., Conner, L., Bond, N., Walters, G. 2002. Flatfish recruitment response to decadal climatic variability and ocean conditions in the eastern Bering Sea. Progress in Oceanography, **55**, 235-247.

Wilderbuer, T., W. Stockhausen, N. Bond. 2013. Updated analysis of flatfish recruitment response to climate variability and ocean conditions in the Eastern Bering Sea. Deep Sea Research II, **94**, 157-164.