SCRS/2021/141 Collect. Vol. Sci. Pap. ICCAT, 78(3): 756-797 (2021)

WESTERN ATLANTIC BLUEFIN TUNA STOCK ASSESSMENT 1950-2020 USING STOCK SYNTHESIS: PART II. MODEL DIAGNOSTICS, RESULTS AND PROJECTION

Y. Tsukahara[1], J. Walter[2], H. Fukuda[1], A. Kimoto[3] and M. Ortiz[3]

SUMMARY

This document describes a stock assessment model using Stock Synthesis (version 3.30.14) for the Western Atlantic population of Bluefin tuna. This document describes model diagnostics and initial results derived from proposed settings for 2021 assessment. The diagnostics result showed relatively better performance with some negative signs that those in 2020 assessment, while some problems remained as it was in the last assessment. The two model runs showed very similar behavior with the stock decreasing during the 1970s, remaining relatively low during the 1980-2000 period and showing a pattern of steady population growth since 2000. This document also describes projection settings and stock status based on F based reference point, F0.1, which is estimated from the YPR curve in assessment result. Current F during 2018-2020 was below the F0.1, hence the stock was not subject to be overfishing. It is also showed that the probability which is that F<F0.1 under several constant catch scenarios for management advice.

RÉSUMÉ

Ce document décrit un modèle d'évaluation des stocks utilisant Stock Synthesis (version 3.30) pour la population de thon rouge de l'Atlantique Ouest. Ce document décrit les diagnostics du modèle et les premiers résultats dérivés des paramètres proposés pour l'évaluation 2021. Le résultat des diagnostics a montré une performance relativement meilleure avec quelques signes négatifs que ceux de l'évaluation 2020, tandis que certains problèmes persistent comme lors de la dernière évaluation. Les deux scénarios du modèle ont montré un comportement très similaire, le stock diminuant dans les années 70, demeurant relativement faible durant la période 1980-2000 et faisant apparaître un schéma de croissance constante de la population depuis 2000. Ce document décrit les paramètres de la projection et l'état des stocks sur la base du point de référence basé sur F, $F_{0,1}$, qui est estimé à partir de la courbe YPR dans le résultat de l'évaluation. Le F actuel pour la période 2018-2020 était inférieur au $F_{0,1}$, le stock n'était donc pas victime de surpêche. Le document montre également la probabilité de $F<F_{0,1}$ en vertu de plusieurs scénarios de captures constantes pour l'avis de gestion.

RESUMEN

Este documento describe un modelo de evaluación de stock que utiliza Stock Synthesis (versión 3.30.14) para la población de atún rojo del Atlántico occidental. Este documento describe los diagnósticos del modelo y los resultados iniciales derivados de las especificaciones propuestas para la evaluación de 2021. Los resultados de diagnósticos mostraban un funcionamiento relativamente mejor, con algunos signos negativos, que los de la evaluación de 2020, aunque continuaban existiendo algunos problemas, como en la última evaluación. Los dos ensayos del modelo mostraban un comportamiento similar, con el stock descendiendo durante los 70, permaneciendo relativamente bajo durante el periodo 1980-2000 y mostrando un patrón constante de crecimiento de la población desde 2000. Este documento describe también las especificaciones de la proyección y el estado del stock basándose en un punto de referencia basado en F, $F_{0,1}$, que se estima a partir de la curva YPR en el resultado de la evaluación. La F actual durante 2018-2020 era inferior a $F_{0,1}$, por lo tanto, el stock no estaba sufriendo sobrepesca. Se demuestra también la probabilidad de que F < F0,1 en el marco de varios escenarios de captura constante para el asesoramiento de ordenación.

KEYWORDS
Stock assessment, bluefin tuna, Stock Synthesis

[1] FRA Fisheries Resources Institute. 2-12-4, Fukuura, Kanazawa, Yokohama, Kanagawa, 236-8648, Japan. tsukahara_y@ affrc.go.jp
[2] NOAA Fisheries, Southeast Fisheries Center, 75 Virginia Beach Drive, Miami, Florida, 33149, United States
[3] ICCAT Secretariat, C/ Corazón de María 8 – 6th floor, 28002 Madrid, Spain

Introduction

Stock Synthesis 3 (SS3) is an integrated statistical catch-at-age model which is widely used for many stock assessments in the United States and throughout the world (Methot and Wetzel 2013 http:// https://vlab.ncep.noaa.gov/web/stock-synthesis). SS3 takes relatively unprocessed input data and incorporates many of the important processes (mortality, selectivity, growth, etc.) that operate in conjunction to produce observed catch, size and age composition and CPUE indices. Because many of these inputs are correlated, the concept behind SS3 is that they should be modeled together, which helps to ensure that uncertainties in the input data are properly accounted for in the assessment. SS3 is comprised of three subcomponents: 1) a population subcomponent that recreates an estimate of the numbers/biomass at age using estimates of natural mortality, growth, fecundity, etc.; 2) an observational sub-component that consists of observed (measured) quantities such as CPUE or proportion at length/age; and 3) a statistical sub-component that uses likelihoods to quantify the fit of the observations to the recreated population.

The stock assessment in 2020 represents as strict of an update of the 2017 stock assessment as possible. The results of strict update resulted in the poor fit to some indices including the USRR_66_114 which was the relative abundance index for the smallest fish in that assessment. ABTWG discussed about the reliability of recent recruitment estimation, and thus WG recommended that TAC should be reviewed annually by the Commission on the advice of the SCRS (which would be based on consideration of updates of the fishery indicators as well as intersessional work conducted to improve indices) (SCRS 2020). Based on this recommendation, ICCAT commission request the assessment again in 2021. The default specifications for this assessment should be very similar to the 2020 assessment unless there are strong rationale for changes. This paper describes the model diagnostics, assessment and projection results derived from proposed base case model documented in the 1 of 2 document for this assessment (Tsukahara et al., 2021).

Model Diagnostics

Model diagnostics

The appropriateness of model convergence was assessed using several means (SCRS/2021/140).

1. Whether the Hessian, (i.e., the matrix of second derivatives of the likelihood with respect to the parameters) inverts.
2. The maximum gradient component which, ideally, should be low.
3. Jitter analysis of parameter starting values to evaluate whether the model has converged to a global solution, rather than a local minimum. Starting values of all estimated parameters were randomly perturbed according to a normal distribution defined where the pr(par min)=0.01 and pr(par max)=0.99).
4. Parameter coefficients of variation where the CV of the parameter estimate comes from the model estimated variance from the variance-covariance matrix.
5. Likelihood profiles were completed for three key model parameters: steepness of the stock-recruit relationship (h) and the log of unexploited equilibrium recruitment (R_0) and sigma R.
6. Evaluation of fits to the indices and length composition.
7. Retrospective analyses. Retrospective analyses are also standard diagnostic practice and were conducted on models 1-2 with 5 year retrospective peels.
8. Sensitivity to sets of different indices (index jackknife evaluation)
9. Parametric bootstrapping to evaluate observation error in parameter estimates and derived quantities.

Both models show nearly identical diagnostic performance and very similar log-likelihoods and thus can be discussed as a single model with regard to the diagnostics. The Hessian matrices were defined positive for the both models and the standard deviations for every parameter could be estimated (**Table 1** and **2**).

No parameters hit bounds and most parameters showed relatively low standard deviations relative to the estimated values, indicating good estimation. The models show relatively good diagnostic performance though the maximum gradient components (usually less than 0.0001) (**Table 3**). Derived quantities, benchmarks and standard errors indicate relatively well determined values (**Table 4**).
Some runs for both models in the jitter analysis for high spawning fraction had much higher log-likelihood than the global solution, which seems not to achieve good convergence (**Figures 1a** and **1b**), however global solutions were found for both models and the practical result of this instability is negligible (**Figures 2a** and **2b**).

Both models converge on particular solution of steepness, sigmaR and R0 (**Figures 3 and 4**), though there is some conflict among data sources for steepness and sigmaR. Although the length composition data diverged from other data sources until last assessment, the steep slope for high R0 is reduced and there are apparent minimum values in the R0 profile due to the change of selectivity.

Fits to indices are generally fairly poor for both models (**Figures 5 and 6**). A fit to index from the Canadian acoustic survey looks relatively better than the other indices, though a decline in the acoustic index in 2017 could not be fit even when the acoustic data point since 2018 was removed.

Overall the length composition data are fairly well fit with few systematic departures (**Figures 7 and 8**). Fits for each year and each fleet indicate that while most fits are good, there are many years with departures, which also appeared in the result of last assessment. Problematic departures can be seen in the Pearson residuals where one would look for strong patterned trends. Of particular note is the recent residual pattern in the length composition of the JAPAN_LL where there remain strong positive residuals along a diagonal and a near absence of fish below this diagonal from about 2000 onward. (**Figures 9 and 10**).

Retrospective performance of the models is good (**Figure 11**) with no perceptible pattern in SSB. There are some patterns in the terminal year estimate of recruitment. This is due to the bias adjustment ramping, which is assumed for recruitment deviation to be 0 at terminal year. The values of Mohn's rho of SSB are 0.10 and 0.08, and those of recruitment are -0.05 and -0.05 for model 1 and model 2, respectively. All Mohn's rho values are less than 0.2, hence the retrospective patterns could be negligible.

The performance evaluations of each index by jackknife analysis indicate that every index does not have strong impacts on over all trajectories of SSB and recruitment, while there were differences of the SSB in the recent years due to the instability of recruitment estimation (**Figure 12**).

Bootstrapping results indicate that the base models which are without data perturbation are relatively well aligned with and mostly centered on the 100 bootstrap replicates for both SSB and recruitment (**Figure 13**), although replicates of recent recruitment are less than the base case model. The estimates from the original run for two of three stock-recruitment relationships (R_0 and steepness) were generally near the center of the histogram of estimates from the bootstrap replicates (**Figure 14**). However, for sigmaR, the estimate from the original run was higher than those from every bootstrap replicate for both models. This may be a product of the bootstraps being created from an assumed multinomial distribution and resampling in accordance with input sample size for the length composition information. Hence the composition data may be far less noisy then the real data, resulting in reduced estimates of recruitment variability, though this does not appear to affect the SSB and recruitment trends. Additional diagnostics, e.g., Age-Structured Production Model (ASPM) and Catch Curve Analysis (CAA) were done to see the consistency among the data sources. Those diagnostics was newly showed to the WG, hence the method and results were documented in detail as appendix in this document.

Model results

Estimated selectivities generally reflected assumed patterns of the actual fisheries (**Figures 15 and 16**). The doming of the Japan_LL is fairly steep but seems rather well determined by the fact that several fleets have asymptotic selectivity and capture much larger fish on average. The size composition is extremely sharp, indicating that it could be a product of several cohorts and that due to the short time period of data the lack of fit may be due to the effect of a transient cohort. Given that this represents some of the earliest length composition in the model this could be one of the factors influencing some of the initial model instability in estimating the earliest recruitment deviations.

Overall, the times series of SSB and recruitment and other derived parameters are extremely similar between the two model runs indicating a relatively limited effect of changing the age at maturity on model fit or model performance (**Figure 17**). While SSB is scaled higher or lower the resulting total biomass estimates and relative levels of depletion from virgin are very similar. Both models indicate stock decline during the 1970s, remaining relatively low during the 1980-2000 period, and showing a pattern of steady population growth since 2000. Fishing mortality has generally decreased in the most recent 20 years. While levels of fishing mortality for both models were relatively stable since 2010, the SSB trends, especially for model 2, shows peaking out since 2015. The time series of SSB and recruitment also show less evidence of a 'regime change' in the longer time series and more an indication of recruitment declining due to a decline in SSB.

Projection Settings and uncertainty quantification

The biological and fisheries parameters for projection, e.g. growth curve and selectivity, are derived from final base cases agreed in this meeting. An F based reference point, F0.1 is calculated using the yield per recruitment (YPR) curve. Future recruitment is usually set to the average of recent six years (2012-2017). The catch in 2021 is assumed to be the current TAC (2,350 t) and those after 2022 are assumed to be constant catch scenarios with

100 t intervals from 1,000 t to 3,500 t, to be subsequently updated with 100 mt intervals for finer resolution for final advice. The future catch by fleet assumed that the recent fisheries would continue, and the allocation was calculated based on the allocation table in Rec. 17-06 by CPC (without considering the transfers) and the average catch (Task1) ratios in 2018-2020 by CPC and by gear. In the projection, every fleet is assumed to exhaust their quota every year. A projection which has no catch limit and set future F to F0.1 is also conducted to evaluate the yield at F based reference point. The uncertainty in around future probabilities of F<F0.1 is taken into account by the multivariate lognormal approximation (MVLN).

Projection Results

The projection results would update during the meeting after deciding the all of setting, i.e the recent and future recruitment setting.

Acknowledgements

We are grateful for the contributions of the Secretariat, the combined efforts of a vast number of colleagues who, through GBYP, have resurrected age-length information, catches and other historical data that facilitate creating an integrated model that uses as much data as possible for WBFT.

References

Anonymous (2020) REPORT OF THE 2019 STANDING COMMITTEE ON RESEARCH AND STATISTICS (SCRS)

Methot, R.D. (2000) Technical description of the stock synthesis assessment program. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-43, 46 p.

Methot, R.D. and Wetzel C.R. (2013) Stock synthesis: A biological and statistical framework for fish stock assessment and fishery management, Fisheries Research 142: 86-99.

Tsukahara, Y., Walter, J., Fukuda, H., Kimoto, A., Ortiz, M., (2021) Western Atlantic bluefin tuna stock assessment 1950-2020 using stock synthesis: part i. model specification and data, ICCAT - SCRS/2021/141

Table 1. Parameter estimates, phases initial values and standard deviations for model 1. Rec devs not shown.

Label	Value	Active	Pha	Min	Max	Init	Parm_StD	Gradient
NatM_p_1_Fem_GP_1	0.1	_	-3	0.05	0.3	0.1	_	_
L_at_Amin_Fem_GP_1	42.9753	_	-2	0	50	42.975	_	_
L_at_Amax_Fem_GP_1	273.217	1	3	240	350	273.21	0.777489	6.69E-07
VonBert_K_Fem_GP_1	0.28929	2	3	0.2	0.4	0.2892	0.008331	-2.21E-
Richards_Fem_GP_1	-	3	3	-2	0	-	0.070234	-2.75E-
CV_young_Fem_GP_1	0.09101	4	4	0.03	0.15	0.0910	0.005386	-1.51E-
CV_old_Fem_GP_1	0.06629	5	4	0.03	0.15	0.0662	0.001541	-1.79E-
Wtlen_1_Fem_GP_1	1.77E-	_	-3	1.00E-	0.01	1.77E-	_	_
Wtlen_2_Fem_GP_1	3.00125	_	-3	2	4	3.0012	_	_
Mat50%_Fem_GP_1	8.8	_	-3	4	15	8.8	_	_
Mat_slope_Fem_GP_1	-50	_	-3	-100	-1	-50	_	_
Eggs_scalar_Fem_GP_1	1	_	-3	1	1	1	_	_
Eggs_exp_wt_Fem_GP_1	1	_	-3	1	1	1	_	_
CohortGrowDev	1	_	-1	0.1	10	1	_	_
FracFemale_GP_1	0.5	_	-99	1.00E-	0.999	0.5	_	_
SR_LN(R0)	6.6199	6	1	5	10	6.6199	0.038194	-8.12E-
SR_BH_steep	0.58086	7	2	0.5	0.99	0.5808	0.028263	-7.10E-
SR_sigmaR	0.66728	8	3	0.2	1.2	0.6672	0.082027	7.03E-07
SR_regime	0	_	-4	-5	5	0	_	_
SR_autocorr	0	_	-99	0	0	0	_	_
Main_RecrDev_1961	1.31847	9	1	-5	5	1.3184	0.18383	-7.44E-
Main_RecrDev_1962	-	10	1	-5	5	-	0.557804	-6.12E-
Main_RecrDev_1963	0.52228	11	1	-5	5	0.5222	0.271899	-3.35E-
Main_RecrDev_1964	-	12	1	-5	5	-	0.445212	-6.22E-
Main_RecrDev_1965	-	13	1	-5	5	-	0.437705	1.49E-06
Main_RecrDev_1966	-	14	1	-5	5	-	0.381975	2.46E-07
Main_RecrDev_1967	-	15	1	-5	5	-	0.482442	-1.45E-
Main_RecrDev_1968	0.32284	16	1	-5	5	0.3228	0.353605	-2.22E-
Main_RecrDev_1969	0.40538	17	1	-5	5	0.4053	0.270549	-7.62E-
Main_RecrDev_1970	-	18	1	-5	5	-	0.303355	6.38E-07
Main_RecrDev_1971	-	19	1	-5	5	-	0.29088	2.36E-07
Main_RecrDev_1972	1.23528	20	1	-5	5	1.2352	0.110751	-2.13E-
Main_RecrDev_1973	0.49925	21	1	-5	5	0.4992	0.177829	4.54E-07
Main_RecrDev_1974	-	22	1	-5	5	-	0.238923	7.41E-07
Main_RecrDev_1975	-	23	1	-5	5	-	0.249383	-2.13E-
Main_RecrDev_1976	-	24	1	-5	5	-	0.217418	3.23E-07
Main_RecrDev_1977	-	25	1	-5	5	-	0.249214	-4.18E-
Main_RecrDev_1978	-	26	1	-5	5	-	0.177675	-7.32E-
Main_RecrDev_1979	-	27	1	-5	5	-	0.157748	3.29E-07
Main_RecrDev_1980	-	28	1	-5	5	-	0.215084	1.27E-07
Main_RecrDev_1981	0.30797	29	1	-5	5	0.3079	0.098798	1.19E-06
Main_RecrDev_1982	-	30	1	-5	5	-	0.140691	1.72E-07
Main_RecrDev_1983	-	31	1	-5	5	-	0.187434	7.86E-07
Main_RecrDev_1984	0.01824	32	1	-5	5	0.0182	0.134066	1.09E-07
Main_RecrDev_1985	-	33	1	-5	5	-	0.192541	-5.76E-
Main_RecrDev_1986	0.19582	34	1	-5	5	0.1958	0.138358	3.76E-07

