**Reference Point Calculations for Haida Gwaii Herring**

Equilibrium relationships for different fishing mortalities and reference points (e.g., Fmsy) were calculated for each sub-area SISCAH OM under 3 different management procedure options in Haida Gwaii:

1. Closed pond SOK fishery (**cSOK**): A maximum of 10 closed pond licenses were allocated in Haida Gwaii across all 3-sub areas in each year, of which there can only be 1 in C/S and 1 in Lou sub-areas. Each license was allocated 16,000 lbs of SOK product, which required a minimum of 90.7 metric tonnes (100 short tons) of herring TAC to allow SOK fishing in a given area. If TAC was sufficient for all 3 areas, then one license was allocated to C/S, one license to Lou and eight licenses to JP/S. For example, given that TAC = 250 t in C/S, TAC = 100 t in Lou, and TAC = 1500 t in JP/S, then one license (90.7 t) would be allocated to both C/S and Lou, and anoth 8 licenses (725.6 t) to JP/S. The remaining TAC of 159.3 t in C/S, 9.3 t in Lou, and 774.4 t in JP/S would be foregone. Alternatively, given that TAC = 50 t in C/S, TAC=80 in Lou, and TAC = 1500 t in JP/S, there would be insufficient TAC to allocate a license to C/S and Lou, therefore, all 10 SOK licenses (907 t) would be allocated to JP/S. The remaining TAC of 50 t in C/S, 80 t in Lou, and 593 t in JP/S would be foregone.
2. Seine roe fishery (**SR**): All available TAC for JP/S is allocated to the seine roe fishery. A minimum TAC of 300 t is required to open the seine roe fishery, based on the lowest levels of fishing observed in the historical time series. There is no SR fishing in C/S or Lou.
3. Closed pond SOK + seine roe fishery (**cSOK+SR**): The same rules as **cSOK** are used, except additional TAC not allocated to cSOK licenses in JP/S is allocated to the seine roe fleet. For example, in the second cSOK scenario above, all 10 SOK licenses (907 t) would be allocated to JP/S and the 593 t remaining TAC is allocated to seine roe fisheries. Note, however, that, as in 3), the seine roe fishery still requires a minimum TAC = 300 t to open.

Equilibrium relationships are calculated following an age-structured yield per recruit formulation, previously developed for the mseR package (Kronlund et al. 2012). Calculations for spawning stock biomass are modified to account for the portion of ponded fish that survive following release from SOK ponds but do not contribute to recruitment (Table 2). Therefore, we use the term mature biomass rather than spawning biomass to describe biomass equilibrium relationships involving SOK fisheries.

Equilibrium relationships for different harvest rates (U) and fishing mortalities (F) are shown for the three sub-areas under each MP in figures 1-3 and 4-6, respectively. The main difference between reference curves for cSOK and SR fisheries can be attributed to changes in the recruitment vs mature biomass curves and egg yield per recruit. For SOK fisheries, all mature biomass does not generate recruitment (i.e., less recruitment per unit of mature biomass for SOK), since a portion of the spawning stock is removed for ponding. SOK fisheries also have less egg yield per recruit since the proportion of individuals ponded that will spawn is less than 100% (i.e., , proportion of effective spawners), whereas SR fisheries are assumed to extract all eggs (i.e., , Table 2). The reference curves for the mixed fishery (cSOK+SR) are essentially a weighted average of the individual curves for cSOK and SR, according to the proportion of the catch allocated to SOK fleet (, Table 2). The catch allocation to the SOK fleet is 100% for yields between 0-907 t and varies from 16-100% for equilibrium yields ranging from 907 t to 5676 t (MSY).

