Appendix I

Supporting Herring PDT Analyses of Rebuilding Plan Alternatives

1.0 ADDITIONAL PDT ANALYSIS OF ATLANTIC HERRING GENERATION TIME

Various definitions exist for determining generation time; for rebuilding time horizons NMFS guidance recommends defining generation time using an unfished state (Thompson et al, 1998). The default generation time included in NMFS guidance is based on Goodyear 1995 defined below. In the Atlantic herring assessment, the proportion of mature fish is calculated using samples from quarter three of each year (July-September), just prior to spawning. In recent years, age-2 are almost never mature, while age-3 fish are always >50% mature (NEFSC, 2018).

The PDT discussed that while fish may be in spawning condition in year 3-4 they may not successfully spawn until later. Therefore, the PDT calculated generation time using the formula below, consistent with NMFS guidance.

$$G = \frac{\sum_{a=1}^{A} a E_a N_a}{\sum_{a=1}^{A} E_a N_a},$$

where a denotes age, A is the oldest age expected in a pristine (unfished) condition, E_a is the mean fecundity at age of females, and N_a is the average number of females per recruit alive at age a in the absence of fishing, i.e.,

$$N_a = N_1 \exp(-\sum_{j=1}^{a-1} M_j),$$

where M is the natural mortality rate. These expressions should be computed on an equilibrium per-recruit basis, i.e., setting $N_1 = 1$. When fecundity data are not available, G can be computed by replacing E_a with an age-specific vector of maturity ratios times body weight (as commonly used to compute spawning biomass).

A reasonable approximation for generation time when M is between 0.1 and 2 is 1/M + Am50. Therefore, the PDT recommends that generation time for Atlantic herring is equivalent to six years, about two years longer than the age when 50% of fish are mature (3-4 years). Natural mortality (M) for Atlantic herring is assumed to be 0.35, A_{m50} is 3 years based on the assessment, so GT = (1/(0.35)) + 3 = 5.85, or six years.

References:

Goodyear, C.P. 1995. Red snapper in U.S. waters of the Gulf of Mexico. NMFS/SEFSC Contribution MIA-95/96-05.

Northeast Fisheries Science Center (NEFSC). 2018. 65th Northeast Regional Stock Assessment Workshop (65th SAW) Assessment Report. US Dept Commer, Northeast Fish Sci Cent Ref Doc. 18-11; 659 p. Available from: http://www.nefsc.noaa.gov/publications/

Thomspon et al. 1998. Technical Guidance On the Use of Precautionary Approaches to Implementing National Standard 1 of the Magnuson-Stevens Fishery Conservation and Management Act. NOAA Technical Memorandum NMFS–F/SPO–31.

2.0 DETAILED METHODS OF AUTOREGRESIVE RECRUITMENT ANALYSES

The PDT developed a second set of projections assuming recruitment followed an autoregressive (AR; or autocorrelated) process. The Committee requested the PDT explore an EDM like approach, and this was deemed the best solution for the time and resources available. Using autocorrelated recruitment was done to maintain short-term low recruitment regardless of stock size. The AR projections do not only assume low recruitment when SSB is low, that would imply a stock recruit relationship. Instead, autocorrelation assumes annual recruitment values depend on recruitment from the previous year and some random noise.

$$R_t = e^{\mu_{\log(\hat{R})} + \epsilon_t};$$

$$\epsilon_t = \rho\epsilon_{t-1} + \omega_t;$$

$$\omega_t \sim N(0, \sigma_\omega^2);$$

$$\sigma_\omega^2 = (1 - \rho^2)\sigma_{\log(\hat{R})}^2;$$

where R_t is recruitment in year t, $\mu_{\log(\hat{R})}$ is the mean of the log-scale recruitments estimated by the stock assessment, the "hat" symbol denotes a recruitment estimated by the stock assessment (or value dependent on those estimates) and absence of a "hat" indicates a recruitment projected into the future, ρ is the degree of autocorrelation between log-scale annual recruitment deviations (see below), and $\sigma_{\log(\hat{R})}^2$ is the variance of the log-scale recruitments estimated by the stock assessment. These parameters were defined using the full time series of estimated herring recruitments from the 2020 stock assessment, and:

