# Data inputs

**Absolute observations or indices of biomass/abundance (survey indices)**

Preferred file format: csv file or Rdata/rds file

Fields:

* gear (1 for each survey series),
* year,
* value,
* units (CPUE, expanded numbers, swept area biomass etc)

**Catch/Landings data**

Preferred format: csv or Rdata/rds file

Fields:

* Gear
* Year
* Value
* Units (kg,t,kt etc)

**Biological (age/length) data**

Preferred format: csv or Rdata file

Fields:

* Gear (all gears, commercial and surveys)
* Year
* Length
* Age
* TripID (so we can count the number of distinct trips for commercial data)
* Source (at-sea observer, survey, or port samples)

If there is no/limited age data available, we will need to fit to length data only (as with AH). In that case, please provide an acceptable von Bertalanffy growth model for use in the modeling, as well as the uncertainty (i.e., SD as a proportion of mean length) in the length-at-age distributions.

We also need info on:

Discarding for each gear/fleet: Grading length or size limit, year that it was introduced, discard induced mortality rates

Proportion mature-at-age (full ogive or parameters for a logistic model)

**Model Description**

**Statistical Catch at Age and Length model**

The SISCL-AH model is an age- and sex-structured population dynamics model fit to fishery independent indices and length compositions, and fishery dependent landings and catch-at-length data. Fishery landings and length compositions are split by gear type (longline and otter trawl) and area (NAFO areas 3 and 4), making the SISCAL-AH model a fleets-as-areas model. Explain survey data (design, gear, etc)… Model notation is given in Table 1 and, and population dynamics process model and statistical model equations in Tables 2 and 3, respectively.

Model parameters (Table 2, P.1 - P.4) are partitioned into four subsets consisting of leading parameters , nuisance catchability and observation model variance parameters estimated conditionally on leading parameter values, fixed parameters for maturity-at-age parameters and recruitment deviation and natural mortality random walk deviation standard errors, and finally prior distribution hyperparameters .

**SISCAL model state dynamics**

The model parameters, equilibrium states, and full state dynamics for SISCAL are given in Table 2. Unfished equilibrium recruitment (EQ.4) and numbers-at-age (EQ.5) are derived via spawning biomass per recruit (EQ.3), which is itself a function of time-averaged natural mortality, weight-at-age, maturity-at-age (EQ.1), and unfished equilibrium survivorship-at-age (EQ.2).

A model year in SISCAL begins on April 1 and ends on March 31. Annual recruitment (occurring on the first day of the year) is assumed to follow a Beverton-Holt stock-recruitment function parameterized via stock-recruitment steepness , unfished spawning stock biomass , recruitment process error deviations , and annual natural mortality rates . The time-varying mortality rate starts with an initial estimated in 1970 and then proceeds via a random walk with the same jumps applied to both sexes (Table 2 – EQ.2).

Age- and sex-class abundances are initialised in a fished state by estimating long-term average fishing mortality for each gear type (NEQ.1). Initial fishing mortality is used over initial abundance-at-age as the uncertainty is too great to estimate the latter without catch-at-age data. Long-term average fishing mortality rates are bounded between 0.05 and 0.7 .

Selectivity-at-age for each sex and fleet is modeled as a logistic function of length-at-age (Table 2, S.1). Selectivity is asymptotic (logistic) for the long line fleets, and dome shaped (double asymptotic) for the otter trawl fleets. All fleets use the same parameters for the ascending limb: length-at-50% selectivity and the difference between length-at-50% and length-at-95% selectivity . For otter trawls, there are additional descending limb length-at-95% selectivity and length-at-50% selectivity parameters. Length-at-95% selectivity for the descending limb is modeled as a step from length-at-95%, i.e., selectivity for the ascending limb, and descending limb length-at-50% selectivity a further step from length-at-95%, i.e. , thereby ensuring the descending limb is always to the right of the ascending limb, which reduces the sharpness of the peak in selectivity. Selectivity-at-length is converted to sex-specific selectivity-at-age via the sexually dimorphic von Bertalanffy growth model (G.1).

Commercial removals by longline (LL) and otter trawl (OT) fisheries in both NAFO areas 3 and 4 are represented as discrete fisheries occurring around halfway through the year at a fractional time step (Table 2, C.1 - C.9), where . Fish are removed from each area by converting landings to total catch by scaling by the probability released and the proportion of vulnerable biomass at age (C.6), which is then converted to total caught numbers-at-age via the mean weight-at-age (C.7). Total caught numbers are then removed from the vulnerable numbers-at-age (C.8), from which sub-legal fish are discarded with a discard induced mortality (C.9). Annual exploitation rates for total landings and each commercial fleet are calculated as the ratio of landed legal sized catch to the total legal biomass (Table 2, C.10).

