**Exercise 4. Stock status in non-traditional stock assessment paradigms (Arctic sardine MU1)**

**Exercise Goal:** Identify ways to approach defining a single metric of stock status for Arctic sardine MU1in a data-rich context with time varying productivity when there is more than one model that is an acceptable characterization of the population dynamics.

Suppose the key uncertainty for characterizing the dynamics of the fishery is the assumed “resilience” of the stock (in terms of the steepness of the stock recruitment relationship) and a management strategy evaluation (MSE) is being conducted to identify a management procedure that is robust to this uncertainty. Suppose three models are defined to characterize the uncertainty in resilience using different assumed steepness (h) values for the Beverton-Holt (BH) stock recruitment relationship.

**Exercise Questions:**

1. Identify the “preferred” approach to defining a metric of stock status (indicator and LRP) for Arctic sardine MU1 that you feel is most consistent with the candidate criteria for best-practice indicators and LRPs (and any other criteria you feel are important)
2. As a group, prepare a 1-2 slide (< 5 minute) presentation to explain:
   * Candidate approaches (indicators and LRPs) considered, and their pros and cons
   * The preferred approach (indicator and LRP)
   * The rationale for and underlying assumptions of the preferred approach and any considerations for the role of Arctic sardine as a forage fish
   * Include a time series plot of the indicator and add a line to represent the LRP.

**Background:**

An age structured model for Arctic sardine MU1 has been fit. This is the same model that was used for Exercise 3. For this exercise, three models are fit:

* Low Resilience: steepness of BH stock recruitment relationship (*h*) = 0.65
* Moderate Resilience: *h* = 0.75 (consider as the best estimate of *h*)
* High Resilience: *h* = 0.95

**Dataset (for each model):**

* Annual weight-at-age (g), maturity-at-age (proportion mature), and vulnerability-at-age (proportion selected to the fishery) over the historical time period
* Model-estimated spawning stock biomass (SSB in kt), recruitment (Rec of Age 0 in billions), total biomass (B in kt), catch (kt), fishing mortality rate (*F*), empirical acoustic index of SSB (kt) from 1999-2020
* Unfished spawning biomass per recruit (phi0) and steepness (*h*) calculated using annual weight-at-age and maturity-at-age
* A dynamic unfished spawning stock biomass (dynamic SSB0) has been provided for the historical time series (a projected SSB0 from the beginning of the time series with *F*=0 using the recruitment deviations from the model fit with no catch. The dynamic SSB0 was estimated 4 different ways (see Exercise 3)

**Some options:** (some calculations have been started in the R script)

* Empirical indicator (acoustic index of SSB) and LRP
* Model-based indicator (e.g., SSB) and theoretical or historical LRP based on one model
* Model-based indicator (e.g., SSB) and theoretical or historical LRP based on information from multiple models

Table 1. Data Files for Exercise 4

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| File Type | File Name | Description |
|  | Exercise 4 Background Figures.html | Fishery background and figures |
| R (programming language) - Wikipedia | ex4\_data.rda | R data object: a list with elements:  WAA = data frame (weight-at-age by year)  MAT = data frame (maturity-at-age by year)  VUL65 = data frame (vulnerability-at-age by year for model with h = 0.65)  VUL75 = as per VUL65 but for h = 0.75  VUL90 = as per VUL65 but for h = 0.90  D65 = data frame (SSB, recruitment, total biomass, catch, F, acoustic index, unfished spawning biomass, steepness, dynamic SSB0 estimates, by year for model with h = 0.65)  D75 = as per D65 but for h = 0.75  D90 = as per D65 but for h = 0.90 |
| C:\Users\barretttj\AppData\Local\Microsoft\Windows\INetCache\Content.MSO\3B9046F.tmp | ex4.R | R script that imports data with plots and calculations started |
| C:\Users\barretttj\AppData\Local\Microsoft\Windows\INetCache\Content.MSO\3B9046F.tmp | functions.R | R script with functions (in main LRP directory) |