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Update to 3LN Redfish Operating Models

Perreault A.[1], Hatefi F.[1]

[1]Northwest Atlantic Fisheries Centre
Fisheries and Oceans Canada, 80 East White Hills Road
St. John's, Newfoundland and Labrador, A1C 5X1, Canada

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Introduction

The survey-based assessment model (SURBA) is based on the age structured catch at length model from Perreault and Hatefi (2023). The base model details are described in Appendix A, however preliminary model runs did not fit the data well and variance parameter estimates for recruitment and fishing mortality rates were very large. To better capture underlying processes and/or stabilize the model, the following modifications to the model were explored:

1) Implementing a contaminated distribution for recruitment, i.e. changing Eq. 2 to:

$$\log(N_{y,1}) = \mu_R + \delta_{R_y}, \text{ where } \delta_{R_y} \sim \begin{cases} N(\mu_R,\ \sigma_0^2)\ if\ I_t = 0 \\ N(\mu_R,\ \sigma_1^2)\ ifif\ I_t = 1 \end{cases}.$$

   Here σ_1^2, σ_2^2 are separate variance parameters to estimate and I_t is an indicator variable that indicates whether deviations arise from the first distribution with probability p or the second with probability 1-p. This formulation allows for some years with extremely high recruitment estimates, which should better represent the episodic nature of redfish recruitment.

2) There were strange patterns present in the early SURBA model residual plots, namely with increased variance at the largest and smallest lengths (e.g., Fig. 1). Explorations into the survey data found similar trends in the estimates of the design-based survey cvs (i.e., √variance/mean; Fig. 2). Since the information from survey uncertainties were available and appeared to follow the misfits that were seen in the model predictions, the mean survey cvs were integrated into the model and treated as data inputs.

3) Aggregated commercial landings were incorporated into the model in order to better capture the impact of fishing mortality on the stock. Additionally, the inclusion of commercial landings allowed fully selected survey catchability for both surveys to be estimated. From Eq. 8 predicted aggregate landings are derived from,

$$\hat{C}_y = \sum_l C_{ly} cw_{ly,} \qquad (8a)$$

where cw are the catch weights at length. Log landings are assumed from a normal distribution with mean zero and standard deviation to estimate in the model.

4) The model was reformulated to allow for process errors in the cohort abundance, i.e. Eq. 1 was rewritten as

$$\begin{aligned} \log(N_{y,a}) &= \log(N_{y-1,a-1}) - Z_{y-1,a-1} + \delta_{N_{y-1,a-1}}, \\ \log(N_{y,A^+}) &= \log[N_{y-1,A^+-1}\exp^{-Z_{y-1,A^+-1}} + N_{y-1,A^+}\exp^{-Z_{y-1,A^+}}] + \delta_{N_{y-1,A^+}}, \end{aligned}$$

where process errors were assumed $\delta_{N_{y,a}} \sim N(0, \sigma_{pe})$. Further explorations included allowing for an AR1 process within years (AR1year), ages (AR1age) and in both age and years (AR1ageAR1year).

Various combinations of these model modifications were fit in an attempt to resolve the issues of misfit to the data and large process variance parameter estimates.

Results

No matter the model formulation, the SURBA model could not resolve the issue of estimating very large process variances (i.e. process, recruitment and/or fishing mortality variances, depending on model formulation). This indicates that there are underlying mechanisms driving the stock that are not explained by our stock assessment model formulations. An example of a model run is provided below and aims to give some insight into general model fit. The selected model is fit to the unconverted 3LN Canadian Fall and Spring RV survey indices. This formulation assumes a contaminated distribution for recruitment (p=0.0035), integrates the information from the external survey cv estimates and fits to the aggregated commercial landings. Process error standard deviation was fixed at log(0.35),with AR1ageAR1year both fixed at 0.5 to allow the process errors to vary smoothly over ages and years.

Discussion

The models discussed were all developed with intended use as operating models (OMs) for the 3LN redfish management strategy evaluation (MSE; WG-RBMS 2022). Our preliminary models (Perreault & Hatefi, 2023) were based on Cadigan et al., 2024 and addressed some issues flagged in the paper that may have contributed to model misfit, including accounting for sex-specific differences in growth, incorporating older commercial and survey data, and extending the age and length bins used in the model, the latter two to better capture the dynamics of this long-lived species. However, our models that included these modifications still required large process error variance estimates and did not address the mismatch between the length compositions of the survey and commercial data. As a way forward, we fit models to the survey length composition data only (i.e. dropping the commercial data) to better understand the signals in the survey data (Perreault & Hatefi, 2023). A variety of SURBA model formulations were explored including divisional (3L,3N), sex-disaggregated, and depth-based and models that allowed for flexible fishing selectivity, static and Lorenzen M, and seasonal and various growth model formulations. However, in all cases, no matter the underlying model formulation, the SURBA models required large process error variance estimates (i.e., recruitment, fishing mortality rates) to fit the survey data. This indicated that there are underlying mechanisms driving the stock that are not explained by our stock assessment model formulations.

Recent dynamic factor analysis models (Perreault & Hatefi, 2025) found that common trends in 3LN redfish survey indices were related to a combination of lagged ocean climate drivers (cold intermediate layer, lagged ten years; spring bottom temperatures, lagged three years). This DFA analysis added to the growing body of work that identified extrinsic drivers as important in explaining changes in redfish population dynamics (Devine & Haedrich, 2011; Burns et al., 2020; Cousseau et al., 2024) and provides some rationale behind our current models' use of process errors. An ACL or SURBA model that integrates ocean climate drivers may address the issues with model fit, however, how to integrate these into the model remains difficult given a lack of understanding of the mechanisms driving these processes.

The lack of speciation in the commercial and survey data may also be contributing to the large process error estimates. It has been suggested that the commercial fishery is targeting the larger *S. mentella* stock whereas the surveys are targeting the smaller *S. fasciatus* (Perreault et al., 2022; Cadigan et al., 2024). If this is the case, then it is not surprising that the commercial catches are not describing the dynamics of the survey catches. Further work to speciate the catches, both forward and back in time would alleviate a large component of uncertainty for the 3LN redfish stock.