**Tables**

**Table 1.** Notation used in the SISCAH OM.

| Symbol | Value | Description |
| --- | --- | --- |
|  |  | Total number of time steps 1951 - 2019 |
|  |  | Plus group age-class |
|  |  | Time step |
|  |  | Initialisation time step for each stock |
|  |  | Age-class index |
|  |  | Total number of sub-areas |
|  |  | Indicator of sub-area (C/S, JP/S, Lou) |
|  |  | Gear index for (1) Reduction, (2) Seine-Roe, and (3) Gillnet fisheries, |
|  |  | (4) Surface and (5) dive spawn survey indices, and (6) the closed pond SOK fishery. |
|  |  | Unfished spaning stock biomass for area |
|  |  | Beverton-Holt stock-recruitment steepness for area |
|  |  | Unfished equilibrium recruitment |
|  |  | Initial recruitment parameter |
|  |  | Unfished equilibrium survivorship-at-age |
|  |  | Unfished equilibrium spawning biomass per recruit |
|  |  | Beta prior parameters for steepness |
|  |  | Annual recruitment processs error log-deviations |
|  |  | Standard error of recruitment deviations |
|  |  | Catchability coefficient for surface () and dive () survey designs in sub-area |
|  |  | Annual convex-combination of survey catchabilities |
|  |  | Proportion of annual spawn survey index that was observed by the surface survey design |
|  |  | Prior mean catchability on the log-scale for gear in sub-area |
|  |  | Log-normal prior standard deviation on catchability coefficient for gear in sub-area |
|  |  | Initial natural mortality rate for area |
|  |  | Annual log-deviations in natural mortality rate for area |
|  |  | Standard error in annual natural mortality log-devations for area |
|  |  | Annual natural mortality rate for area |
|  |  | Annual post-ponding mortality rate |
|  |  | Annual average weight-at-age observations for area |
|  |  | Age-at-50% selectivity for gear in stock area |
|  |  | Difference between age-at-50% and age-at-95% selectivity for |
|  |  | Gear in stock area |
|  |  | Selectivity-at-age for area and gear in year |
|  |  | Fractional time-step at which catch from gear type is |
|  |  | removed from the population |
|  |  | Total numbers-at-age in area in year at fractional time-step |
|  |  | Total numbers-at-age in area vulnerable to gear in |
|  |  | year at fractional time-step |
|  |  | Spawning biomass of area in year |
|  |  | Expected catch-at-age in numbers from area by gear in year |
|  |  | Expected catch-at-age in biomass units from area by gear in year |
|  |  | Harvest rate of population by gear in year |
|  |  | Total landed weight of Spawn-on-Kelp product from area at time |
|  |  | Biomass of fish ponded for Spawn-on-Kelp fishery from area at time |
|  |  | Conversion factor from ponded fish to landed SOK |
|  |  | Average fecundity of mature, female herring (eggs per gram of spawning biomass) |
|  |  | Proportion of individuals that are mature in area at time |
|  |  | Proportion of individuals that are female in area at time |
|  |  | Proportion of individuals from area at time that will spawn in the closed pond |
|  |  | Conversion factor from eggs to SOK product |
|  |  | Observed area spawn index for survey at time |
|  |  | Expected area spawn index for survey at time |
|  |  | Standard deviation of spawn index observation log-residuals |
|  |  | Observed composition data for age in area by gear at time |
|  |  | Expected composition data for age in area by gear at time |
|  |  | Total number of age classes with age observations above 2% of the total sample size in year |
|  |  | Conditional MLE of age composition sampling error |
|  |  | Population mean initial natural mortality |
|  |  | log-deviation of from |
|  |  | Population mean age-at-50% selectivity for gear |
|  |  | log-deviation of from |
|  |  | Population mean step from age-at-50% to age-at-95% selectivity for gear |
|  |  | log-deviation of from |
|  |  | Correlation-at-lag-1 coefficient for age composition residuals |
|  |  | Lag-1 correlation matrix for age composition residuals |
|  |  | Dimension transformation matrix for age composition logistic normal likelihood |
|  |  | Centred logistic normal age-composition log-residuals for sub-are , gear at time step |