**Observation models, likelihood functions, and priors**

Temporal variation in Atlantic halibut stock abundance and population composition are monitored via a research vessel (RV) trawl survey in area NAFO area 4VWX, and industry chartered longline Halibut survey (HS), the latter of which is currently transitioning from a fixed survey design to a random design. Length compositions are also collected by both surveys and all four commercial fleets (OT and LL in NAFO areas 3 and 4).

**Survey index observations**

Survey indices are assumed to be linear (i.e., no hyperstability or hyperdepletion) in the quantity that they are indexing, which is total vulnerable numbers for the RV survey, and vulnerable biomass for both HS surveys (Table 3, O.1). Catchability parameters are estimated as conditional maximum likelihood estimates

**Length composition observation models**

Proportion-at-length (i.e., length composition) observations are modeled in 5cm bins via a logistic-normal likelihood function (Schnute and Haigh 2007; Francis 2014), with expected values calculated as proportions of the catch-at-length (Table 3, O.2). Annual length data samples for both sexed and unsexed samples were weighted relative to the average annual sample size for each fleet/sex combination (L.4), and fleet-specific lag-1 auto-correlation matrices were estimated for length composition residuals (L.1). To avoid zeroes in the length composition data, a tail-compression procedure was applied that combined data from length bins with less than 2\% of the samples with neighbouring length bins (to the right) that were above that threshold, creating a variable number of bins at each time step (L.5). Fleet and sex specific length sampling error standard deviations were conditionally estimated as nuisance parameters (L.7).

The proportion of each length class that was made up of female fish was also fit to

**Objective function and optimisation**

The SISCAL objective function is proportional to the negative log posterior density function and defined as the sum of the negative log likelihood function values for observed data (Table 3, NLL.5, L.8 and F.4), negative log prior densities for process errors (P.1 - P.2), and priors on other leading parameters (P.3 - P.7).

The SISCAL TMB model objective function is optimised via the nlminb() function in the R statistical package (R core team 2015; Kristensen et al. 2015). Model parameters were considered converged when the maximum gradient component of the likelihood surface had absolute value less then , and the Hessian matrix was positive definite. Bayes posterior distributions were then sampled as 4 independent chains of 1000 samples each using Hamiltonian Monte-Carlo (Monnahan and Kristensen 2018), or No U-turn Sampling. Hamiltonian Monte-Carlo differs from Markov-Chain Monte-Carlo by minimising the auto-correlation between successive posterior samples, thereby producing a mixed model posterior sample with lower absolute sample sizes and little or no thinning (Monnahan, Thorson, and Branch 2017).

**RESULTS**

**REFERENCES**

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**TABLES**

Table 1: Notation used in the SISCAH OM.