Although an interesting application, the SURBA models as presented may not be suitable for use in an MSE context, since projecting forward with such large process error uncertainties is expected to swamp any nuances in the implementation of harvest control rules. A similar issue was faced in a previous NAFO MSE, namely 3M cod, where the Working Group could not recommend any of the HCRs for implementation driven mainly by large uncertainties in recruitment projections (WG-RBMS, 2015).

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Figures

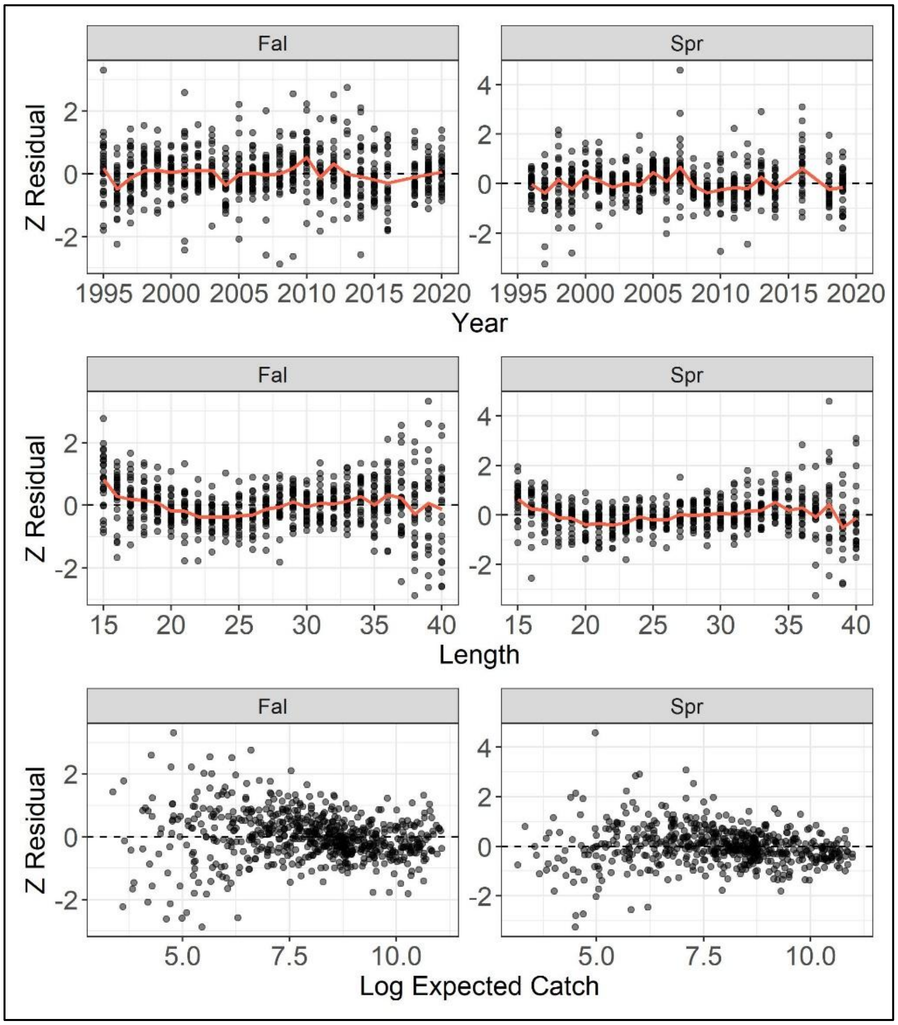