Main_RecrDev_1987	-0.4628	35	1	-5	5	-	0.246544	-3.05E-
Main_RecrDev_1988	-	36	1	-5	5	-	0.227864	-6.69E-
Main_RecrDev_1989	0.91003	37	1	-5	5	0.9100	0.110409	5.64E-07
Main_RecrDev_1990	-	38	1	-5	5	-	0.25256	6.27E-07
Main_RecrDev_1991	0.38303	39	1	-5	5	0.3830	0.140481	6.32E-07
Main_RecrDev_1992	-	40	1	-5	5	-	0.350034	3.51E-08
Main_RecrDev_1993	0.29911	41	1	-5	5	0.2991	0.174595	-6.38E-
Main_RecrDev_1994	1.00168	42	1	-5	5	1.0016	0.106203	-1.23E-
Main_RecrDev_1995	-	43	1	-5	5	-	0.286764	-3.24E-
Main_RecrDev_1996	-	44	1	-5	5	-	0.25421	-1.15E-
Main_RecrDev_1997	0.11746	45	1	-5	5	0.1174	0.179778	6.78E-07
Main_RecrDev_1998	-0.1365	46	1	-5	5	-	0.229749	2.49E-07
Main_RecrDev_1999	0.12123	47	1	-5	5	0.1212	0.186475	-5.33E-
Main_RecrDev_2000	0.28917	48	1	-5	5	0.2891	0.16638	-7.70E-
Main_RecrDev_2001	0.27358	49	1	-5	5	0.2735	0.178825	-3.14E-
Main_RecrDev_2002	-	50	1	-5	5	-	0.276014	1.58E-07
Main_RecrDev_2003	1.26591	51	1	-5	5	1.2659	0.090544	1.08E-06
Main_RecrDev_2004	-1.0106	52	1	-5	5	-	0.396769	3.53E-07
Main_RecrDev_2005	0.79653	53	1	-5	5	0.7965	0.106158	7.88E-07
Main_RecrDev_2006	-	54	1	-5	5	-	0.289275	2.56E-07
Main_RecrDev_2007	-	55	1	-5	5	-	0.229673	9.53E-07
Main_RecrDev_2008	0.93789	56	1	-5	5	0.9378	0.120764	1.23E-06
Main_RecrDev_2009	0.29902	57	1	-5	5	0.2990	0.186962	3.68E-07
Main_RecrDev_2010	-0.9048	58	1	-5	5	-	0.333116	-2.11E-
Main_RecrDev_2011	0.38210	59	1	-5	5	0.3821	0.154991	-3.38E-
Main_RecrDev_2012	0.08848	60	1	-5	5	0.0884	0.203666	-2.62E-
Main_RecrDev_2013	-	61	1	-5	5	-	0.297449	3.71E-07
Main_RecrDev_2014	-	62	1	-5	5	-	0.234659	-2.50E-
Main_RecrDev_2015	-	63	1	-5	5	-	0.283554	-2.04E-
Main_RecrDev_2016	0.08318	64	1	-5	5	0.0831	0.36129	-8.87E-
Main_RecrDev_2017	0.94784	65	1	-5	5	0.9478	0.398341	4.18E-08
Main_RecrDev_2018	0.82538	66	1	-5	5	0.8253	0.744835	1.31E-07
Main_RecrDev_2019	-	67	1	-5	5	-	0.639784	1.15E-07
Late_RecrDev_2020	0	_	_	_	_	_	_	_
ForeRecr_2021	0	_	_	_	_	_	_	_
Impl_err_2021	0	_	_	_	_	_	_	_
InitF_seas_1_flt_7USA_TRAP	0.01266	68	1	1.00E-	0.1	0.0126	0.002123	-1.31E-
InitF_seas_1_flt_9USA_CAN_HARPOON	0.00221	69	1	1.00E-	0.1	0.0022	0.000161	-3.59E-
LnQ_base_IDX1_JAPAN_LL(18)	-	_	-1	-10	-2	-	_	_
LnQ_base_IDX2_JAPAN_LL2(19)	-	_	-1	-10	-2	-	_	_
LnQ_base_IDX5_MEXUSLL_GOM_LL(22)	-	_	-1	-10	-2	-	_	_
LnQ_base_IDX6_JPNLL_GOM(23)	-	_	-1	-10	-2	-	_	_
LnQ_base_IDX9_US_RR_66_144(26)	-	_	-1	-10	-2	-	_	_
LnQ_base_IDX10_US_RR_LT145(27)	-	_	-1	-10	-2	-	_	_
LnQ_base_IDX11_US_RR_GT177(28)	-	70	1	-10	-2	-	0.088076	6.34E-07
LnQ_base_IDX12_US_RR_GT195(29)	-	_	-1	-10	-2	-	_	_
LnQ_base_IDX14_CAN_SWNS(31)	-	71	1	-10	-2	-	0.098274	4.08E-07
LnQ_base_IDX15_CAN_GSL(32)	-6.0279	72	1	-10	-2	-	0.109839	5.69E-07
LnQ_base_IDX16_CAN_ACOUSTIC(33)	-	73	1	-10	-2	-	0.122313	2.89E-07

LnQ_base_IDX17_GOMlarval(34)	-5.0429	_	-1	-10	-2	-	_	_
LnQ_base_IDX19_oceanographic(36)	-	_	-1	-10	-2	-	_	_
LnQ_base_IDX11_US_RR_GT177(28)_EN	0.16212	74	3	-2	2	0.1621	0.050163	-3.55E-
LnQ_base_IDX14_CAN_SWNS(31)_ENV_	-	75	3	-2	2	-	0.070898	4.53E-08
LnQ_base_IDX15_CAN_GSL(32)_ENV_mu	-	76	3	-2	2	-	0.031397	9.66E-07
LnQ_base_IDX16_CAN_ACOUSTIC(33)_E	-	77	3	-2	2	-	0.038213	4.90E-07
Size_DblN_peak_JAPAN_LL(1)	224.345	78	2	120	250	224.34	2.80239	1.21E-07
Size_DblN_top_logit_JAPAN_LL(1)	-	79	2	-15	3	-	55.6289	-7.48E-
Size_DblN_ascend_se_JAPAN_LL(1)	7.1039	80	3	-5	9	7.1039	0.11988	1.23E-06
Size_DblN_descend_se_JAPAN_LL(1)	5.72573	81	5	-5	9	5.7257	0.375667	4.42E-07
Size_DblN_start_logit_JAPAN_LL(1)	-999	_	-3	-999	15	-999	_	_
Size_DblN_end_logit_JAPAN_LL(1)	-	82	6	-20	10	-	0.53451	4.88E-07
Size_DblN_peak_OTHER_ATL_LL(2)	215.248	83	2	120	285	215.24	2.46535	-8.15E-
Size_DblN_top_logit_OTHER_ATL_LL(2)	-	84	2	-15	3	-	56.7886	7.32E-10
Size_DblN_ascend_se_OTHER_ATL_LL(2	8.04934	85	3	-5	9	8.0493	0.057675	-8.25E-
Size_DblN_descend_se_OTHER_ATL_LL(	7.13219	86	5	-5	9	7.1321	0.208617	-1.02E-
Size_DblN_start_logit_OTHER_ATL_LL(2)	-999	_	-3	-999	15	-999	_	_
Size_DblN_end_logit_OTHER_ATL_LL(2)	-	87	6	-20	10	-	0.418565	-1.40E-
Size_DblN_peak_GOM_US_MEX_LL(3)	247.419	88	2	120	285	247.41	0.351476	-6.69E-
Size_DblN_top_logit_GOM_US_MEX_LL(3	-	89	2	-15	3	-	65.8761	1.70E-08
Size_DblN_ascend_se_GOM_US_MEX_LL	7.57337	90	3	-5	9	7.5733	0.048525	3.83E-07
Size_DblN_descend_se_GOM_US_MEX_L	-	91	5	-5	9	-	9.76936	-7.80E-
Size_DblN_start_logit_GOM_US_MEX_LL(	-999	_	-3	-999	15	-999	_	_
Size_DblN_end_logit_GOM_US_MEX_LL(	0.42905	92	6	-20	10	0.4290	0.21318	4.68E-07
Size_DblN_peak_JPNLL_GOM(4)	233.359	93	2	120	285	233.35	2.51671	-5.05E-
Size_DblN_top_logit_JPNLL_GOM(4)	-	94	2	-15	3	-	53.1059	-1.81E-
Size_DblN_ascend_se_JPNLL_GOM(4)	6.61415	95	3	-5	9	6.6141	0.169194	1.15E-06
Size_DblN_descend_se_JPNLL_GOM(4)	6.20175	96	5	-5	9	6.2017	0.196764	2.19E-07
Size_DblN_start_logit_JPNLL_GOM(4)	-999	_	-3	-999	15	-999	_	_
Size_DblN_end_logit_JPNLL_GOM(4)	-	97	6	-20	10	-	0.44746	1.38E-07
Size_DblN_peak_USA_CAN_PSFS(5)	73.9622	98	3	50	200	73.962	3.91843	-1.06E-
Size_DblN_top_logit_USA_CAN_PSFS(5)	-2	_	-3	-5	3	-2	_	_
Size_DblN_ascend_se_USA_CAN_PSFS(5	4.66474	99	4	-4	12	4.6647	0.713109	9.77E-07
Size_DblN_descend_se_USA_CAN_PSFS(	5.9923	_	-5	-5	6	5.9923	_	_
Size_DblN_start_logit_USA_CAN_PSFS(5)	-999	_	-2	-15	5	-999	_	_
Size_DblN_end_logit_USA_CAN_PSFS(5)	-999	_	-2	-15	10	-999	_	_
Size_DblN_peak_USA_CAN_PSFB(6)	212.515	100	2	150	285	212.51	3.0743	1.82E-06
Size_DblN_top_logit_USA_CAN_PSFB(6)	-	101	2	-5	3	-	0.312036	4.90E-07
Size_DblN_ascend_se_USA_CAN_PSFB(6	6.85504	102	3	-4	8	6.8550	0.13841	-1.30E-
Size_DblN_descend_se_USA_CAN_PSFB(	5.99989	_	-5	-2	6	5.9998	_	_
Size_DblN_start_logit_USA_CAN_PSFB(6)	-999	_	-2	-15	5	-999	_	_
Size_DblN_end_logit_USA_CAN_PSFB(6)	-	103	6	-15	5	-	0.798567	2.54E-08
Size_DblN_peak_USA_TRAP(7)	124.287	104	3	80	150	124.28	6.8177	-1.01E-
Size_DblN_top_logit_USA_TRAP(7)	-	105	3	-5	3	-	0.832139	2.88E-08
Size_DblN_ascend_se_USA_TRAP(7)	7.85593	_	-4	-4	10	7.8559	_	_
Size_DblN_descend_se_USA_TRAP(7)	7.4152	106	5	-2	10	7.4152	0.553243	-1.80E-
Size_DblN_start_logit_USA_TRAP(7)	-999	_	-2	-15	5	-999	_	_
Size_DblN_end_logit_USA_TRAP(7)	-999	_	-2	-15	10	-999	_	_
Size_DblN_peak_CAN_TRAP(8)	272.97	107	2	120	285	272.97	1.88867	-1.16E-

Size_DbIN_top_logit_CAN_TRAP(8)	-12.02	108	2	-15	3	-12.02	50.8964	-9.73E-
Size_DbIN_ascend_se_CAN_TRAP(8)	7.82707	109	3	-5	9	7.8270	0.063859	1.85E-07
Size_DbIN_descend_se_CAN_TRAP(8)	4.45503	110	5	-5	9	4.4550	0.47897	-6.01E-
Size_DbIN_start_logit_CAN_TRAP(8)	-999	_	-3	-999	15	-999	_	_
Size_DbIN_end_logit_CAN_TRAP(8)	-	111	6	-20	10	-	0.646167	-2.58E-
Size_DbIN_peak_USA_CAN_HARPOON(9)	192.489	112	2	120	285	192.48	1.44996	-1.38E-
Size_DbIN_top_logit_USA_CAN_HARPOO	-	113	2	-15	3	-	0.184753	-9.35E-
Size_DbIN_ascend_se_USA_CAN_HARPO	5.74381	114	3	-5	9	5.7438	0.127502	-5.44E-
Size_DbIN_descend_se_USA_CAN_HARP	7.27582	115	5	-5	9	7.2758	0.334701	-6.93E-
Size_DbIN_start_logit_USA_CAN_HARPO	-999	_	-3	-999	15	-999	_	_
Size_DbIN_end_logit_USA_CAN_HARPOO	-	116	6	-20	10	-	1.17338	-3.70E-
Size_inflection_USA_HARPOON(10)	177.036	_	-2	100	220	177.03	_	_
Size_95%width_USA_HARPOON(10)	17.0894	_	-2	10	60	17.089	_	_
Size_DbIN_peak_USA_RRFS(11)	111.804	117	2	80	120	111.80	1.27765	-3.30E-
Size_DbIN_top_logit_USA_RRFS(11)	-	118	3	-5	3	-	0.10278	-2.29E-
Size_DbIN_ascend_se_USA_RRFS(11)	6.51435	_	-4	-4	8	6.5143	_	_
Size_DbIN_descend_se_USA_RRFS(11)	-	119	5	-5	4	-	15.1451	-3.33E-
Size_DbIN_start_logit_USA_RRFS(11)	-999	_	-2	-15	5	-999	_	_
Size_DbIN_end_logit_USA_RRFS(11)	-999	_	-6	-15	10	-999	_	_
Size_DbIN_peak_USA_RRFB(12)	196.659	120	2	140	220	196.65	2.08974	-2.92E-
Size_DbIN_top_logit_USA_RRFB(12)	-	121	3	-5	1	-	0.034252	-9.88E-
Size_DbIN_ascend_se_USA_RRFB(12)	6.72	122	4	-4	8	6.72	0.102262	4.74E-07
Size_DbIN_descend_se_USA_RRFB(12)	2.0829	_	-5	-2	8	2.0829	_	_
Size_DbIN_start_logit_USA_RRFB(12)	-999	_	-2	-15	5	-999	_	_
Size_DbIN_end_logit_USA_RRFB(12)	-	123	6	-15	5	-	0.16517	1.82E-07
Size_inflection_CAN_combinedHL(13)	194.826	_	-2	160	220	194.82	_	_
Size_95%width_CAN_combinedHL(13)	33.0026	_	-2	10	50	33.002	_	_
Size_DbIN_peak_CAN_SWNS_HLnoHP(14	210.574	124	2	120	285	210.57	1.81608	-8.12E-
Size_DbIN_top_logit_CAN_SWNS_HLnoH	-	125	2	-15	3	-	0.692155	1.30E-07
Size_DbIN_ascend_se_CAN_SWNS_HLno	6.61057	126	3	-5	9	6.6105	0.090451	5.04E-08
Size_DbIN_descend_se_CAN_SWNS_HLn	7.68559	127	5	-5	9	7.6855	0.291353	4.06E-07
Size_DbIN_start_logit_CAN_SWNS_HLno	-999	_	-3	-999	15	-999	_	_
Size_DbIN_end_logit_CAN_SWNS_HLnoH	-	128	6	-20	10	-	1.51883	6.77E-08
Size_inflection_CAN_SWNS_HLwithHP(1	194.826	_	-2	150	250	194.82	_	_
Size_95%width_CAN_SWNS_HLwithHP(1	33.0026	_	-2	10	50	33.002	_	_
Size_inflection_CAN_GSL_HL(16)	214.32	129	2	210	330	214.32	2.25331	-1.74E-
Size_95%width_CAN_GSL_HL(16)	31.447	130	2	10	50	31.447	2.49366	1.30E-07
Size_DbIN_peak_IDX7_US_RR_66_114(24	65	_	-3	40	200	65	_	_
Size_DbIN_top_logit_IDX7_US_RR_66_11	-1.7	_	-3	-5	3	-1.7	_	_
Size_DbIN_ascend_se_IDX7_US_RR_66_1	-4	_	-3	-4	12	-4	_	_
Size_DbIN_descend_se_IDX7_US_RR_66_	-2	_	-3	-2.5	6	-2	_	_
Size_DbIN_start_logit_IDX7_US_RR_66_1	-999	_	-2	-15	5	-999	_	_
Size_DbIN_end_logit_IDX7_US_RR_66_11	-5	_	-2	-15	10	-5	_	_
Size_DbIN_peak_IDX8_US_RR_115_144(2	115	_	-3	40	200	115	_	_
Size_DbIN_top_logit_IDX8_US_RR_115_1	-2.1	_	-3	-5	3	-2.1	_	_
Size_DbIN_ascend_se_IDX8_US_RR_115_	-4	_	-3	-4	12	-4	_	_
Size_DbIN_descend_se_IDX8_US_RR_115	-2	_	-3	-2.5	6	-2	_	_
Size_DbIN_start_logit_IDX8_US_RR_115_	-999	_	-2	-15	5	-999	_	_
Size_DbIN_end_logit_IDX8_US_RR_115_1	-5	_	-2	-15	10	-5	_	_