$$\hat{\epsilon}_t = \log\left(\hat{R}_t\right) - \mu_{\log(\hat{R})};$$

where $\hat{R}_t$ were the estimated recruitments from the stock assessment. The degree of autocorrelation, ρ, was estimated using linear regression, as:

$$\hat{\epsilon}_t = \rho\hat{\epsilon}_{t-1}.$$

The intercept of this regression was assumed equal to zero, and the relationship was highly significant (p-value = 0.00067; Figure 1). The estimated values for the parameters defining the AR process were:

$$\mu_{\log(\hat{R})} = 14.937$$

$$\sigma^2_{\log(\hat{R})} = 0.663$$

$$\rho = 0.458$$

and the initial deviation one year prior to the start of the projection period was

$$\hat{\epsilon}_{t=2019} = -1.528 = \log(\hat{R}_{t=2019}).$$

The $\mu_{\log(\hat{R})}$ parameter defines the scale of the AR recruitment process (e.g., this value would be smaller if this were a cod stock). The $\sigma^2_{\log(\hat{R})}$ and ρ parameters interact to define how similar sequential recruitments will be. For example, a high ρ value (e.g., near 1.0) and low $\sigma^2_{\log(\hat{R})}$ would create sequential recruitments that are very similar with systematic trends among years. Conversely, a low ρ value (e.g., near 0) and high $\sigma^2_{\log(\hat{R})}$ would look more like random noise around an average level of recruitment because the random noise swamps the degree of correlation. The herring parameters are moderate between these extremes (Figures 2-4).

Figure 1. Relationship between log-scale sequential recruitments (points) and the estimated regression line that determines the degree of autocorrelation (ρ) in the AR relationship (line).

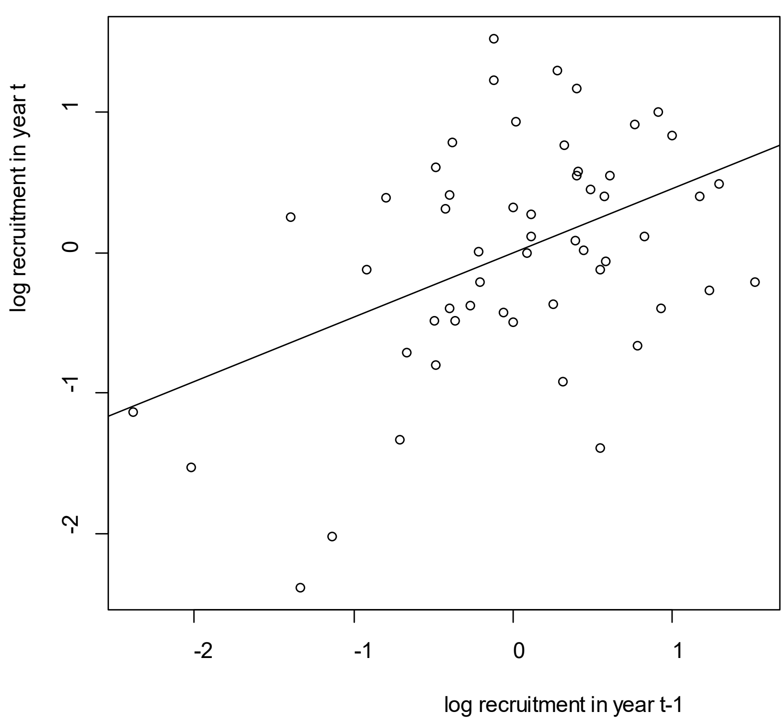

Figure 2. Ten example projected recruitment time series using the herring parameters: $\mu_{\log(\hat{R})} = 14.937$, $\sigma^2_{\log(\hat{R})} = 0.663$, $\rho = 0.458$, and $\hat{\epsilon}_{t=2019} = -1.528$.