Figure 1. Example of pattern in residual plots from SURBA model

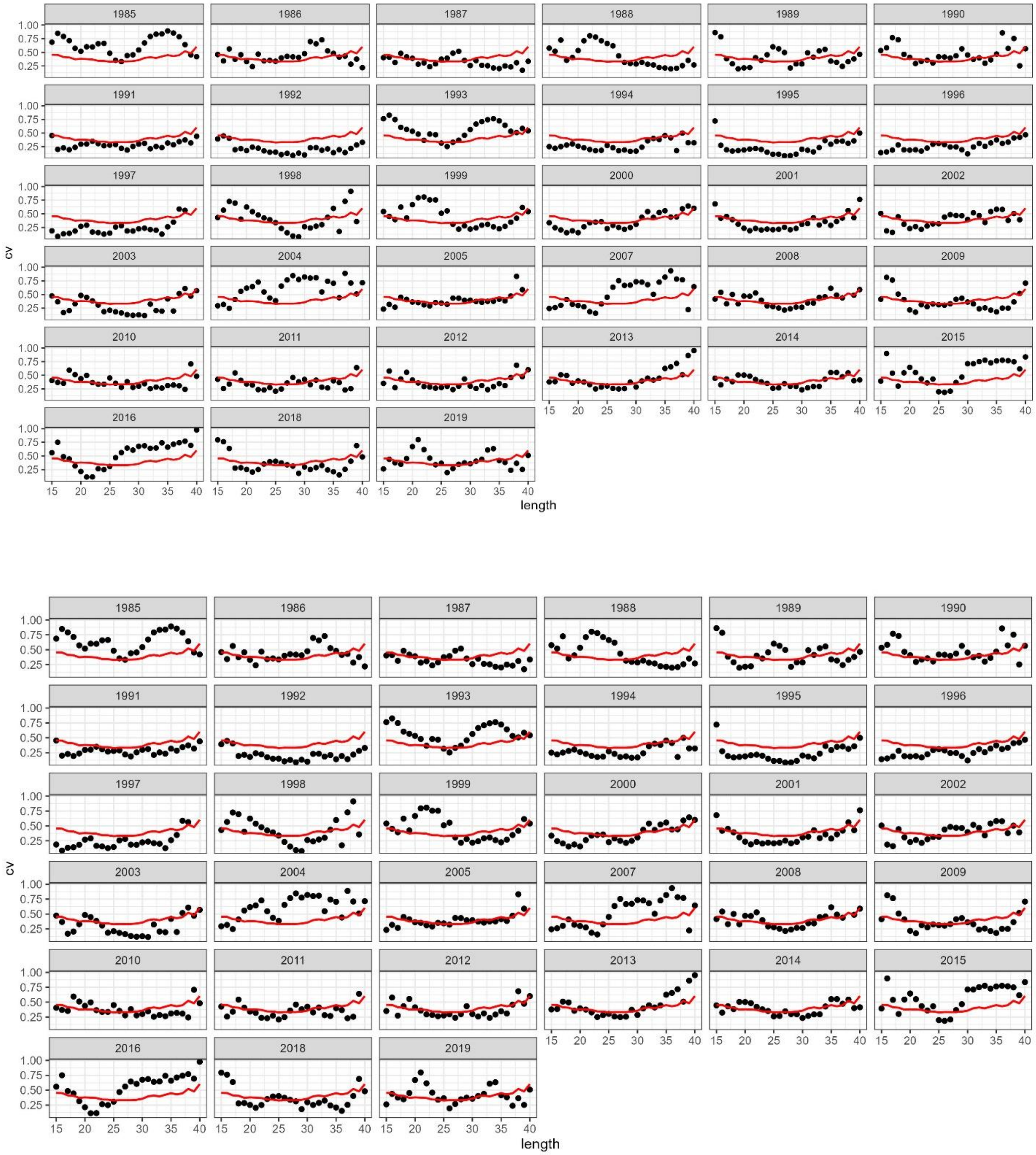

Figure 2. Spring (top) and fall (bottom) estimates of cvs at length from the Canadian RV surveys. The red line is the mean cv at length for all years.

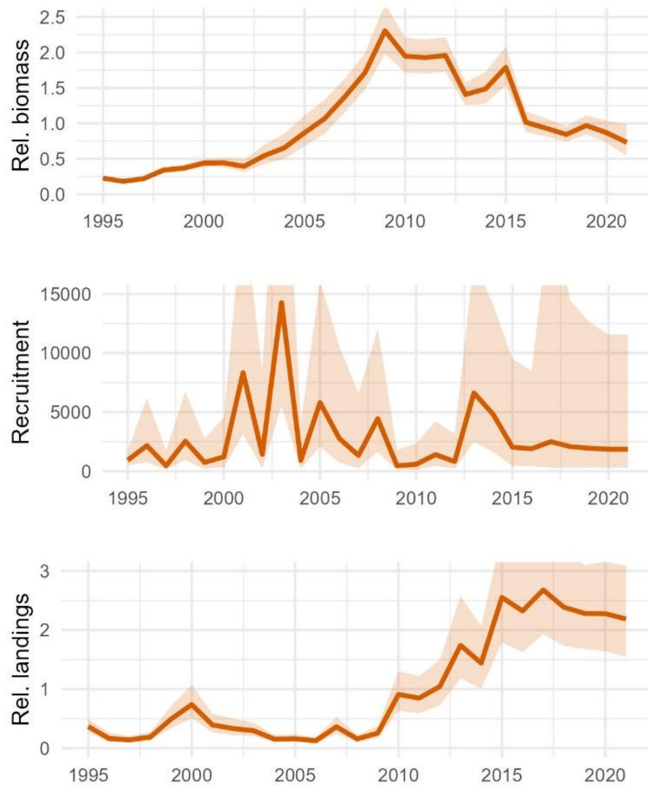

Figure 3. SURBA model estimated population processes (orange line) and confidence intervals (shaded region)

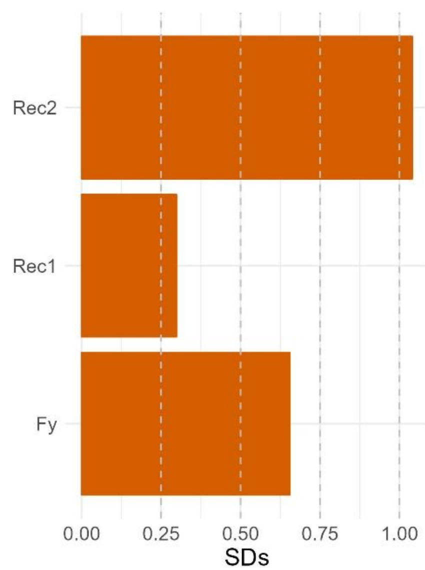

Figure 4. SURBA model estimated standard deviations for recruitment and fishing mortality population processes