Size_DblN_peak_JAPAN_LL(1)_BLK1repl_	165.801	131	5	120	285	165.80	1.08087	-8.28E-
Size_DblN_peak_JAPAN_LL(1)_dev_se	50	_	-5	0.0001	100	50	_	_
Size_DblN_peak_JAPAN_LL(1)_dev_autoc	0	_	-6	-0.99	0.99	0	_	_
Size_DblN_top_logit_JAPAN_LL(1)_BLK1r	-	132	5	-10	1	-	0.660287	1.88E-07
Size_DblN_ascend_se_JAPAN_LL(1)_BLK	7.62543	_	-5	-1	9	7.6254	_	_
Size_DblN_descend_se_JAPAN_LL(1)_BL	7.47737	133	5	-1	9	7.4773	0.130729	-8.98E-
Size_DblN_end_logit_JAPAN_LL(1)_BLK1	-6.1241	134	5	-20	1	-	1.27518	-2.64E-
Size_DblN_peak_USA_RRFS(11)_BLK2re	84.2263	135	5	60	110	84.226	1.48104	1.36E-06
Size_DblN_top_logit_USA_RRFS(11)_BLK	-	136	5	-5	3	-	0.028571	1.03E-05
Size_DblN_ascend_se_USA_RRFS(11)_BL	6.00972	_	-5	-4	10	6.0097	_	_
Size_DblN_descend_se_USA_RRFS(11)_B	-	_	-5	-2	4	-	_	_
Size_inflection_CAN_GSL_HL(16)_BLK3re	256.793	137	2	230	330	256.79	1.59635	-3.33E-
Size_95%width_CAN_GSL_HL(16)_BLK3r	34.9411	138	2	10	50	34.941	1.54319	-7.23E-
Size_DblN_peak_JAPAN_LL(1)_DEVrwalk	-	139	6	-10	10	0	0.102324	2.70E-06
Size_DblN_peak_JAPAN_LL(1)_DEVrwalk	0.36837	140	6	-10	10	0	0.115375	2.83E-06
Size_DblN_peak_JAPAN_LL(1)_DEVrwalk	0.47656	141	6	-10	10	0	0.104087	4.75E-06
Size_DblN_peak_JAPAN_LL(1)_DEVrwalk	0.03360	142	6	-10	10	0	0.093974	4.54E-06
Size_DblN_peak_JAPAN_LL(1)_DEVrwalk	0.06605	143	6	-10	10	0	0.094985	3.15E-06

Table 2. Parameter estimates, phases initial values and standard deviations for model 2. Rec devs not shown.

Label	Value	Active_	Pha	Min	Max	Init	Parm_St	Gradient
NatM_p_1_Fem_GP_1	0.1	_	-3	0.05	0.3	0.1	_	_
L_at_Amin_Fem_GP_1	42.975	_	-2	0	50	42.975	_	_
L_at_Amax_Fem_GP_1	273.33	1	3	240	350	273.33	0.803393	8.67E-05
VonBert_K_Fem_GP_1	0.2891	2	3	0.2	0.4	0.2891	0.008375	-
Richards_Fem_GP_1	-	3	3	-2	0	-	0.07038	-
CV_young_Fem_GP_1	0.0907	4	4	0.03	0.15	0.0907	0.005363	-2.35E-05
CV_old_Fem_GP_1	0.0662	5	4	0.03	0.15	0.0662	0.001545	2.56E-06
Wtlen_1_Fem_GP_1	1.77E-	_	-3	1.00E-	0.01	1.77E-	_	_
Wtlen_2_Fem_GP_1	3.0012	_	-3	2	4	3.0012	_	_
Mat50%_Fem_GP_1	8.8	_	-3	4	15	8.8	_	_
Mat_slope_Fem_GP_1	-50	_	-3	-100	-1	-50	_	_
Eggs_scalar_Fem_GP_1	1	_	-3	1	1	1	_	_
Eggs_exp_wt_Fem_GP_1	1	_	-3	1	1	1	_	_
CohortGrowDev	1	_	-1	0.1	10	1	_	_
FracFemale_GP_1	0.5	_	-99	1.00E-	0.9999	0.5	_	_
SR_LN(R0)	6.6342	6	1	5	10	6.6342	0.038586	-
SR_BH_steep	0.5119	7	2	0.4	0.99	0.5119	0.025893	-
SR_sigmaR	0.6383	8	3	0.2	1.2	0.6383	0.079872	0.000200
SR_regime	0	_	-4	-5	5	0	_	_
SR_autocorr	0	_	-99	0	0	0	_	_
Main_RecrDev_1961	1.2845	9	1	-5	5	1.2845	0.191071	-
Main_RecrDev_1962	-	10	1	-5	5	-	0.542003	-6.69E-05
Main_RecrDev_1963	0.5012	11	1	-5	5	0.5012	0.272853	-
Main_RecrDev_1964	-	12	1	-5	5	-	0.432323	-6.02E-05
Main_RecrDev_1965	-	13	1	-5	5	-	0.425653	-6.78E-05
Main_RecrDev_1966	-	14	1	-5	5	-	0.376766	-
Main_RecrDev_1967	-	15	1	-5	5	-	0.472153	-
Main_RecrDev_1968	0.3463	16	1	-5	5	0.3463	0.351821	-
Main_RecrDev_1969	0.4245	17	1	-5	5	0.4245	0.270861	-
Main_RecrDev_1970	-	18	1	-5	5	-	0.299137	-3.82E-05
Main_RecrDev_1971	-	19	1	-5	5	-	0.288764	-7.84E-05
Main_RecrDev_1972	1.2937	20	1	-5	5	1.2937	0.107744	-
Main_RecrDev_1973	0.5709	21	1	-5	5	0.5709	0.176853	-
Main_RecrDev_1974	-	22	1	-5	5	-	0.237541	-1.14E-05
Main_RecrDev_1975	-	23	1	-5	5	-	0.247412	1.30E-05

Main_RecrDev_1976	-	24	1	-5	5	-	0.216109	1.23E-05
Main_RecrDev_1977	-	25	1	-5	5	-	0.246683	3.35E-05
Main_RecrDev_1978	-	26	1	-5	5	-	0.176921	1.95E-05
Main_RecrDev_1979	-	27	1	-5	5	-	0.156549	2.68E-05
Main_RecrDev_1980	-	28	1	-5	5	-	0.213261	4.08E-05
Main_RecrDev_1981	0.3883	29	1	-5	5	0.3883	0.097958	-1.02E-05
Main_RecrDev_1982	0.0642	30	1	-5	5	0.0642	0.140433	2.60E-05
Main_RecrDev_1983	-	31	1	-5	5	-	0.187852	4.38E-05
Main_RecrDev_1984	0.1713	32	1	-5	5	0.1713	0.134476	2.56E-05
Main_RecrDev_1985	-	33	1	-5	5	-	0.193072	4.01E-05
Main_RecrDev_1986	0.3020	34	1	-5	5	0.3020	0.137969	2.99E-05
Main_RecrDev_1987	-	35	1	-5	5	-	0.245344	5.33E-05
Main_RecrDev_1988	-	36	1	-5	5	-	0.223873	4.87E-05
Main_RecrDev_1989	0.8688	37	1	-5	5	0.8688	0.108587	1.36E-05
Main_RecrDev_1990	-	38	1	-5	5	-	0.246164	5.30E-05
Main_RecrDev_1991	0.2968	39	1	-5	5	0.2968	0.138715	4.42E-05
Main_RecrDev_1992	-	40	1	-5	5	-	0.337923	6.42E-05
Main_RecrDev_1993	0.2498	41	1	-5	5	0.2498	0.172004	5.46E-05
Main_RecrDev_1994	0.9343	42	1	-5	5	0.9343	0.103732	3.49E-05
Main_RecrDev_1995	-	43	1	-5	5	-	0.278969	6.45E-05
Main_RecrDev_1996	-	44	1	-5	5	-	0.247196	6.32E-05
Main_RecrDev_1997	0.0282	45	1	-5	5	0.0282	0.176576	5.77E-05
Main_RecrDev_1998	-	46	1	-5	5	-	0.223407	6.38E-05
Main_RecrDev_1999	0.0401	47	1	-5	5	0.0401	0.183223	6.41E-05
Main_RecrDev_2000	0.2352	48	1	-5	5	0.2352	0.163205	6.25E-05
Main_RecrDev_2001	0.1990	49	1	-5	5	0.1990	0.176476	6.35E-05
Main_RecrDev_2002	-	50	1	-5	5	-	0.267195	6.71E-05
Main_RecrDev_2003	1.2017	51	1	-5	5	1.2017	0.087214	5.14E-05
Main_RecrDev_2004	-	52	1	-5	5	-	0.384711	6.61E-05
Main_RecrDev_2005	0.8184	53	1	-5	5	0.8184	0.104778	6.25E-05
Main_RecrDev_2006	-	54	1	-5	5	-	0.284552	7.07E-05
Main_RecrDev_2007	-	55	1	-5	5	-	0.226114	6.81E-05
Main_RecrDev_2008	0.8474	56	1	-5	5	0.8474	0.117961	6.32E-05
Main_RecrDev_2009	0.1936	57	1	-5	5	0.1936	0.184711	6.92E-05
Main_RecrDev_2010	-	58	1	-5	5	-	0.320281	6.85E-05
Main_RecrDev_2011	0.2435	59	1	-5	5	0.2435	0.152864	7.17E-05
Main_RecrDev_2012	-	60	1	-5	5	-	0.200552	7.04E-05
Main_RecrDev_2013	-	61	1	-5	5	-	0.289992	7.10E-05
Main_RecrDev_2014	-	62	1	-5	5	-	0.23235	7.57E-05
Main_RecrDev_2015	-	63	1	-5	5	-	0.280262	7.18E-05
Main_RecrDev_2016	0.0594	64	1	-5	5	0.0594	0.355834	6.93E-05
Main_RecrDev_2017	0.9456	65	1	-5	5	0.9456	0.384481	6.85E-05
Main_RecrDev_2018	0.7381	66	1	-5	5	0.7381	0.738749	7.05E-05
Main_RecrDev_2019	-	67	1	-5	5	-	0.615299	7.07E-05
Late_RecrDev_2020	0	_	_	_	_	_	_	_
ForeRecr_2021	0	_	_	_	_	_	_	_
Impl_err_2021	0	_	_	_	_	_	_	_
InitF_seas_1_flt_7USA_TRAP	0.0124	68	1	1.00E-	0.1	0.0124	0.00209	3.03E-05
InitF_seas_1_flt_9USA_CAN_HARPOON	0.0022	69	1	1.00E-	0.1	0.0022	0.000159	1.76E-05
LnQ_base_IDX1_JAPAN_LL(18)	-	_	-1	-10	-2	-	_	_
LnQ_base_IDX2_JAPAN_LL2(19)	-	_	-1	-10	-2	-	_	_
LnQ_base_IDX5_MEXUSLL_GOM_LL(22	-	_	-1	-10	-2	-	_	_
LnQ_base_IDX6_JPNLL_GOM(23)	-	_	-1	-10	-2	-	_	_
LnQ_base_IDX9_US_RR_66_144(26)	-	_	-1	-10	-2	-	_	_
LnQ_base_IDX10_US_RR_LT145(27)	-	_	-1	-10	-2	-	_	_
LnQ_base_IDX11_US_RR_GT177(28)	-	70	1	-10	-2	-	0.088439	-1.95E-05
LnQ_base_IDX12_US_RR_GT195(29)	-	_	-1	-10	-2	-	_	_
LnQ_base_IDX14_CAN_SWNS(31)	-	71	1	-10	-2	-	0.098675	-1.30E-05
LnQ_base_IDX15_CAN_GSL(32)	-	72	1	-10	-2	-	0.111689	-2.29E-05
LnQ_base_IDX16_CAN_ACOUSTIC(33)	-	73	1	-10	-2	-	0.124069	-1.50E-05
LnQ_base_IDX17_GOMlarval(34)	-	_	-1	-10	-2	-	_	_

LnQ_base_IDX19_oceanographic(36)	-	_	-1	-10	-2	-	_	_
LnQ_base_IDX11_US_RR_GT177(28)_E	0.1636	74	3	-2	2	0.1636	0.050104	1.11E-05
LnQ_base_IDX14_CAN_SWNS(31)_ENV_	-	75	3	-2	2	-	0.070771	3.98E-06
LnQ_base_IDX15_CAN_GSL(32)_ENV_m	-	76	3	-2	2	-	0.03129	1.23E-05
LnQ_base_IDX16_CAN_ACOUSTIC(33)_	-	77	3	-2	2	-	0.038094	1.57E-05
Size_DblN_peak_JAPAN_LL(1)	224.33	78	2	120	250	224.33	2.79804	2.87E-06
Size_DblN_top_logit_JAPAN_LL(1)	-	79	2	-15	3	-	55.6057	3.45E-08
Size_DblN_ascend_se_JAPAN_LL(1)	7.1034	80	3	-5	9	7.1034	0.119779	6.83E-07
Size_DblN_descend_se_JAPAN_LL(1)	5.7266	81	5	-5	9	5.7266	0.374043	4.69E-06
Size_DblN_start_logit_JAPAN_LL(1)	-999	_	-3	-999	15	-999	_	_
Size_DblN_end_logit_JAPAN_LL(1)	-	82	6	-20	10	-	0.534939	1.03E-06
Size_DblN_peak_OTHER_ATL_LL(2)	215.25	83	2	120	285	215.25	2.46007	-1.43E-05
Size_DblN_top_logit_OTHER_ATL_LL(2)	-	84	2	-15	3	-	56.7212	1.14E-09
Size_DblN_ascend_se_OTHER_ATL_LL(	8.0494	85	3	-5	9	8.0494	0.057597	1.45E-05
Size_DblN_descend_se_OTHER_ATL_LL	7.1288	86	5	-5	9	7.1288	0.206045	-6.85E-06
Size_DblN_start_logit_OTHER_ATL_LL(2	-999	_	-3	-999	15	-999	_	_
Size_DblN_end_logit_OTHER_ATL_LL(2)	-	87	6	-20	10	-	0.419912	-1.28E-05
Size_DblN_peak_GOM_US_MEX_LL(3)	244.95	88	2	120	285	244.95	2.26098	-3.47E-06
Size_DblN_top_logit_GOM_US_MEX_LL(	-	89	2	-15	3	-	57.8742	-7.65E-09
Size_DblN_ascend_se_GOM_US_MEX_L	7.5165	90	3	-5	9	7.5165	0.079429	-1.00E-06
Size_DblN_descend_se_GOM_US_MEX_	3.6620	91	5	-5	9	3.6620	1.29539	-1.42E-07
Size_DblN_start_logit_GOM_US_MEX_L	-999	_	-3	-999	15	-999	_	_
Size_DblN_end_logit_GOM_US_MEX_LL	0.4193	92	6	-20	10	0.4193	0.233643	-2.00E-06
Size_DblN_peak_JPNLL_GOM(4)	233.18	93	2	120	285	233.18	2.5061	-1.17E-05
Size_DblN_top_logit_JPNLL_GOM(4)	-	94	2	-15	3	-	52.9973	-2.69E-09
Size_DblN_ascend_se_JPNLL_GOM(4)	6.6082	95	3	-5	9	6.6082	0.169301	7.31E-06
Size_DblN_descend_se_JPNLL_GOM(4)	6.2046	96	5	-5	9	6.2046	0.194699	-1.17E-05
Size_DblN_start_logit_JPNLL_GOM(4)	-999	_	-3	-999	15	-999	_	_
Size_DblN_end_logit_JPNLL_GOM(4)	-	97	6	-20	10	-	0.447661	-1.08E-05
Size_DblN_peak_USA_CAN_PSFS(5)	74.530	98	3	50	200	74.530	3.96195	-
Size_DblN_top_logit_USA_CAN_PSFS(5)	-2	_	-3	-5	3	-2	_	_
Size_DblN_ascend_se_USA_CAN_PSFS(	4.7173	99	4	-4	12	4.7173	0.695461	0.000296
Size_DblN_descend_se_USA_CAN_PSFS	5.9923	_	-5	-5	6	5.9923	_	_
Size_DblN_start_logit_USA_CAN_PSFS(	-999	_	-2	-15	5	-999	_	_
Size_DblN_end_logit_USA_CAN_PSFS(5	-999	_	-2	-15	10	-999	_	_
Size_DblN_peak_USA_CAN_PSFB(6)	212.51	100	2	150	285	212.51	3.07247	-1.27E-05
Size_DblN_top_logit_USA_CAN_PSFB(6)	-	101	2	-5	3	-	0.311949	-9.66E-06
Size_DblN_ascend_se_USA_CAN_PSFB(	6.8550	102	3	-4	8	6.8550	0.138349	-1.86E-07
Size_DblN_descend_se_USA_CAN_PSF	5.9998	_	-5	-2	6	5.9998	_	_
Size_DblN_start_logit_USA_CAN_PSFB(	-999	_	-2	-15	5	-999	_	_
Size_DblN_end_logit_USA_CAN_PSFB(6	-	103	6	-15	5	-	0.804065	-1.94E-06
Size_DblN_peak_USA_TRAP(7)	124.25	104	3	80	150	124.25	6.82337	-1.84E-05
Size_DblN_top_logit_USA_TRAP(7)	-	105	3	-5	3	-	0.830073	-1.56E-05
Size_DblN_ascend_se_USA_TRAP(7)	7.8559	_	-4	-4	10	7.8559	_	_
Size_DblN_descend_se_USA_TRAP(7)	7.4158	106	5	-2	10	7.4158	0.553718	-2.46E-05
Size_DblN_start_logit_USA_TRAP(7)	-999	_	-2	-15	5	-999	_	_
Size_DblN_end_logit_USA_TRAP(7)	-999	_	-2	-15	10	-999	_	_
Size_DblN_peak_CAN_TRAP(8)	272.80	107	2	120	285	272.80	1.89903	-4.39E-07
Size_DblN_top_logit_CAN_TRAP(8)	-	108	2	-15	3	-	50.9915	1.09E-08
Size_DblN_ascend_se_CAN_TRAP(8)	7.8277	109	3	-5	9	7.8277	0.064045	2.54E-06
Size_DblN_descend_se_CAN_TRAP(8)	4.4753	110	5	-5	9	4.4753	0.475652	3.22E-07
Size_DblN_start_logit_CAN_TRAP(8)	-999	_	-3	-999	15	-999	_	_
Size_DblN_end_logit_CAN_TRAP(8)	-	111	6	-20	10	-	0.648062	-7.61E-07
Size_DblN_peak_USA_CAN_HARPOON(	192.49	112	2	120	285	192.49	1.44959	-1.29E-05
Size_DblN_top_logit_USA_CAN_HARPO	-	113	2	-15	3	-	0.183912	-1.39E-05
Size_DblN_ascend_se_USA_CAN_HARP	5.7437	114	3	-5	9	5.7437	0.127455	2.65E-06
Size_DblN_descend_se_USA_CAN_HAR	7.2703	115	5	-5	9	7.2703	0.329381	-4.87E-06
Size_DblN_start_logit_USA_CAN_HARP	-999	_	-3	-999	15	-999	_	_
Size_DblN_end_logit_USA_CAN_HARPO	-	116	6	-20	10	-	1.16492	-2.55E-06
Size_inflection_USA_HARPOON(10)	177.03	_	-2	100	220	177.03	_	_
Size_95%width_USA_HARPOON(10)	17.089	_	-2	10	60	17.089	_	_