**Table 2.** Equilibrium relationships as a function of fishing mortality rate

|  |  |  |
| --- | --- | --- |
| Equation | Formula | Description |
| E.1 | ) | parameters |
| E.2 |  | survivorship to age a |
| E.3 |  | biomass yield/ponding per recruit |
| E.3 |  | egg yield per recruit, for SOK and for SR |
| E.4 |  | spawning biomass per recruit |
| E.5 |  | equilibrium recruitment |
| E.6 |  | equilibrium spawning biomass |
| E.7 |  | equilibrium total yield (catch + ponded fish) |
| E.8 |  | proportion of yield allocated to SOK fleet |
| E.9 |  | mature biomass per recruit for SOK fleet |
| E.10 |  | equilibrium mature biomass |
| E.11 |  | equilibrium harvest rate |

**Figures**



Figure 1. Equilibrium relationships for **spawn-on-kelp (SOK) fisheries** from the base OM for areas Cumshewa/Selwyn (C/S), Juan Perez/Skincuttle (JP/S), and Louscoone (Lou) showing a) egg yield (billions) per recruit for different harvest rates, b) mature biomass (MB) per recruit for different harvest rates, c) egg yield for different harvest rates d) spawning biomass for different harvest rates e) recruitment for different levels of spawning biomass, and f) egg yield for different levels of mature biomass. In all plots the circles shown indicate values at Fmsy.



Figure 2. Equilibrium relationships for **seine roe (SR) fisheries** from the base OM for areas Cumshewa/Selwyn (C/S), Juan Perez/Skincuttle (JP/S), and Louscoone (Lou) showing a) egg yield (billions) for different harvest rates b) mature biomass (MB) per recruit for different harvest rates, c) egg yield for different harvest rates d) mature biomass for different harvest rates, e) recruitment for different levels of mature biomass, and f) egg yield for different levels of mature biomass. In all plots the circles shown indicate values at Fmsy.



Figure 3. Equilibrium relationships for **mixed spawn on kelp and seine roe (SOK+SR) fisheries** from the base OM for areas Cumshewa/Selwyn (C/S), Juan Perez/Skincuttle (JP/S), and Louscoone (Lou) showing a) egg yield (billions) per recruit for different harvest rates, b) spawning biomass (SB) per recruit for different harvest rates, c) egg yield for different harvest rates, d) spawning biomass for different harvest rates, e) recruitment for different levels of spawning biomass, and f) egg yield for different levels of spawning biomass. In all plots the circles shown indicate values at Fmsy.



Figure 4. Equilibrium relationships for **spawn-on-kelp (SOK) fisheries** from the base OM for areas Cumshewa/Selwyn (C/S), Juan Perez/Skincuttle (JP/S), and Louscoone (Lou) showing a) egg yield (billions) recruit for different fishing mortality (F), b) mature biomass (MB) per recruit for different fishing mortality (F), c) egg yield for different fishing mortality (F), d) mature biomass for different fishing mortality (F), e) recruitment for different levels of mature biomass, and f) egg yield for different levels of mature biomass. In all plots the circles shown indicate values at Fmsy.



Figure 5. Equilibrium relationships for **seine roe (SR) fisheries** from the base OM for areas Cumshewa/Selwyn (C/S), Juan Perez/Skincuttle (JP/S), and Louscoone (Lou) showing a) egg yield (billions) per recruit for different fishing mortality (F), b) mature biomass (MB) per recruit for different fishing mortality (F), c) egg yield for different fishing mortality (F), d) mature biomass for different fishing mortality (F), e) recruitment for different levels of mature biomass, and f) egg yield for different levels of mature biomass. In all plots the circles shown indicate values at Fmsy.



Figure 6. Equilibrium relationships for **mixed spawn on kelp and seine roe (SOK+SR) fisheries** from the base OM for areas Cumshewa/Selwyn (C/S), Juan Perez/Skincuttle (JP/S), and Louscoone (Lou) showing a) egg yield (billions) per recruit for different fishing mortality (F), b) mature biomass (MB) per recruit for different fishing mortality (F), c) egg yield for different fishing mortality (F), d) mature biomass for different fishing mortality (F), e) recruitment for different levels of mature biomass, and f) egg yield for different levels of spawning biomass. In all plots the circles shown indicate values at Fmsy.