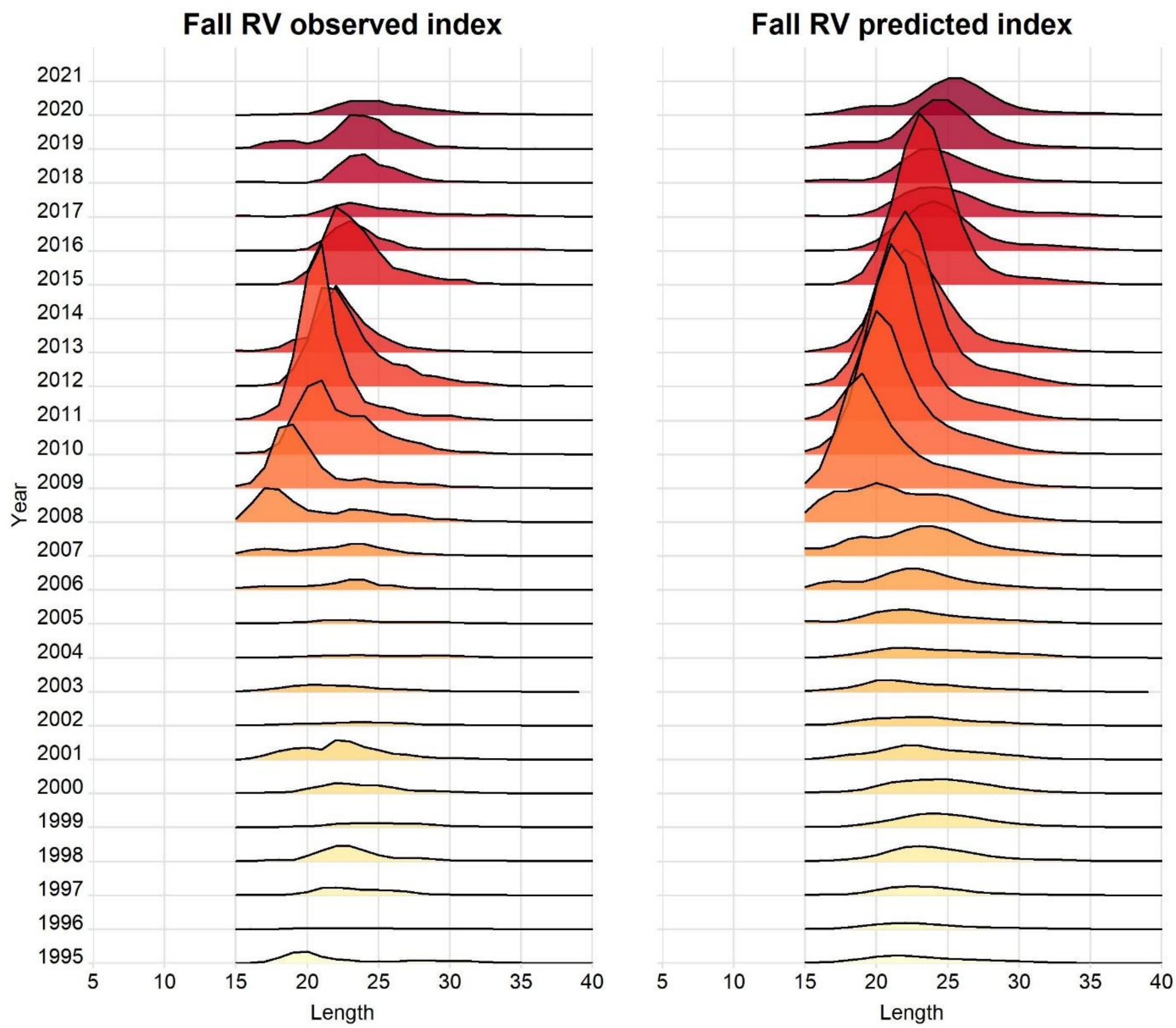

Figure 5. Canadian fall RV observed (left) and predicted (right) abundance at length from the SURBA model

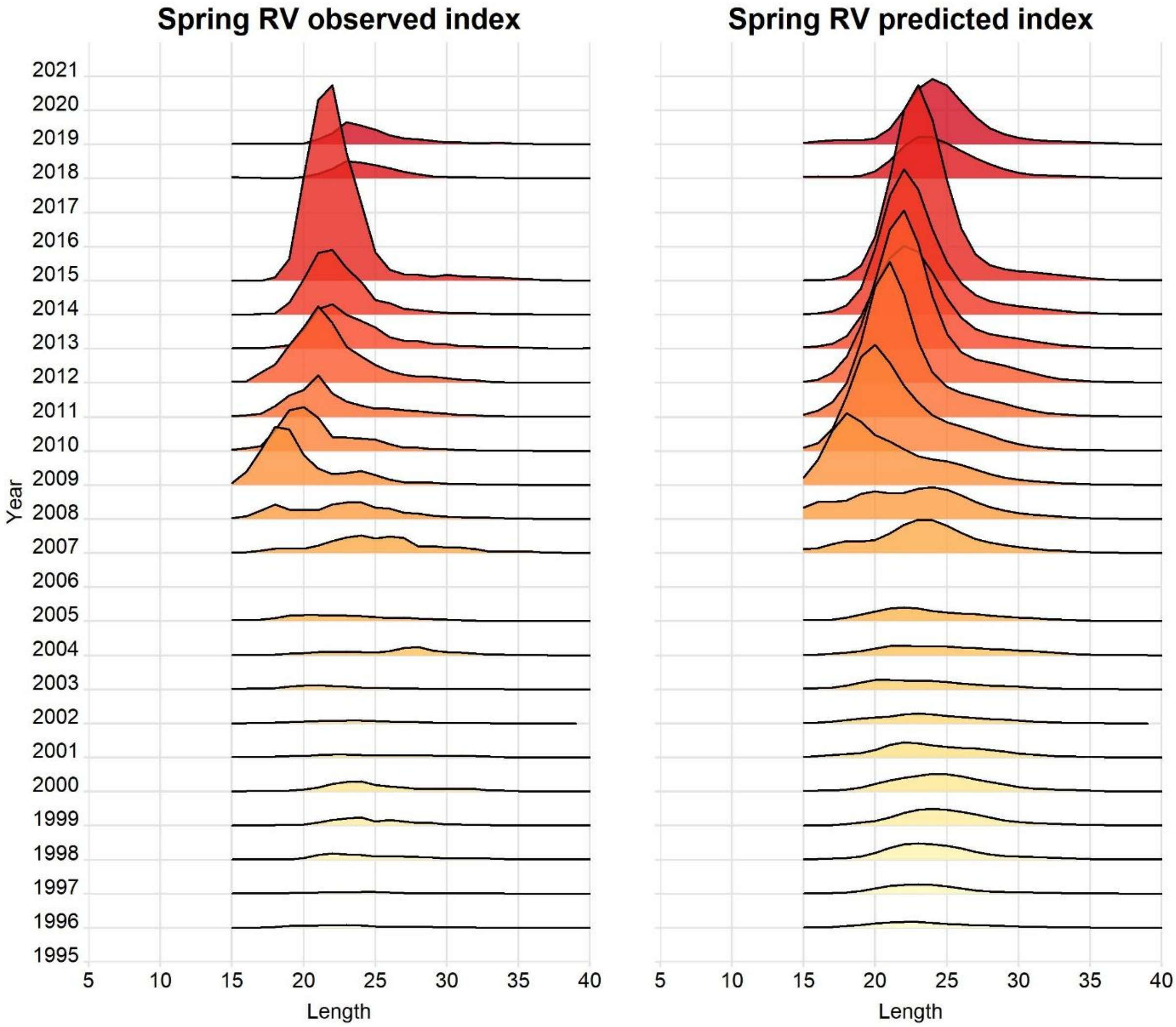

Figure 6. Canadian spring RV observed (left) and predicted (right) abundance at length from the SURBA model