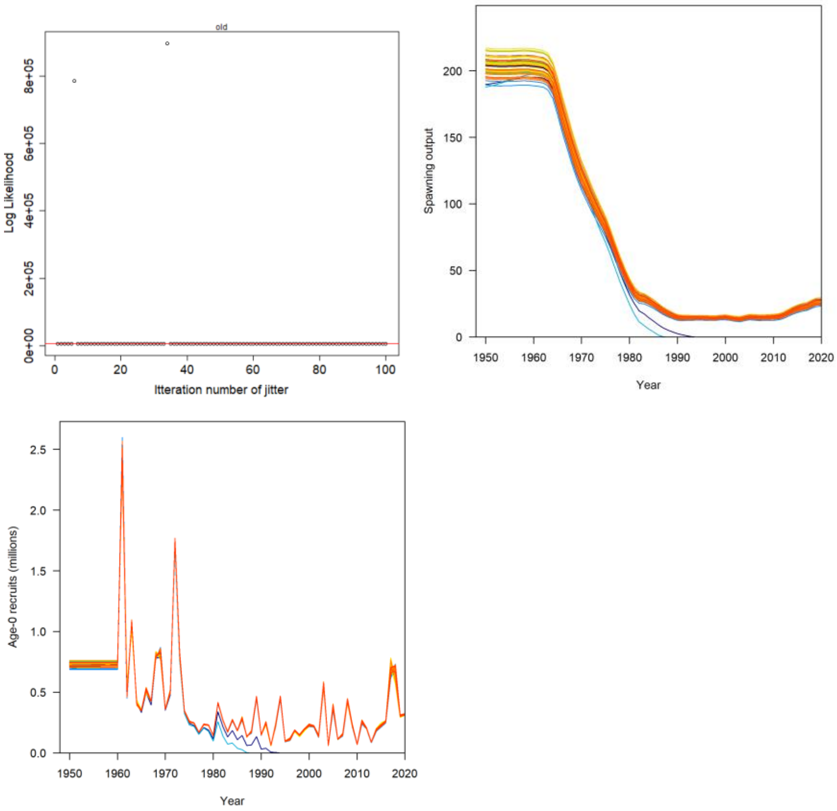
Size_DblN_peak_USA_RRFS(11)	111.77	117	2	80	120	111.77	1.27957	6.35E-07
Size_DblN_top_logit_USA_RRFS(11)	-	118	3	-5	3	-	0.102811	1.50E-05
Size_DblN_ascend_se_USA_RRFS(11)	6.5143	_	-4	-4	8	6.5143	_	_
Size_DblN_descend_se_USA_RRFS(11)	-	119	5	-5	4	-	15.1505	-8.41E-08
Size_DblN_start_logit_USA_RRFS(11)	-999	_	-2	-15	5	-999	_	_
Size_DblN_end_logit_USA_RRFS(11)	-999	_	-6	-15	10	-999	_	_
Size_DblN_peak_USA_RRFB(12)	196.59	120	2	140	220	196.59	2.09241	-9.73E-06
Size_DblN_top_logit_USA_RRFB(12)	-	121	3	-5	1	-	0.034232	-2.47E-05
Size_DblN_ascend_se_USA_RRFB(12)	6.7181	122	4	-4	8	6.7181	0.102421	5.14E-06
Size_DblN_descend_se_USA_RRFB(12)	2.0829	_	-5	-2	8	2.0829	_	_
Size_DblN_start_logit_USA_RRFB(12)	-999	_	-2	-15	5	-999	_	_
Size_DblN_end_logit_USA_RRFB(12)	-	123	6	-15	5	-	0.165747	-1.45E-05
Size_inflection_CAN_combinedHL(13)	194.82	_	-2	160	220	194.82	_	_
Size_95%width_CAN_combinedHL(13)	33.002	_	-2	10	50	33.002	_	_
Size_DblN_peak_CAN_SWNS_HLnoHP(1	210.57	124	2	120	285	210.57	1.8175	1.98E-05
Size_DblN_top_logit_CAN_SWNS_HLno	-	125	2	-15	3	-	0.688609	-2.56E-06
Size_DblN_ascend_se_CAN_SWNS_HLn	6.6103	126	3	-5	9	6.6103	0.09052	-1.44E-05
Size_DblN_descend_se_CAN_SWNS_HL	7.6760	127	5	-5	9	7.6760	0.287056	2.61E-06
Size_DblN_start_logit_CAN_SWNS_HLn	-999	_	-3	-999	15	-999	_	_
Size_DblN_end_logit_CAN_SWNS_HLno	-	128	6	-20	10	-	1.50674	2.73E-06
Size_inflection_CAN_SWNS_HLwithHP(	194.82	_	-2	150	250	194.82	_	_
Size_95%width_CAN_SWNS_HLwithHP(	33.002	_	-2	10	50	33.002	_	_
Size_inflection_CAN_GSL_HL(16)	214.00	129	2	210	330	214.00	2.25162	9.61E-07
Size_95%width_CAN_GSL_HL(16)	31.225	130	2	10	50	31.225	2.48619	-3.27E-07
Size_DblN_peak_IDX7_US_RR_66_114(2	65	_	-3	40	200	65	_	_
Size_DblN_top_logit_IDX7_US_RR_66_1	-1.7	_	-3	-5	3	-1.7	_	_
Size_DblN_ascend_se_IDX7_US_RR_66_	-4	_	-3	-4	12	-4	_	_
Size_DblN_descend_se_IDX7_US_RR_66	-2	_	-3	-2.5	6	-2	_	_
Size_DblN_start_logit_IDX7_US_RR_66_	-999	_	-2	-15	5	-999	_	_
Size_DblN_end_logit_IDX7_US_RR_66_1	-5	_	-2	-15	10	-5	_	_
Size_DblN_peak_IDX8_US_RR_115_144(	115	_	-3	40	200	115	_	_
Size_DblN_top_logit_IDX8_US_RR_115_	-2.1	_	-3	-5	3	-2.1	_	_
Size_DblN_ascend_se_IDX8_US_RR_115	-4	_	-3	-4	12	-4	_	_
Size_DblN_descend_se_IDX8_US_RR_11	-2	_	-3	-2.5	6	-2	_	_
Size_DblN_start_logit_IDX8_US_RR_115	-999	_	-2	-15	5	-999	_	_
Size_DblN_end_logit_IDX8_US_RR_115_	-5	_	-2	-15	10	-5	_	_
Size_DblN_peak_JAPAN_LL(1)_BLK1rep	165.82	131	5	120	285	165.82	1.08054	-
Size_DblN_peak_JAPAN_LL(1)_dev_se	50	_	-5	0.000	100	50	_	_
Size_DblN_peak_JAPAN_LL(1)_dev_auto	0	_	-6	-0.99	0.99	0	_	_
Size_DblN_top_logit_JAPAN_LL(1)_BLK	-	132	5	-10	1	-	0.65257	-5.12E-05
Size_DblN_ascend_se_JAPAN_LL(1)_BL	7.6254	_	-5	-1	9	7.6254	_	_
Size_DblN_descend_se_JAPAN_LL(1)_B	7.4737	133	5	-1	9	7.4737	0.129905	-
Size_DblN_end_logit_JAPAN_LL(1)_BLK	-	134	5	-20	1	-	1.2871	-1.79E-05
Size_DblN_peak_USA_RRFS(11)_BLK2r	84.241	135	5	60	110	84.241	1.48176	-
Size_DblN_top_logit_USA_RRFS(11)_BL	-	136	5	-5	3	-	0.0286	-
Size_DblN_ascend_se_USA_RRFS(11)_B	6.0097	_	-5	-4	10	6.0097	_	_
Size_DblN_descend_se_USA_RRFS(11)_	-	_	-5	-2	4	-	_	_
Size_inflection_CAN_GSL_HL(16)_BLK3	256.57	137	2	230	330	256.57	1.617	7.32E-06
Size_95%width_CAN_GSL_HL(16)_BLK3	34.967	138	2	10	50	34.967	1.55429	-3.49E-07
Size_DblN_peak_JAPAN_LL(1)_DEVrwal	-	139	6	-10	10	0	0.102129	8.90E-06
Size_DblN_peak_JAPAN_LL(1)_DEVrwal	0.3685	140	6	-10	10	0	0.115207	3.67E-06
Size_DblN_peak_JAPAN_LL(1)_DEVrwal	0.4760	141	6	-10	10	0	0.10396	-1.86E-07
Size_DblN_peak_JAPAN_LL(1)_DEVrwal	0.0335	142	6	-10	10	0	0.093811	3.25E-06
Size_DblN_peak_JAPAN_LL(1)_DEVrwal	0.0656	143	6	-10	10	0	0.094726	1.57E-06

Table 3. Table of key information for models 1 and 2, noting the specifications, log-likelihoods, run time, and parameters that hit bounds.

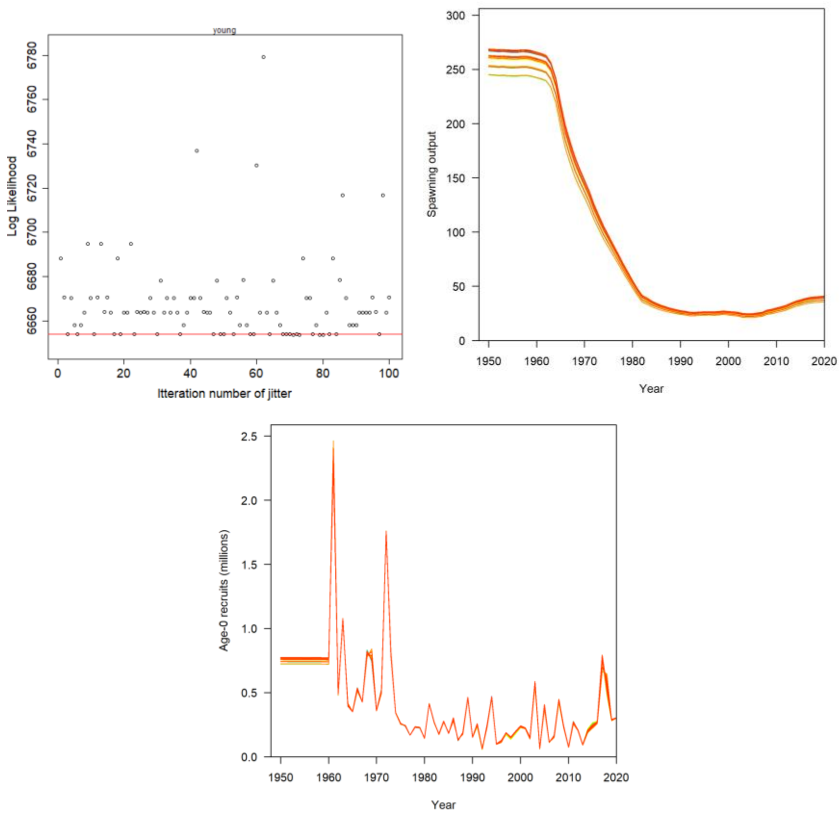
model	Model 1 later spawning schedule Size_DblN_peak_GOM_US_MEX_LL	Model 2 later spawning schedule LN(R0):
max gradient component	6.69287E-05	0.00261594
run time	14min	14 min
total loglikelihood	6656	6653.78
Catch	1.86203e-011	1.83856e-011
Equil_catch	0.00430699	0.0039966
Survey	496.519	495.602
Length_comp	4291.39	4291.65
Age_comp	1863.87	1863.9
Recruitment	3.19877	1.61142
InitEQ_Regime	0	0
Forecast_Recruitment	0	0
Parm_priors	0.514845	0.512015
Parm_softbounds	0.0255719	0.0233103
Parm_devs	0.476118	0.476171
Crash_Pen	0	0
bounded parms	0	0

Table 4. Benchmarks (SE) and relative stock status for model 1 and model 2.

	Model 1 late spawning	Model 2 early spawning
SSB Unfished	225683 (8514.86)	276295 (10475.9)
Total Biomass Unfished	278420 (10486)	282394 (10732.2)
Recruitment Unfished	749.87 (28.6)	760.726 (29.36)
F current (geomean F of age 10-20 in 2018-20)	0.0716	0.0708
F0.1(geomean F of age 10-20) from YPR curve	0.1065	0.0851
Total Yield at F0.1	3969.58	3599..29
F current / F0.1	0.672	0.832
Fishing status	Not overfishing	Not overfishing

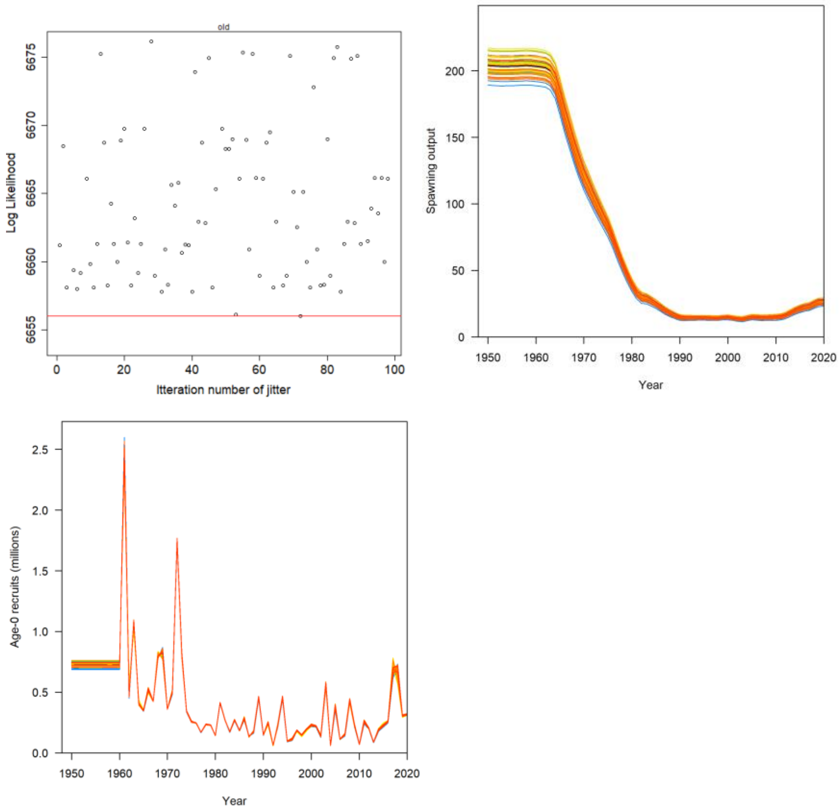


(a) Model 1

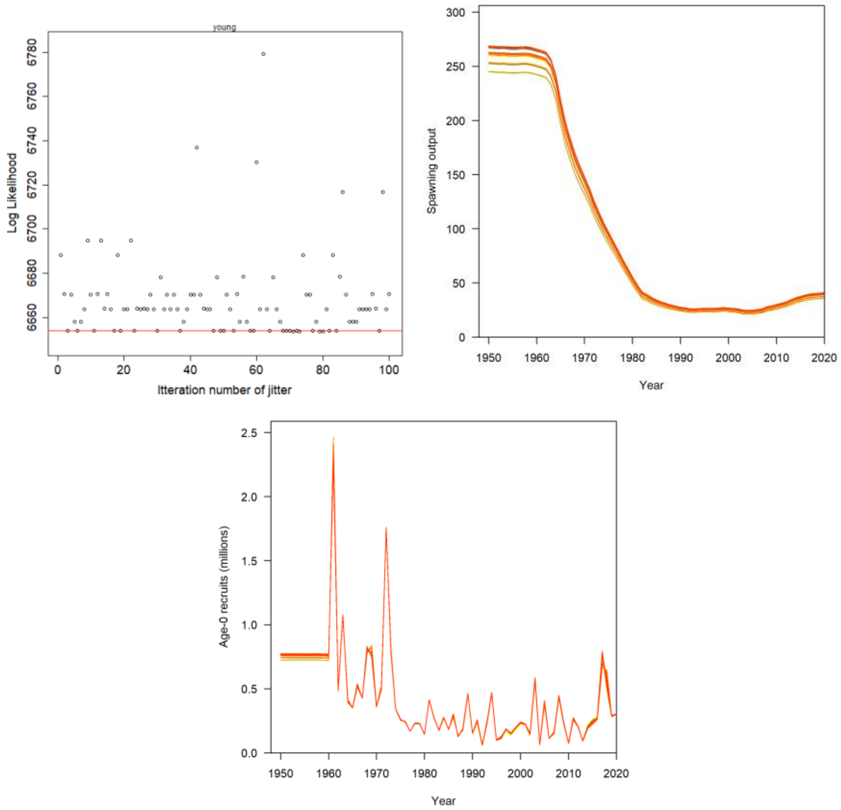


(b) Model 2

Figure 1. All results of the jitter analysis for (a) model 1 and (b) model 2.