|  |  |  |
| --- | --- | --- |
| Symbol | Value | Description |
|  |  | Total number of time steps 1951 - 2019 |
|  |  | Plus group age-class |
|  |  | Length bin midpoints ( length bins in total) |
|  |  | Time step |
|  |  | Age-class index |
|  |  | Gear index for (1) LL\_NAFO3, (2) LL\_NAFO4, and (3) OT\_NAFO3, (4) OT\_NAFO4, (5) RV\_4VWX, (6) HS\_Fixed, (7) HS\_Random |
|  | 1,2 | Sex index for male (1) and female (2) fish for model states, and in length compositions collected at sea, (3) combined sexes |
|  |  | Maturity-at-age |
|  | 8.5, 11.5 | Age-at-50% and age-at-95% maturity |
|  |  | Unfished female spawning stock biomass |
|  |  | Beverton-Holt stock-recruitment steepness |
|  |  | Unfished equilibrium recruitment |
|  |  | Average recruitment |
|  |  | Pre-1970 long-term average fishing mortality rates for gears |
|  |  | Unfished equilibrium survivorship-at-age- for sex |
|  |  | Weight-at-age for sex |
|  |  | Length-at-age 1 for sex |
|  |  | Asymptotic mean length for sex |
|  |  | Von Bertalanffy growth coefficient for sex |
|  |  | Mean length-at-age- for sex |
|  | 0.15 | CV in length-at-age distribution |
|  |  | Allometric length-weight conversion parameters |
|  |  | 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 RV\_4VWX (), HS\_Fixed (), and HS\_Random ( surveys |
|  |  | Annual natural mortality rates for male and female fish |
|  |  | Length-at-50% selectivity for gear (Ascending limb) |
|  |  | Difference between length-at-50% and length-at-95% selectivity for gear (Ascending limb) |
|  |  | Difference between length-at-95% ascending and length-at-95% descending selectivity for gear (g = 3, 4, 5) |
|  |  | Difference between length-at-50% and length-at-95% selectivity for gear (Descending limb, g = 3, 4, 5) |
|  |  | Fractional time-step at which catch from gear type is removed from the population |
|  | 81 | Minimum size limit applied to commercial landings for gear in year |
|  | 1988, 1988, 1990, 1995 | First year of discarding fish below the legal size |
|  | 0.23,1.26 | Instantaneous discard induced mortality rate |
|  |  | Probability of releasing an age fish of sex when caught by gear (post first year of size limit) |
|  |  | Total numbers-at-age for sex in year at fractional time-step |
|  |  | Total numbers-at-age for sex vulnerable to gear in year at fractional time-step |
|  |  |  |
|  |  | Spawning biomass of area in year |
|  |  | Observed landings from gear at time (kilotonnes) |
|  |  | Estimated total catch (landings and releases) from gear at time (kilotonnes) |
|  |  | Estimated total discards (releases) from gear at time (kilotonnes) |
|  |  | Expected catch-at-age in numbers from sex by gear in year |
|  |  | Expected catch-at-age in biomass units from sex by gear in year |
|  |  | Harvest rate by gear in year |
|  |  | Observed survey index for gear at time |
|  |  | Expected survey index for gear at time |
|  |  | Standard deviation of survey index observation log-residuals |
|  |  | Observed composition data for length bin from gear at time |
|  |  | Expected composition data for length bin from gear at time |
|  |  | Total number of length bins with age observations above 2% of the total sample size in year |
|  |  | Conditional MLE of age composition sampling error |
|  |  | Correlation-at-lag-1 coefficient for length composition residuals |
|  |  | Lag-1 correlation matrix for length composition residuals |
|  |  | Dimension transformation matrix for length composition logistic normal likelihood |
|  |  | Centred logistic normal length-composition log-residuals for sex in gear at time step |
|  |  | Proportion of observations in length bin that were female |
|  |  | Expected Proportion of fish in length bin that are female |

Table 2: Process model equations for the SISCAH OM.

|  |  |
| --- | --- |
| No. | Equation |
| (P.1) |  |
| (P.2) |  |
| (P.3) |  |
| (P.4) |  |
| (EQ.1) |  |
| (EQ.2) |  |
| (EQ.3) |  |
| (EQ.4) |  |
| (EQ.5) |  |
| (EQ.6) |  |
| (EQ.7) |  |
| (G.1) |  |
| (G.2) |  |
| (G.3) |  |
| (S.1) |  |
| (NEQ.1) |  |
| (NEQ.2) | s |
| (NEQ.3) |  |
| (D.1) |  |
| (C.1) |  |
| (C.2) |  |
| (C.3) |  |
| (C.4) |  |
| (C.5) |  |
| (C.6) |  |
| (C.7) |  |
| (C.7) |  |
| (C.8) |  |
| (C.9) |  |
| (C.10) |  |
| (A.1) |  |
| (A.2) |  |
| (A.3) |  |
| (A.3) |  |

Table 3: Data likelihoods, model prior density functions, and the final objective function for the SISCAH OM. is the indicator function that takes value 1 when the statement is true, and otherwise.

|  |  |
| --- | --- |
| No. | Equation |
| (O.1) |  |
| (O.2) |  |
| (O.3) | = |  | Proportion of observations in length bin that were female |
| (NLL.1) |  |
| (NLL.2) |  |
| (NLL.3) |  |
| (NLL.4) |  |
| (NLL.5) |  |
| (L.1) |  |
| (L.2) |  |
| (L.3) |  |
| (L.4) |  |
| (L.5) |  |
| (L.6) |  |
| (L.7) |  |
| (L.8) |  |
| (F.1) |  |
| (F.2) |  |
| (F.3) |  |
| (F.4) |  |
| (P.1) |  |
| (P.2) |  |
| (P.3) |  |
| (P.4) |  |
| (P.5) |  |
| (P.6) |  |
| (P.7) |  |
| (F.1) |  |