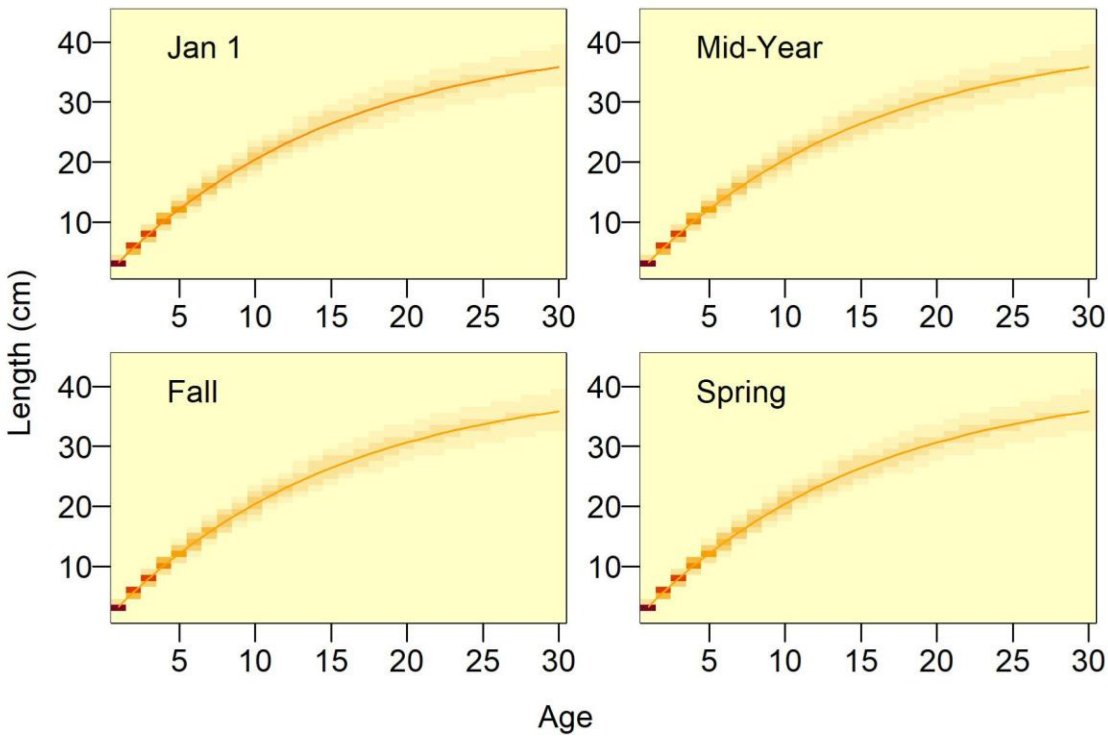

Figure 7. SURBA model predicted distribution of size at age

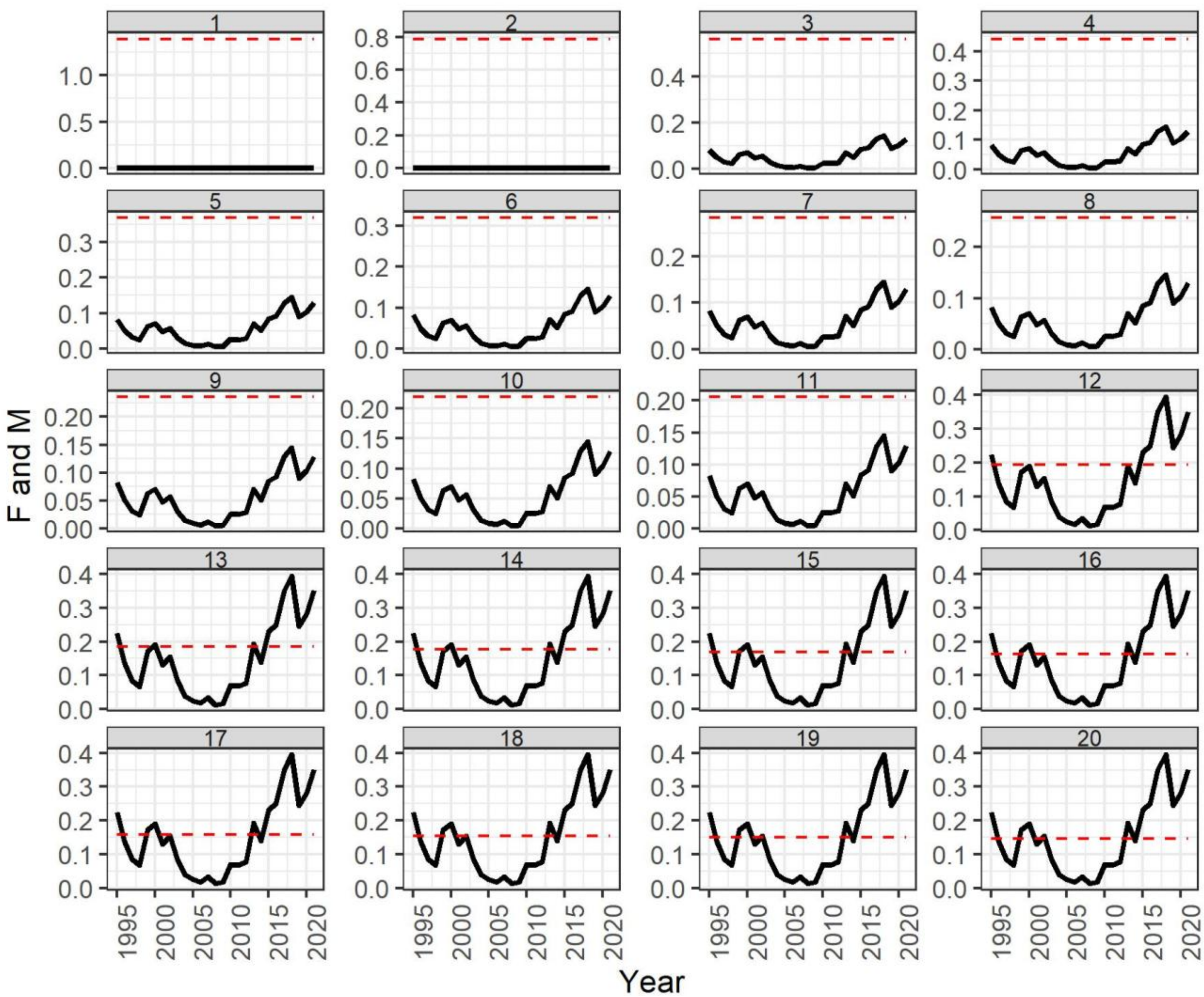

Figure 8. SURBA model predicted fishing (black) and