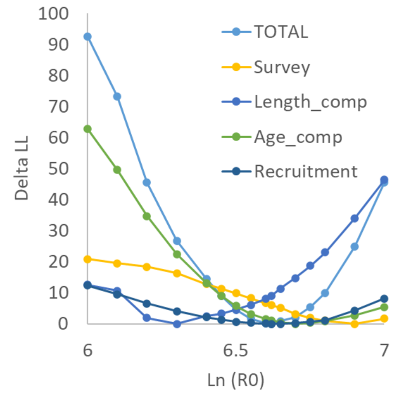
(a) Model 1

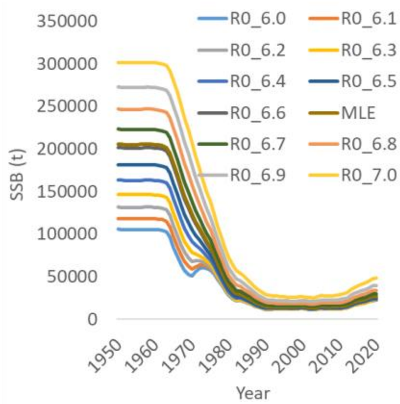


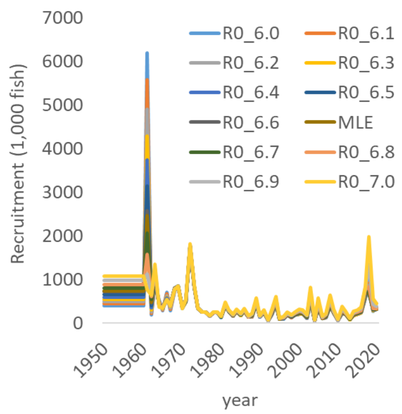
(b) Model 2

Figure 2. The results of the jitter analysis excepting runs with extremely far from global solution for (a) model 1 and (b) model 2. Model 2 is same as Figure 1.

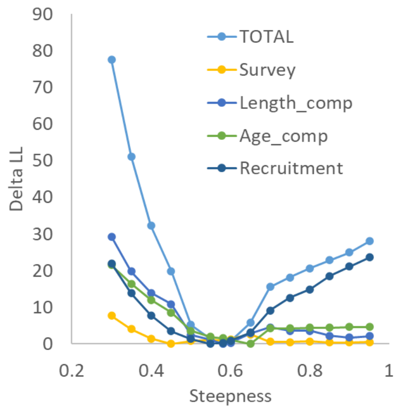
R0 Profile

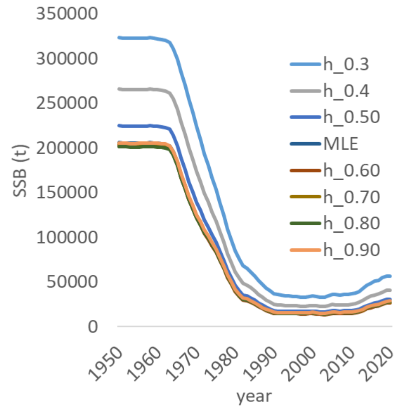


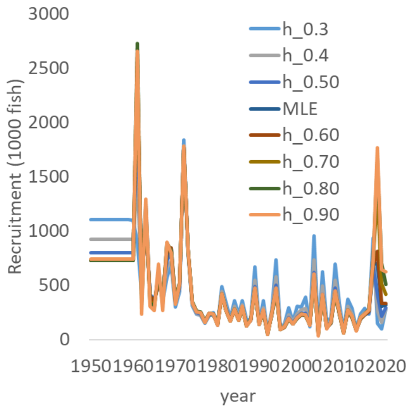




Steepness profile







SigmaR profile

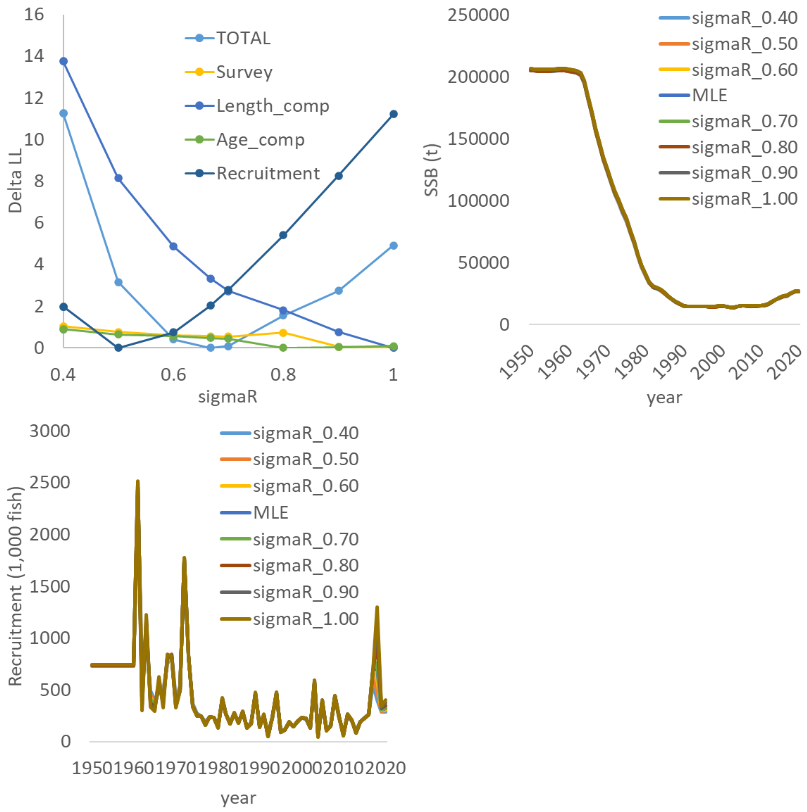
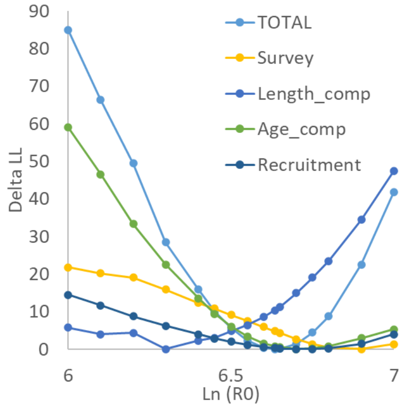
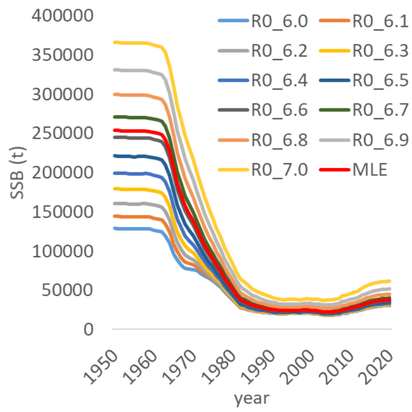
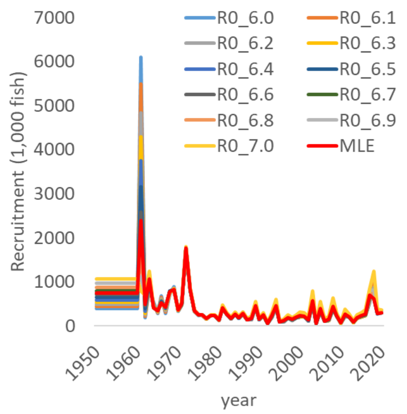


Figure 3. Likelihood profiles (Left) by R0 (Upper), steepness (Middle) and sigmaR (Bottom) and resulting SSB (Center) and recruitment (Right) trends for model 1.

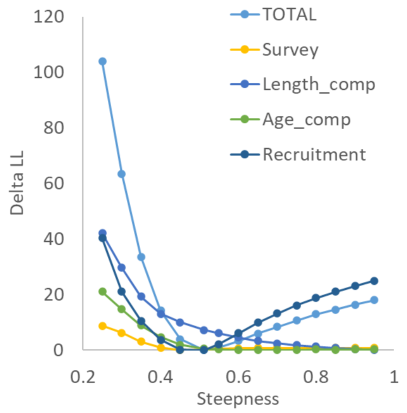
R0 profile

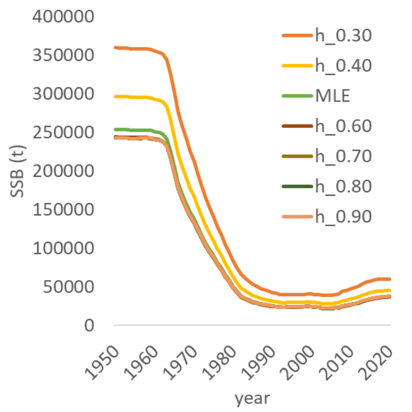


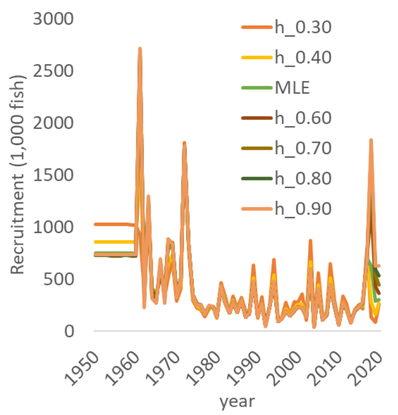




Steepness profile







SigmaR profile

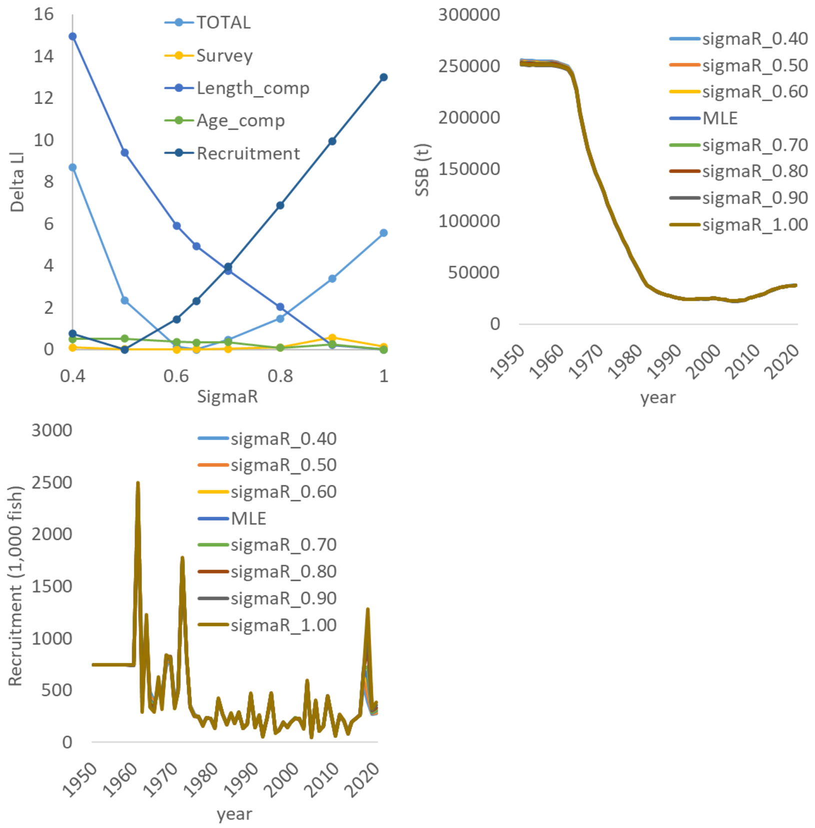
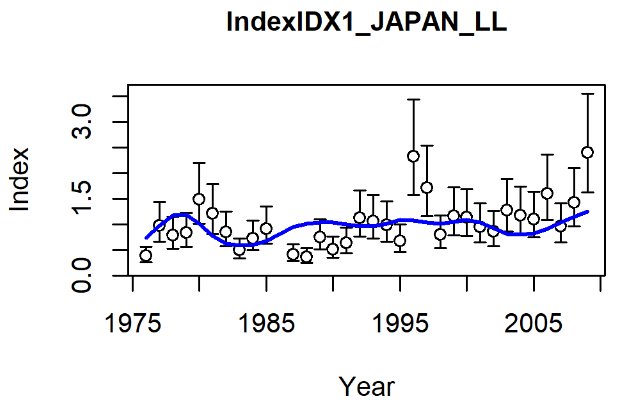
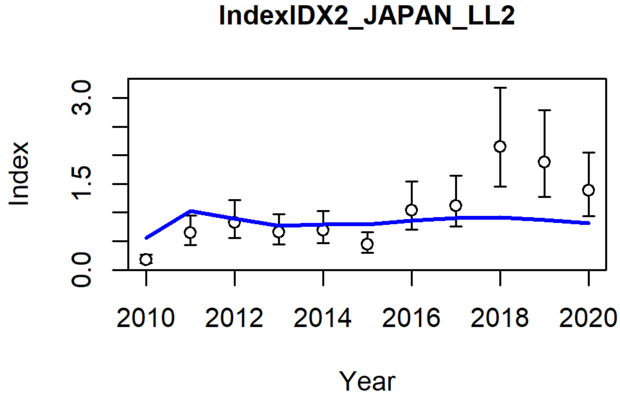
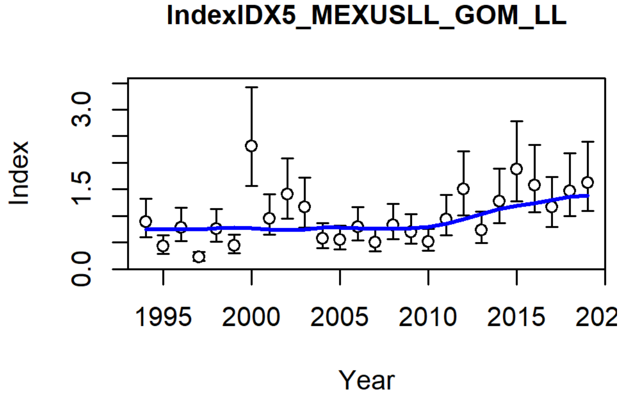
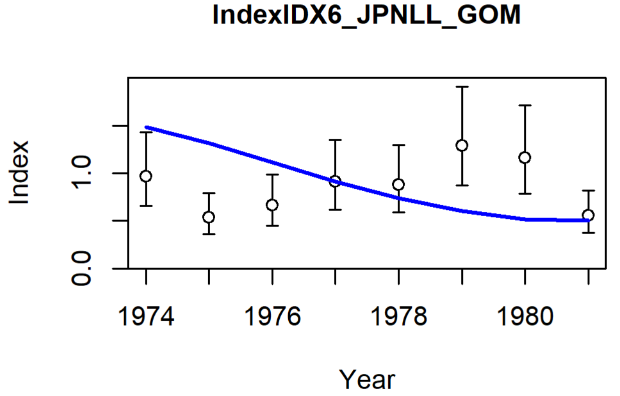


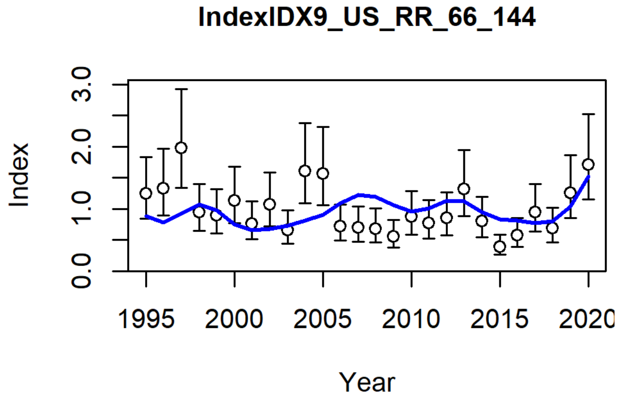
Figure 4. Likelihood profiles (Left) by R0 (Upper), steepness (Middle) and sigmaR (Bottom) and resulting SSB (Center) and recruitment (Right) trends for model 2.

