**Exercise 3. Time-varying productivity (Arctic Sardine MU1)**

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| **Exercise Goal:** Identify ways to define an LRP for Arctic Sardine MU1 in a data-rich context with time varying productivity. |

**Background:**

An age structured model has been fit for Arctic Sardine in MU1. This is the same type of model that was used for Exercise 2. For this exercise, consider that there is non-stationary in weight-at-age and assume a change point in the recruitment of the stock was identified after Year 31 of the time series.

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| **Exercise Activity:**   1. What parameter(s) would you use to represent how productivity is changing over time? 2. How would you describe the change in productivity over time? 3. Evaluate at least 2 approaches to defining an LRP for Arctic sardine MU1 and identify the preferred approach. 4. Estimates of uncertainty are not provided, but describe the approach that you would use to define the uncertainty in the LRP? 5. As a group, prepare a 1-2 slide (< 5 minute) presentation to explain:    1. **Candidate approaches** (indicators and LRPs) considered, and their pros and cons    2. The **preferred approach and rationale** (indicator and LRP)       1. Does the choice reflect any candidate **best practice** criteria?    3. Any underlying **assumptions** of the preferred approach    4. Include a **time series plot** of the indicator and add a line to represent the LRP.    5. Recommend the current (Year 50) **status** for the stock (above or below the LRP). Is the **status** different in Year 20? |

**Dataset:**

* 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 at age 0 (*Rec* in billions), total biomass (*B* in kt), catch (kt), fishing mortality rate (*F*), empirical acoustic index of SSB (kt) for years 26-50
* 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. This is generated by projected *SSB0* from the beginning of the time series to the terminal year of the reconstruction in Year 50 with *F*=0 using the recruitment deviations from the model fit with the historical catch. A dynamic *SSB0* was estimated two different ways:

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| **Type** | **Parameter in Dataset** | **recruitment deviations** | **weight-at-age** |
| Full | dynamicSSB0a | annual | annual |
| Partial | dynamicSSB0g | annual | mean over first 5 years |

The full dynamic *SSB0* assumes that the changes in productivity are independent of *F* and not density dependent. The partial dynamic *SSB0* assumes that the changes in growth observed over time would not have occurred in the presence of fishing.

**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 (e.g., *SSB0*, *SSBMSY*) LRP
  + Static – e.g., based on equilibrium assumptions using weight-, maturity-, and vulnerability-at-age data over a specific time period
  + Dynamic – e.g., using various assumptions for how changes in weight-at-age and maturity-at-age over time are considered
* Model-based indicator (e.g., SSB) and LRP based on stock recruitment relationship or historical SSB

**Candidate Criteria for Best-Practice Indicators and LRPs:**

* Consistent with an objective to avoid serious harm to the stock
* Based on the best available information
* Operationally useful
* Reliably estimated

**Table 1. Data Files for Exercise 3**

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| File Type | File Name | Description |
| Microsoft PowerPoint 2016 - Review 2016 - PCMag UK | BO Group Ex3.pptx | Powerpoint for group exercise and presentation |
|  | Exercise 3 Background Figures.html | Fishery background and figures |
| R (programming language) - Wikipedia | ex3\_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)  VUL = data frame (vulnerability-at-age by year)  D = data frame (SSB, recruitment, total biomass, catch, F, acoustic index, unfished spawning biomass, steepness, dynamic SSB0 estimates, by year) |
| C:\Users\barretttj\AppData\Local\Microsoft\Windows\INetCache\Content.MSO\3B9046F.tmp | ex3.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) |