natural mortality (red) rates at age and year

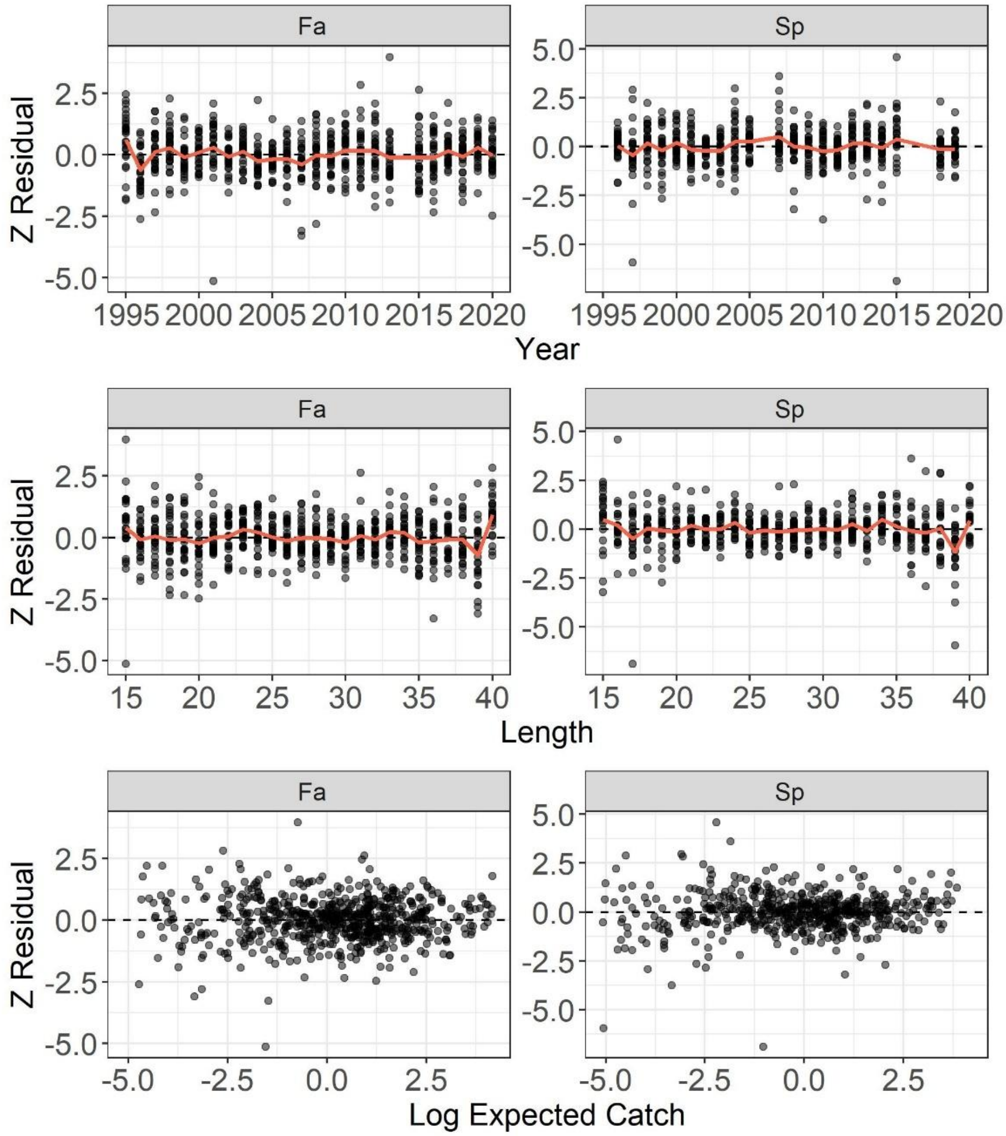

Figure 9. SURBA model predicted residuals for the fall (left) and spring (right) survey indices at length