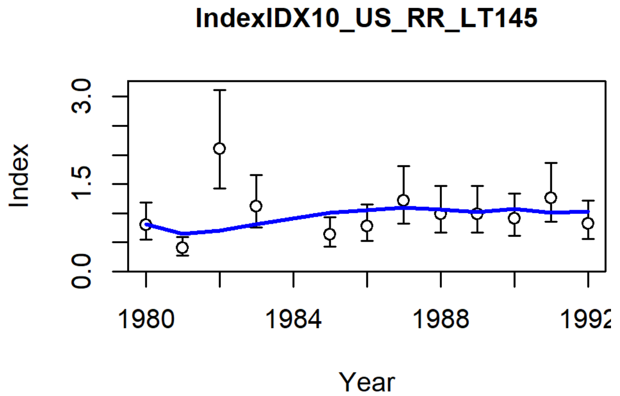

IndexIDX1_JAPAN_LL
Index
0.0
1.5
3.0
1975
1985
1995
2005
Year

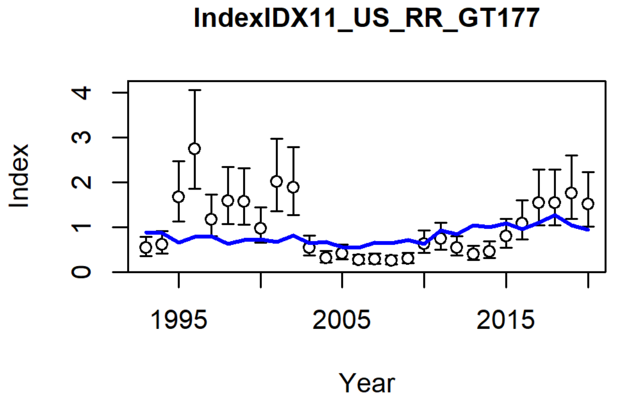

IndexIDX2_JAPAN_LL2
Index
0.0
1.5
3.0
2010
2012
2014
2016
2018
2020
Year

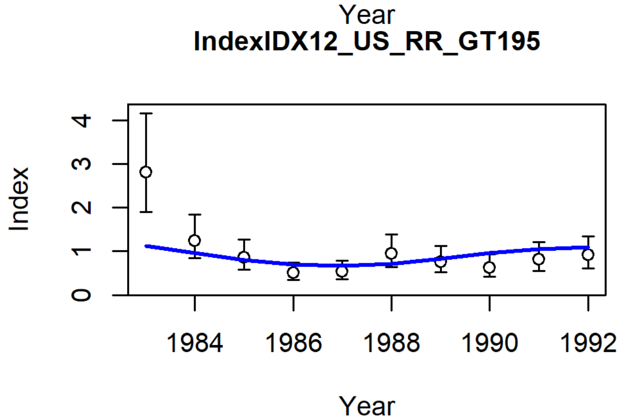

IndexIDX5_MEXUSLL_GOM_LL
Index
0.0
1.5
3.0
1995
2000
2005
2010
2015
202
Year


IndexIDX6_JPNLL_GOM
Index
0.0
1.0
1974
1976
1978
1980
Year


IndexIDX9_US_RR_66_144
Index
0.0
1.0
2.0
3.0
1995
2000
2005
2010
2015
2020
Year


IndexIDX10_US_RR_LT145
Index
0.0
1.5
3.0
1980
1984
1988
1992
Year


IndexIDX11_US_RR_GT177
Index
0
1
2
3
4
1995
2005
2015
Year


IndexIDX12_US_RR_GT195
Index
0
1
2
3
4
1984
1986
1988
1990
1992
Year

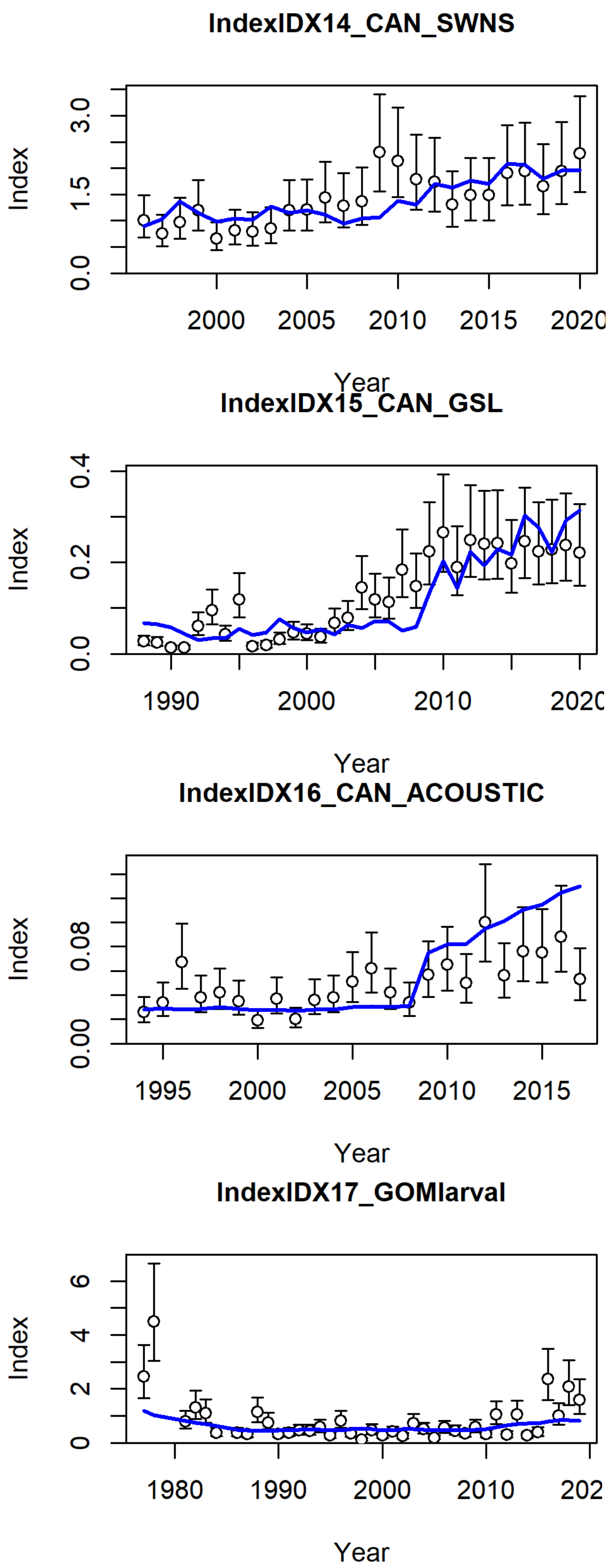
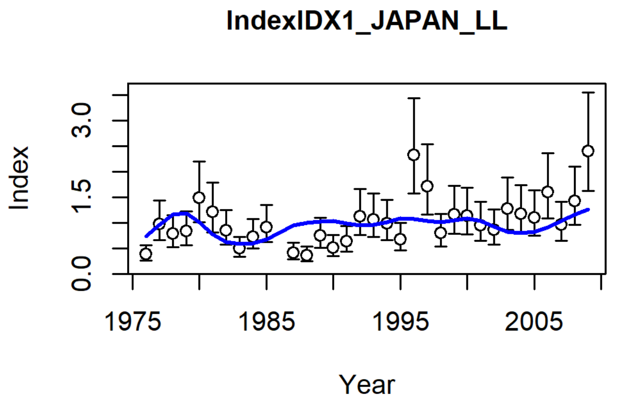
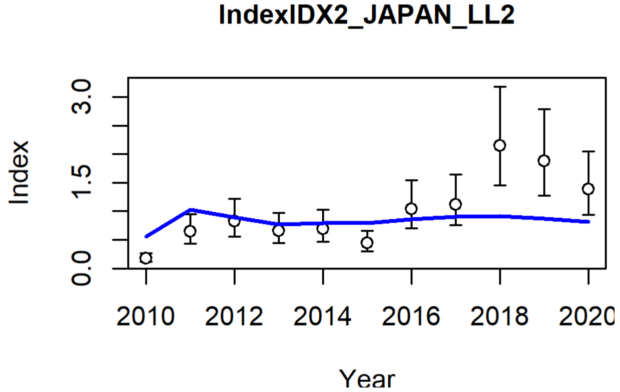
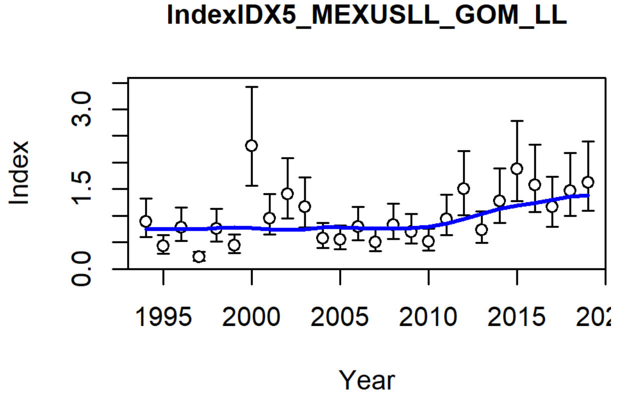
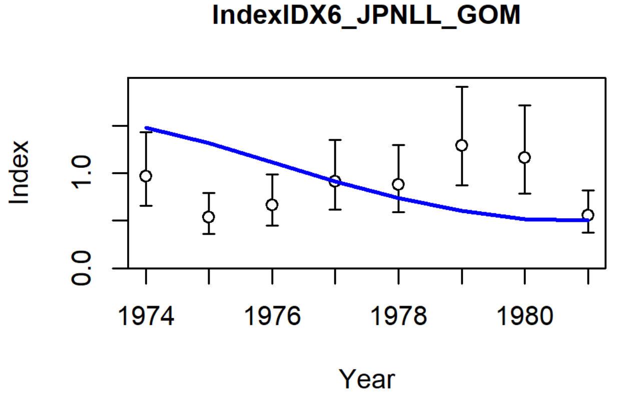


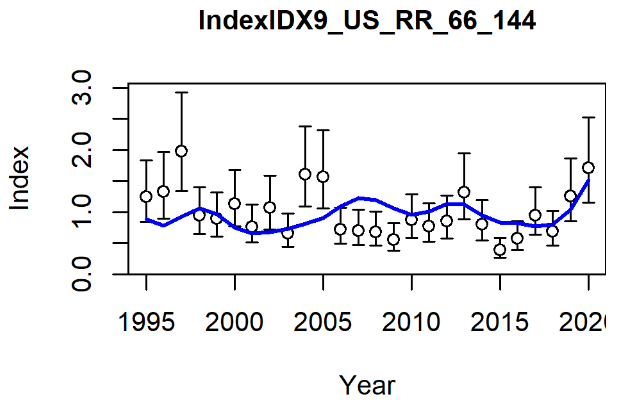
Figure 5. Fits to each CPUE index for model 1.

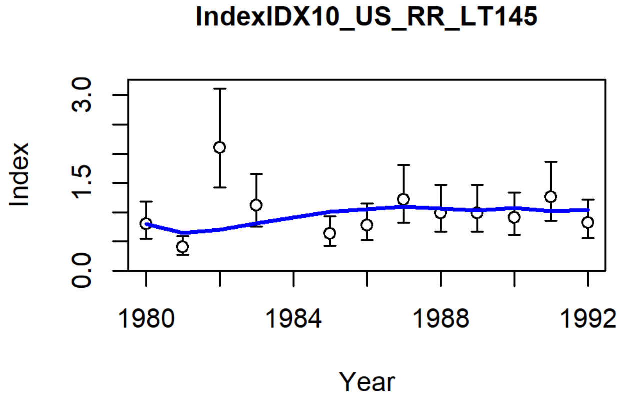

IndexIDX1_JAPAN_LL
Index
0.0
1.5
3.0
1975
1985
1995
2005
Year

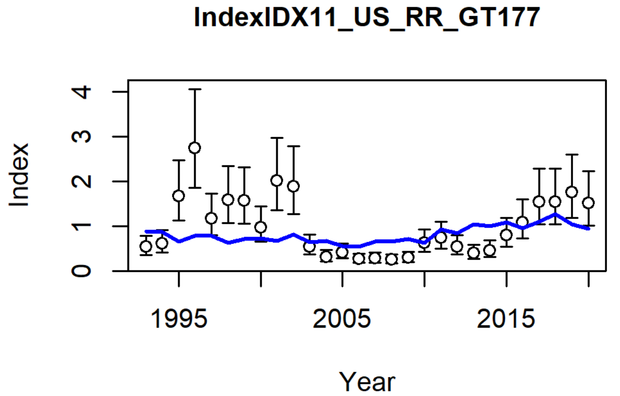

IndexIDX2_JAPAN_LL2
Index
0.0
1.5
3.0
2010
2012
2014
2016
2018
2020
Year

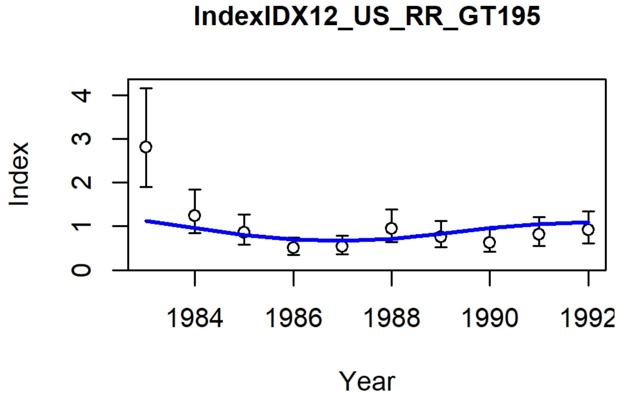

IndexIDX5_MEXUSLL_GOM_LL
Index
0.0
1.5
3.0
1995
2000
2005
2010
2015
Year


IndexIDX6_JPNLL_GOM
Index
0.0
1.0
1974
1976
1978
1980
Year


IndexIDX9_US_RR_66_144
Index
0.0
1.0
2.0
3.0
1995
2000
2005
2010
2015
Year


IndexIDX10_US_RR_LT145
Index
0.0
1.5
3.0
1980
1984
1988
1992
Year


IndexIDX11_US_RR_GT177
Index
0
1
2
3
4
1995
2005
2015
Year


IndexIDX12_US_RR_GT195
Index
0
1
2
3
4
1984
1986
1988
1990
1992
Year

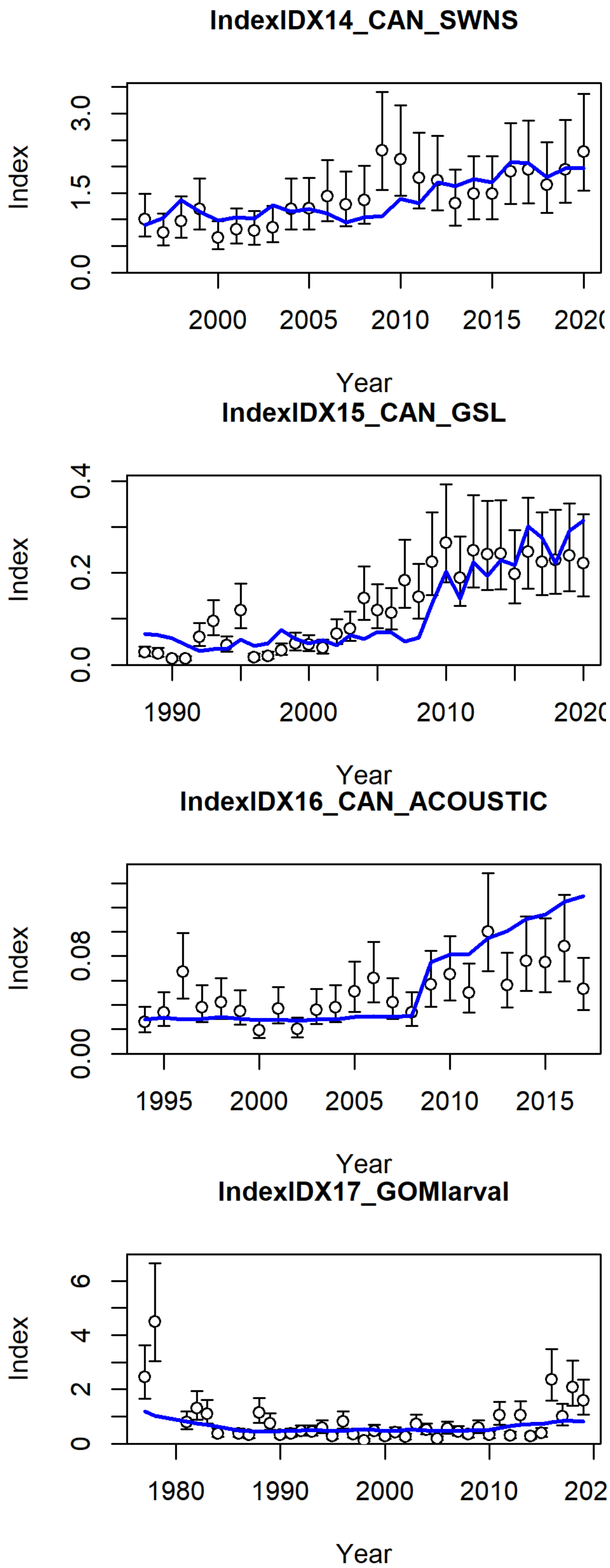


Figure 6. Fits to each CPUE index for model 2.