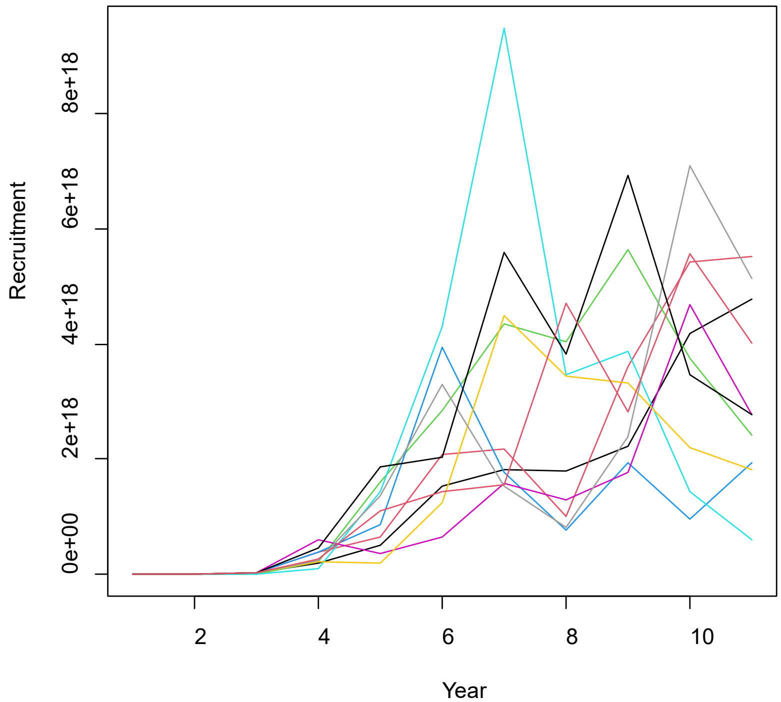

Figure 3. Ten example projected recruitment time series using parameters to create relatively low correlation: $\mu_{\log(\hat{R})} = 14.937$, $\sigma^2_{\log(\hat{R})} = 1.0$, $\rho = 0.1$, and $\hat{\epsilon}_{t=2019} = -1.528$.

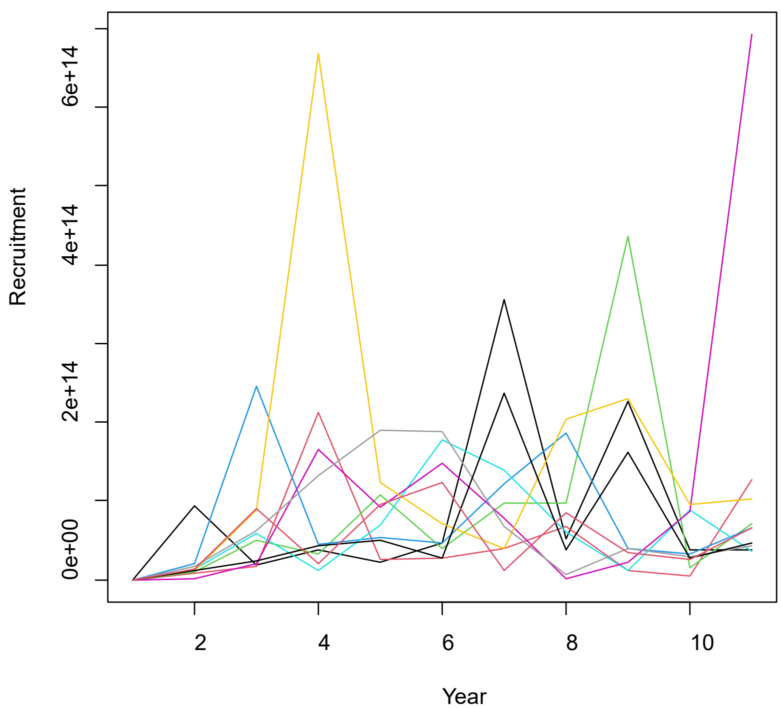

Figure 4. Ten example projected recruitment time series using parameters to create relatively high correlation: $\mu_{\log(\hat{R})} = 14.937$, $\sigma^2_{\log(\hat{R})} = 0.6$, $\rho = 0.7$, and $\hat{\epsilon}_{t=2019} = -1.528$.