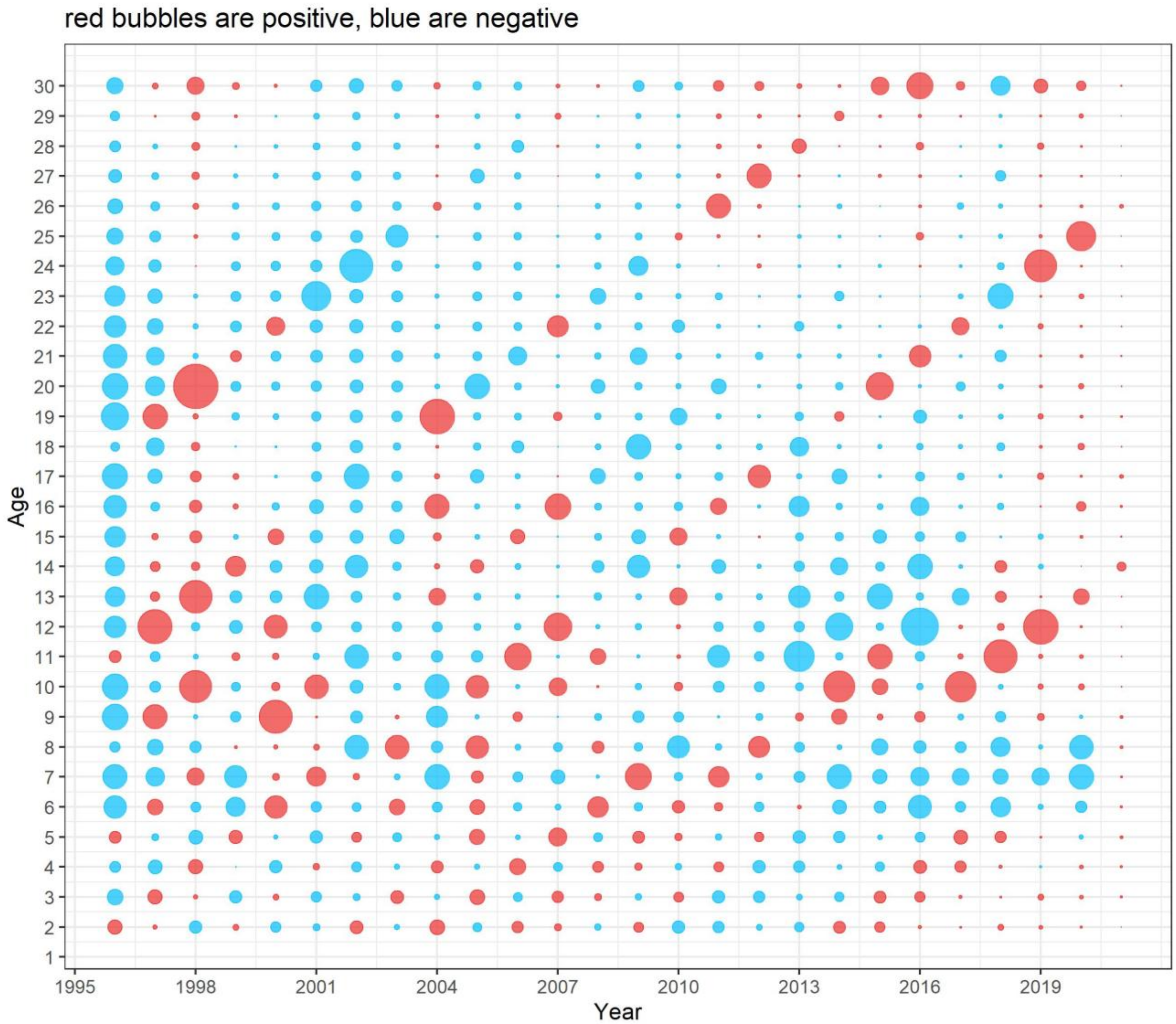

Figure 10. SURBA model predicted process errors at age and year

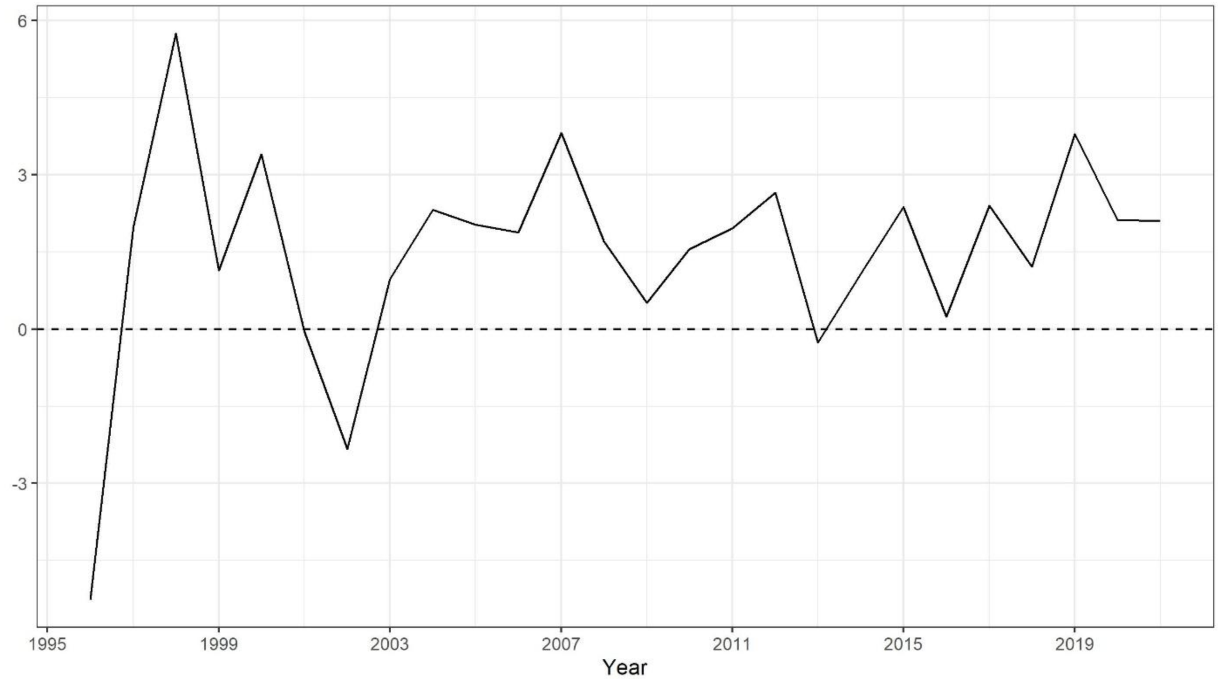

Figure 11. SURBA model predicted process errors summed across ages

Tables

Table 1. Some parameter estimates from the SURBA model

Model results, nll = 1481.05, AIC = 2990.09, BIC = 3061.59			
	est	**CV**	**GRD**
F_fish	0.063	0.265	-0.000008
F_mort	0.021	0.306	0.000004
meanR	1859.315	0.303	0.000024
L50Fall	20.474	0.010	0.001309
DiffFall	3.792	0.035	-0.000313
L50Spr	20.968	0.009	-0.000994
DiffSpr	1.368	0.036	0.000198
FA50	11.469	22.836	-0.000029
DiffF	0.078	581.438	0.000001
qFactor	0.730	0.029	0.000172
Lt	33.664	0.011	0.000192
ga	1.069	0.002	-0.000193
cv_len	0.081	0.036	0.000000