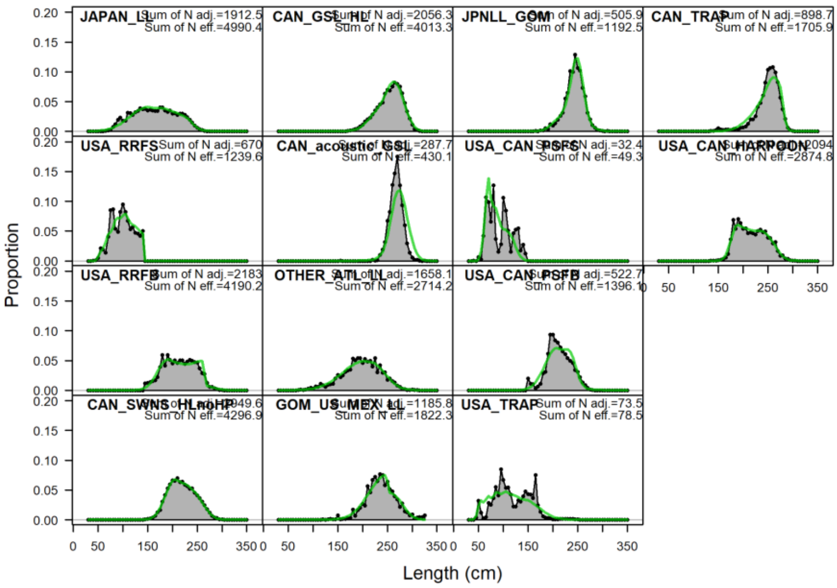


Figure 7. Fits to length composition data over all years for model 1.

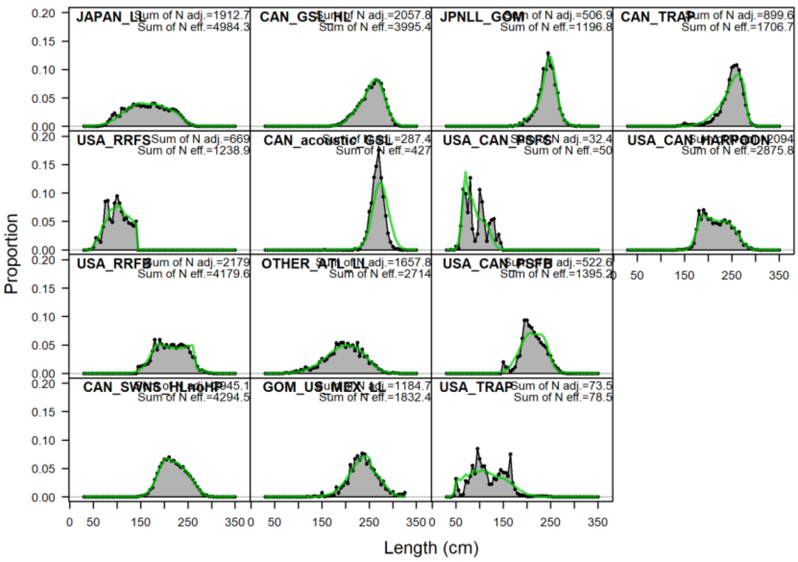
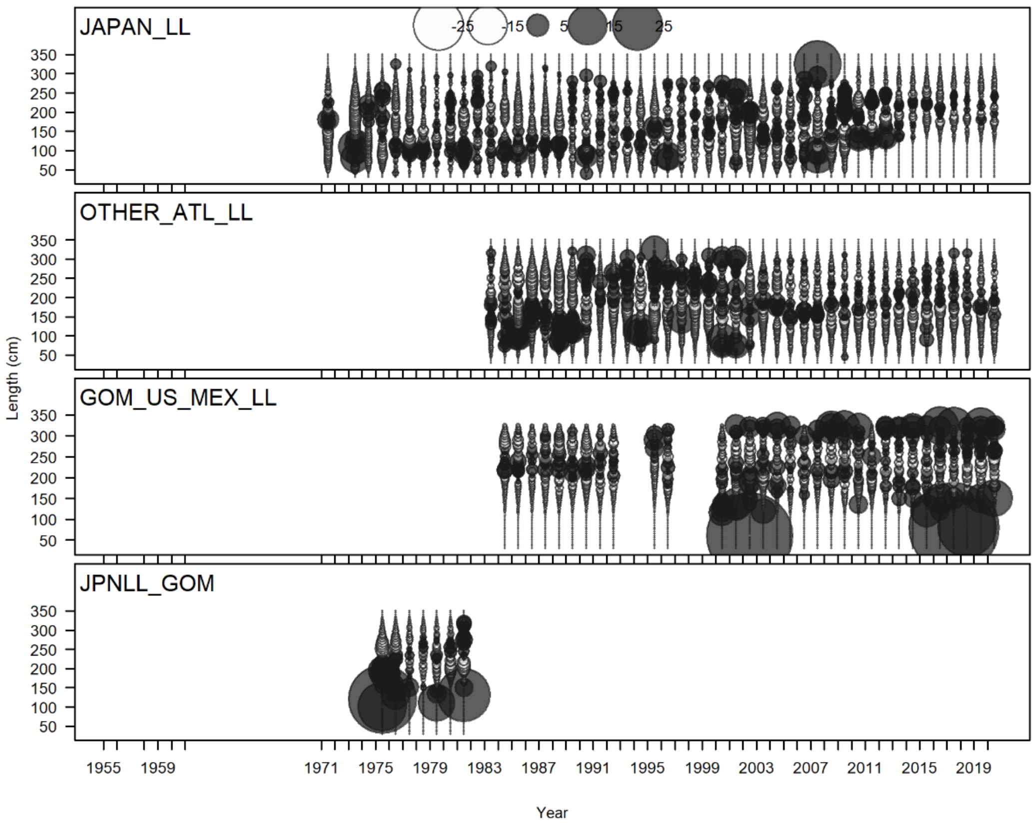
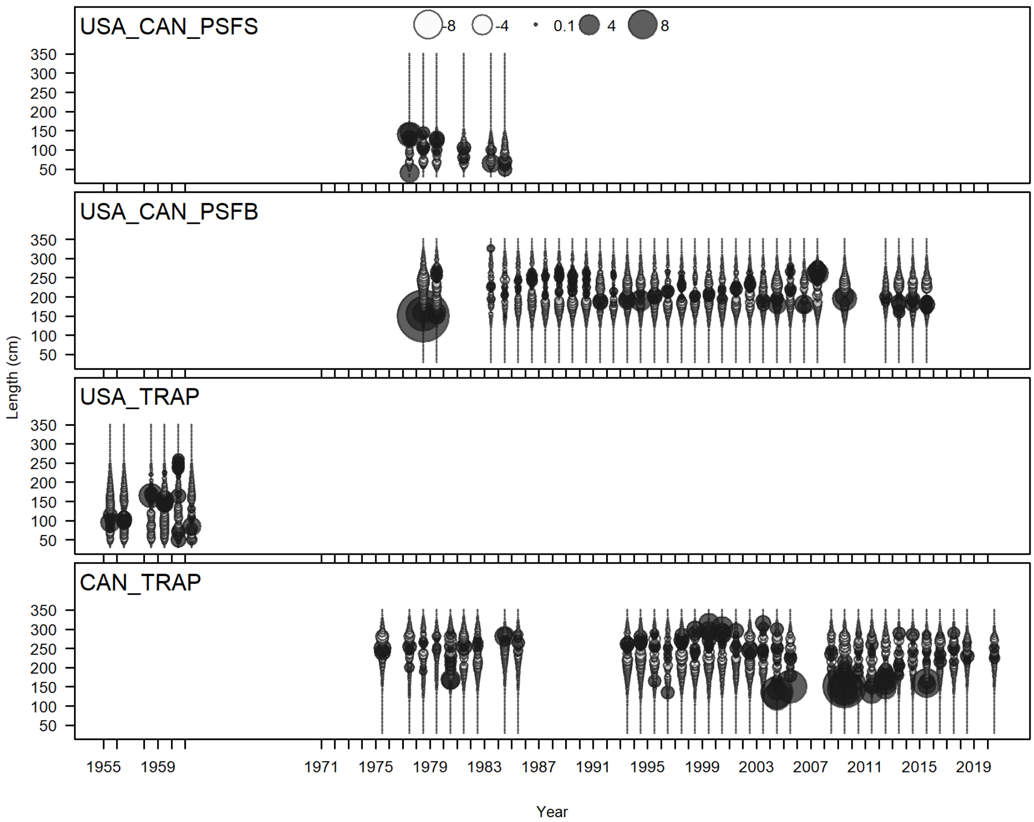


Figure 8. Fits to length composition data over all years for model 2.


JAPAN_LL
OTHER_ATL_LL
GOM_US_MEX_LL
JPNLL_GOM
-25 -15 5 15 25
Length (cm)
350
300
250
200
150
100
50
1955 1959 1971 1975 1979 1983 1987 1991 1995 1999 2003 2007 2011 2015 2019
Year


USA_CAN_PSFS
USA_CAN_PSFB
USA_TRAP
CAN_TRAP
-8 -4 0.1 4 8
Length (cm)
350
300
250
200
150
100
50
1955 1959 1971 1975 1979 1983 1987 1991 1995 1999 2003 2007 2011 2015 2019
Year

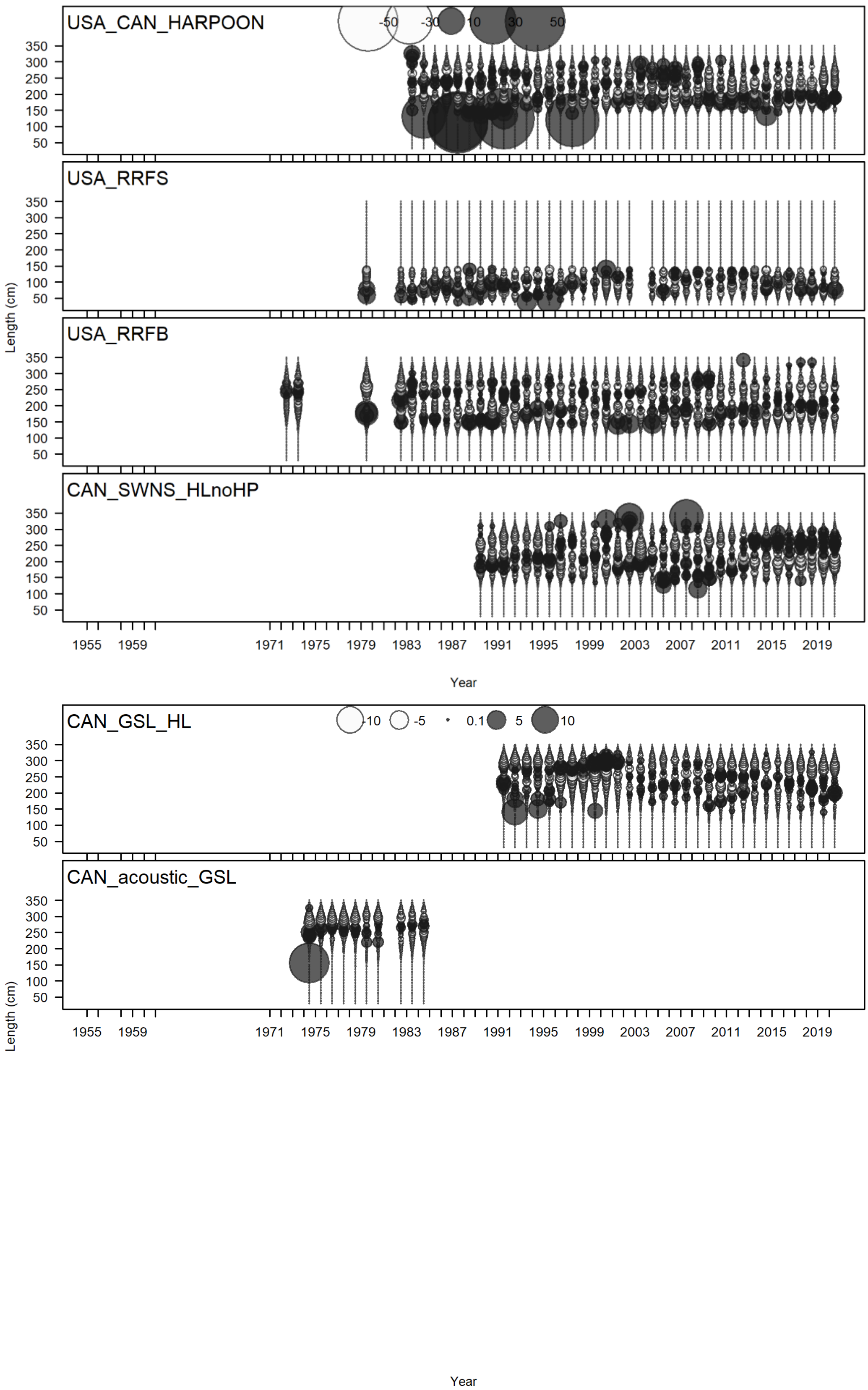
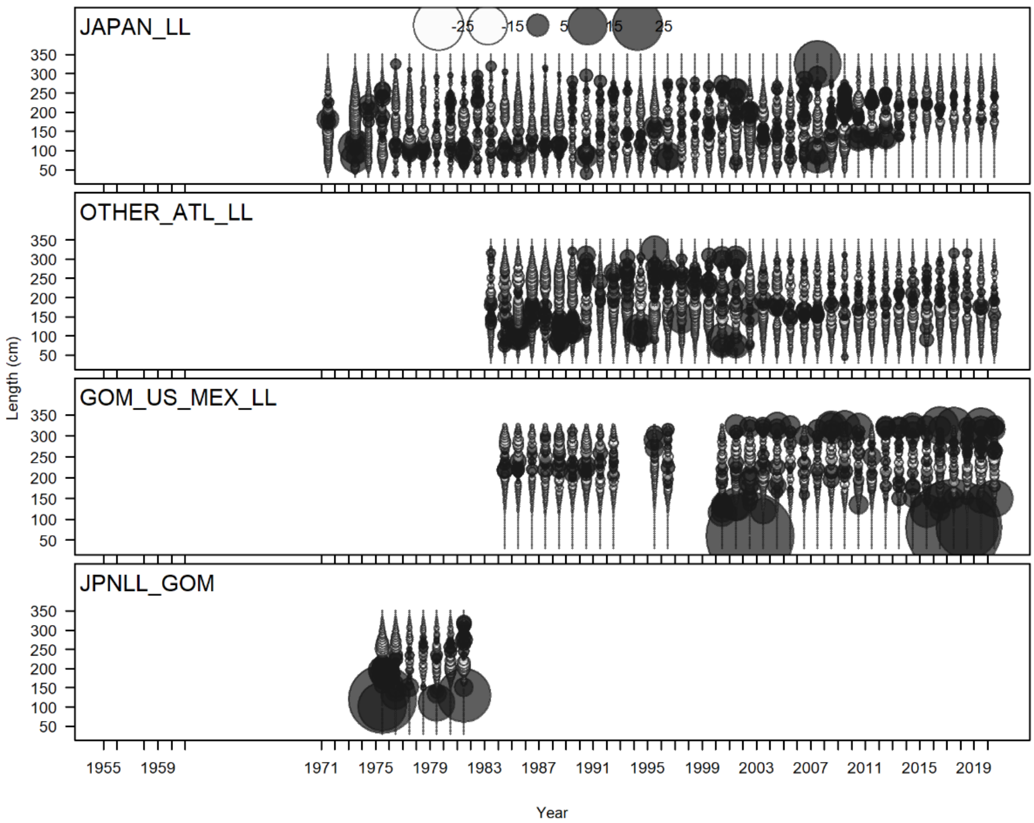
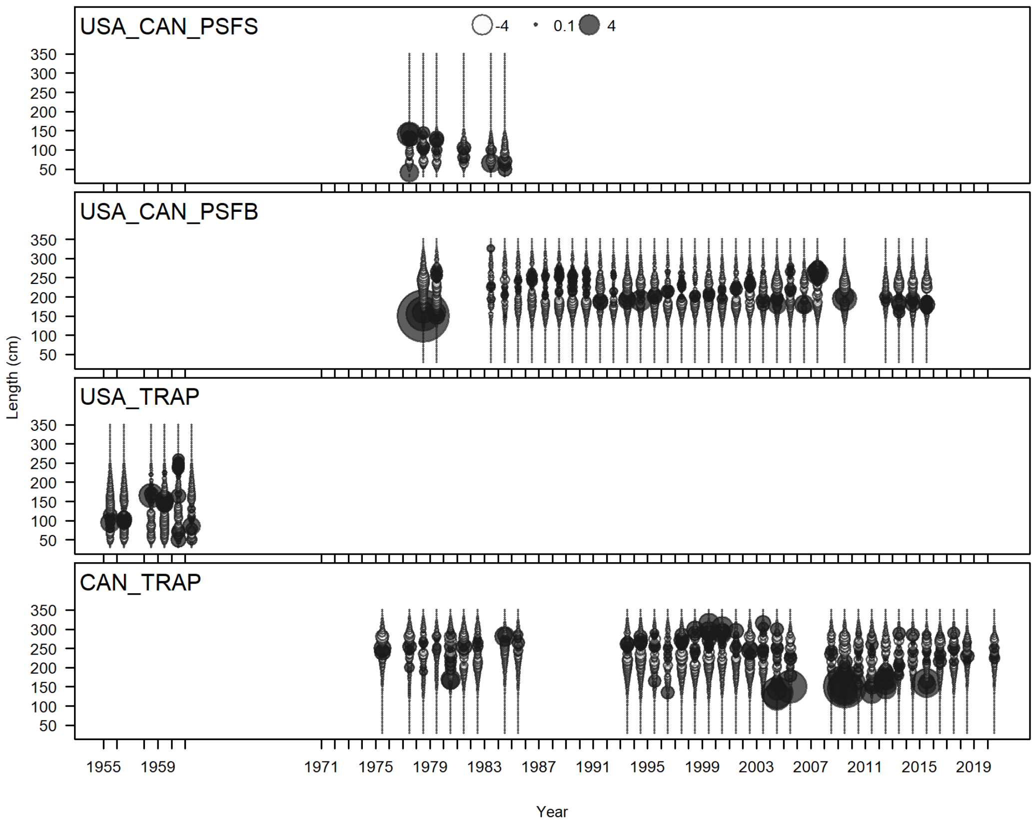


Figure 9. Time series of Pearson residuals on the length composition data by fleets for model 1.