Appendix A: SURBA

Survey Based Assessment Model

Process model

The SURBA model is based on the standard age-structured model, for years $y = 1995, \ldots, 2021$ and for ages $a = 1, \ldots, 30+$, where $30+$ represents the plus group.

$$\begin{aligned} \log(N_{y,a}) &= \log(N_{y-1,a-1}) - Z_{y-1,a-1}, \\ \log(N_{y,A^+}) &= \log\left[N_{y-1,A^+-1}\exp^{-Z_{y-1,A^+-1}} + N_{y-1,A^+}\exp^{-Z_{y-1,A^+}}\right] \end{aligned} \quad (1)$$

$Z_{y,a} = M_{y,a} + F_{y,a}$ is the total mortality rate given by the sum of the natural mortality rate, $M_{y,a}$, and the fishing mortality rate $F_{y,a}$. Here the $M_{y,a}$ were predicted as a function of length using the Lorenzen method,

$$M_a = M_o L_a^{-1},$$

where $M_o = \mu\left(M_a/(\min M_a)\right)$, and $\mu = 0.125$ is the median natural mortality rate from Cadigan et al. (2022). Recruitment, i.e., the numbers at the first ages, $N_{y,1}$, are treated as random deviations from a fixed mean effect,

$$\log(N_{y,1}) = \mu_R + \delta_{R_y}, \quad (2)$$

where μ_R is the mean recruitment. The deviations from the mean recruitment δ_{R_y} are assumed to follow a normal distribution with AR(1) correlation across years with the AR parameters σ_R^2 and ϕ_R to be estimated.

The ACL model does not have direct information about the initial age-distribution of the stock, therefore a prior based on the numbers in the first year is given by $\log\left(\frac{N_{a,1}}{N_{a-1,1}}\right) \sim iidN\left(-Z_{a-1,1}, \sigma_{N0}^2\right)$, with σ_{N0}^2 fixed at 0.2. Fixing σ_{N0}^2 at 0.2 allows enough flexibility for the intial age distribution of the stock to deviate from the prior, but not enough to have wildly varying numbers in the first year.

The fishing mortality rates are set to zero for ages 1-2, as it is assumed that the fishing gear does not target those smaller sizes, and for all ages greater than two,

$$\log(F_{y,a}) = \mu_{F_{y,a}} + \delta_{F_y} + s_{F_a}, \quad (3)$$

where $\mu_{F_{y,a}}$ is the mean fishing mortality rate and s_{F_a} is assumed to follow a logistic selectivity pattern with parameters L_{f50} and L_{fd} to estimate (note throughout the text L_d represents the difference between the L_{50} and L_{95} parameters). Depending on the model formulation, δ_{F_y} are estimated as fixed or random effects.

Probability of length at age

Consistent ageing data are not available for 3LN redfish, therefore, the numbers at age in the model need to be converted to numbers at length. The mean length at age L_a is defined as

$$L_a = L_0 + (L_1 - L_0)(1 - e^{-K(a-a_0)})/(1 - e^{-K(a_1-a_0)}), \quad (4)$$

where L_0=0.58 (ref) for $a_0 = 0$, K is the growth rate parameter and L_1 is a fixed parameter to estimate. The length information is given for one centimeter length bins, and we assume that there is a mid-point of the length bins. Therefore, a fish of length bin l will have length $L \in (l - 0.5cm, l + 0.5cm)$. The cumulative distribution function is used to calculate the probability that a fish is in length bin l given its age. As is often the case in fisheries applications, we assume that length-at-age is normally distributed with mean L_a, with standard deviation that increases with the mean, i.e., $L_a \sim N(L_a, \tau L_a)$. Then, the CDF for the normal distribution gives the probability that a fish is in length bin l given its age,

$$P(L_a \in l) = \phi\left(\frac{l - L_a + 0.5}{\tau L_a}\right) - \phi\left(\frac{l - L_a - 0.5}{\tau L_a}\right) \tag{5}$$

The number of fish in each length bin $\left(N_{ly}\right)$ is then given by

$$N_{ly} = \sum_a N_{ay} P_{la} \tag{6}$$

where P_{la} is shorthand for $P(L_a \in l)$.

Observation model

The Baranov catch equation relates the expected catch to the stock size,

$$C_{y,a} = \frac{F_{y,a}}{Z_{y,a}}(1 - \exp^{-Z_{y,a}})N_{y,a}. \tag{7}$$

where we convert catch at age to catch at length using the approach described above,

$$C_{ly} = \sum_a C_{ay} P_{cla}, \tag{8}$$

with P_{cla} representing the assumption that the catch are sampled in the middle of the year (i.e. we add 0.5 to the ages). The relationship between stock size and the timing of the survey is given by

$$N_{say} = N_{ay} e^{-f_s Z_{ay}}, \tag{9}$$

where f_s represents the fraction of the year that the survey takes places. The number of fish in each length bin is given by

$$N_{sly} = \sum_a N_{say} P_{sla}, \tag{10}$$

with P_{sla} representing the probability of length at age for each survey $P_{sla} = p_{l,(a+f_s)}$. The expected survey index is then

$$E_{Isly} = q_{sl} N_{sly}, \tag{11}$$

where q_{sl} represents a separate catchability at length estimate for each survey. Catchability is assumed to follow a logistic selectivity pattern with parameters L_{s50} and L_{sd} to estimate. Note that to ensure that the model is identifiable, the maximum catchability of the Spring survey is fixed at 1. To account for uncertainties in the observed indices, we add an observational error term to describe the relationship between the predicted and observed index

$$I_{sly} = E_{Isly} e^{\epsilon_{sly}} \tag{12}$$

The ϵ_{sly} sampling errors were multivariate normal (MVN) with mean zero and lag-1 autoregressive correlation ρ_I among length classes each year, and conditional standard deviations σ_{sI} that were estimated separately for each survey s. For simplicity the autocorrelation was assumed to be the same for all surveys.