JAPAN_LL
-25
-15
5
15
25
OTHER_ATL_LL
GOM_US_MEX_LL
JPNLL_GOM
Length (cm)
350
300
250
200
150
100
50
1955
1959
1971
1975
1979
1983
1987
1991
1995
1999
2003
2007
2011
2015
2019
Year


USA_CAN_PSFS
-4
0.1
4
USA_CAN_PSFB
USA_TRAP
CAN_TRAP
Length (cm)
350
300
250
200
150
100
50
1955
1959
1971
1975
1979
1983
1987
1991
1995
1999
2003
2007
2011
2015
2019
Year

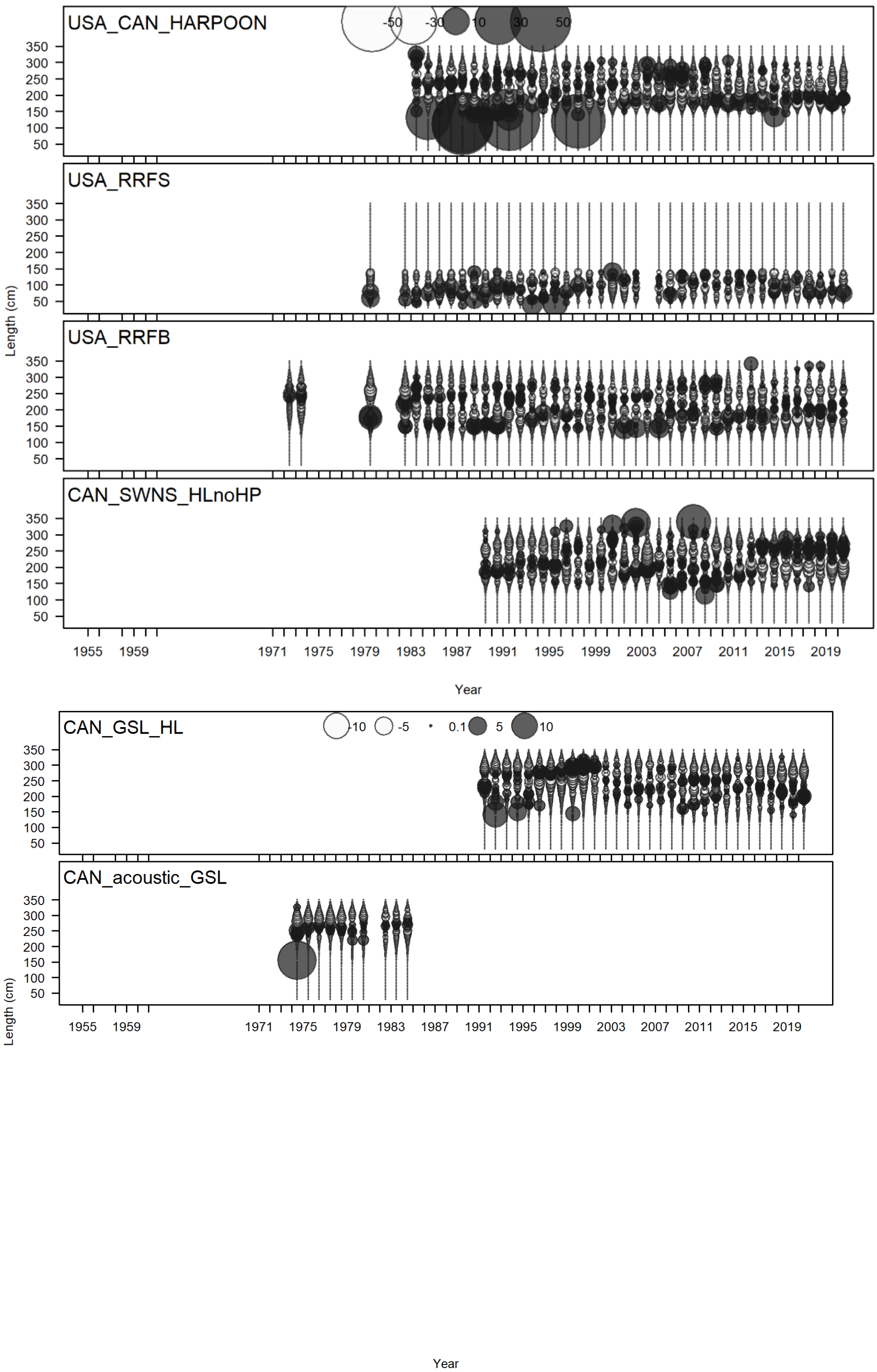
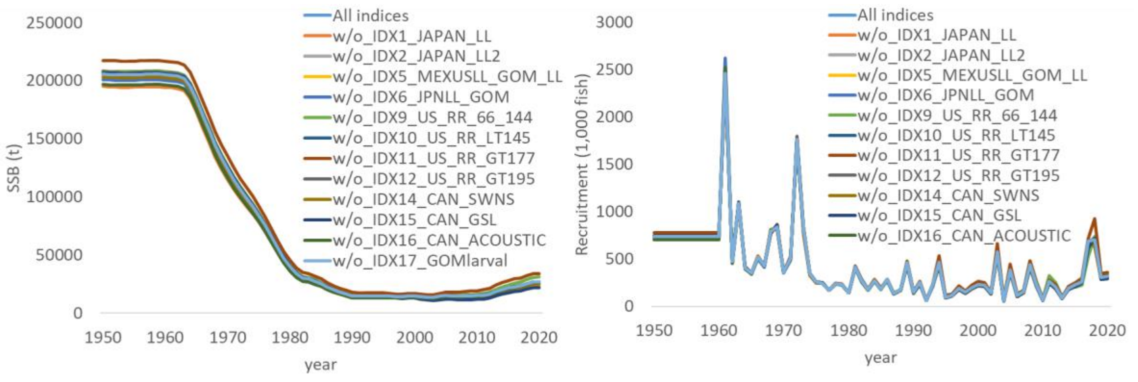
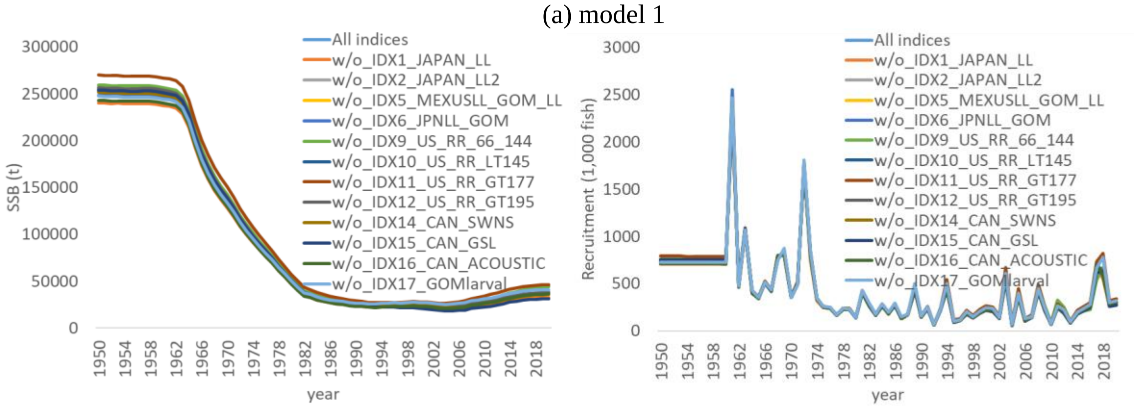


Figure 10. Time series of Pearson residuals on the length composition data by fleets for model 2.

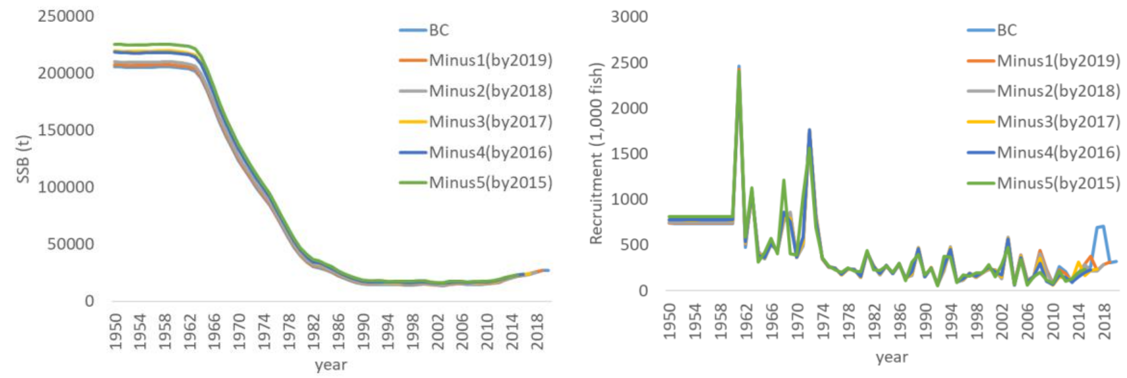


(a) model 1

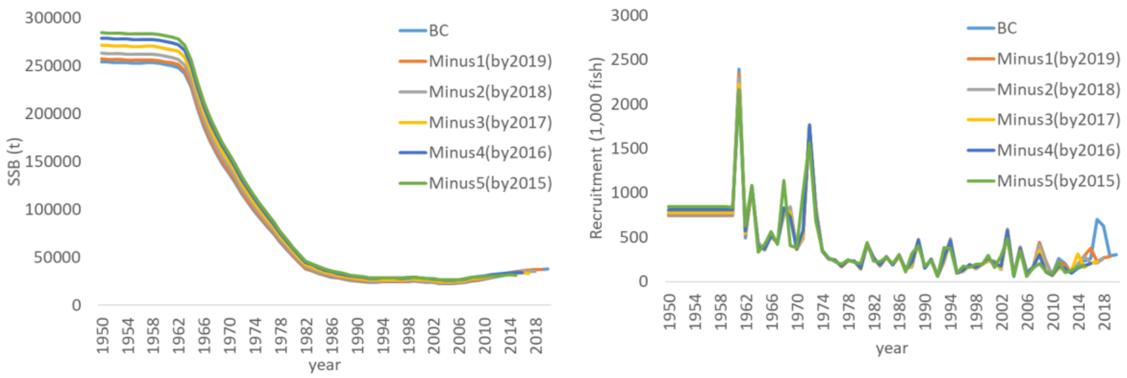


(b) model 2

Figure 11. The result of jackknife analysis regarding abundance indices for (a) model 1 and (b) model 2

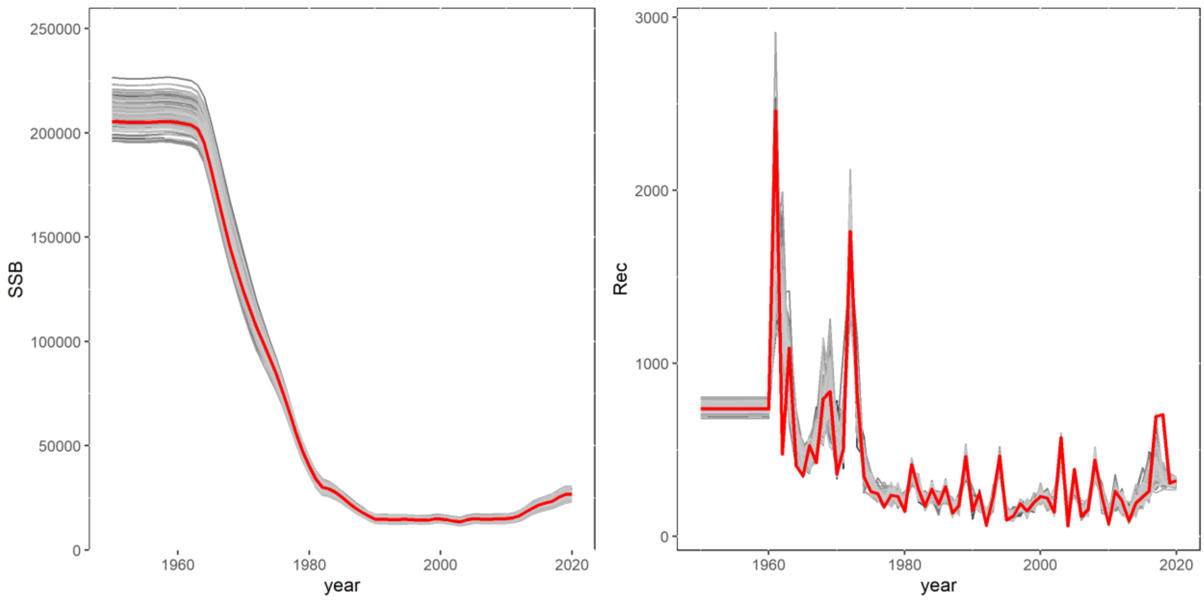


(a) Model 1

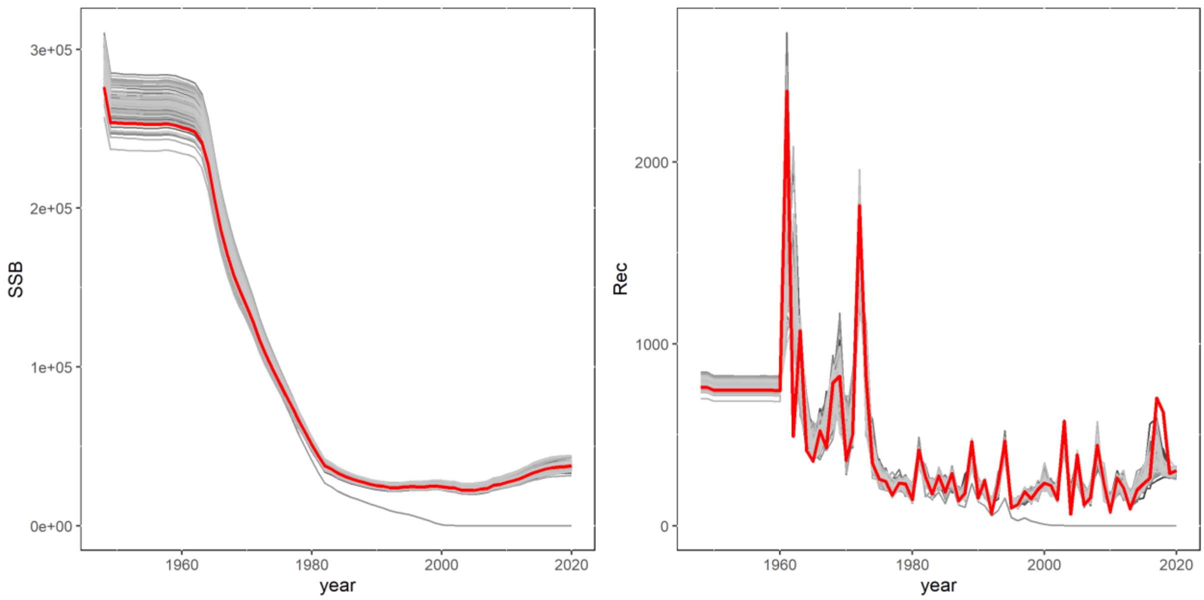


(b) Model 2

Figure 12. Retrospective plots of SSB and recruitment trends for (a) model 1 and (b) model 2.

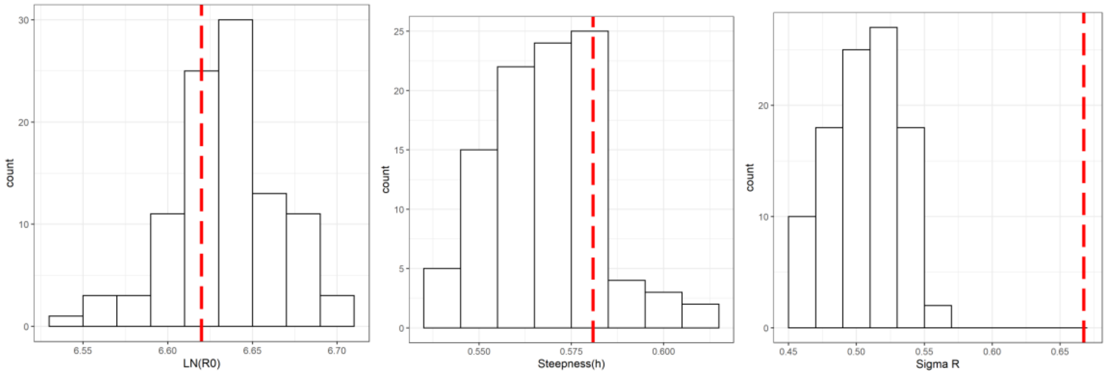


(a) Model 1

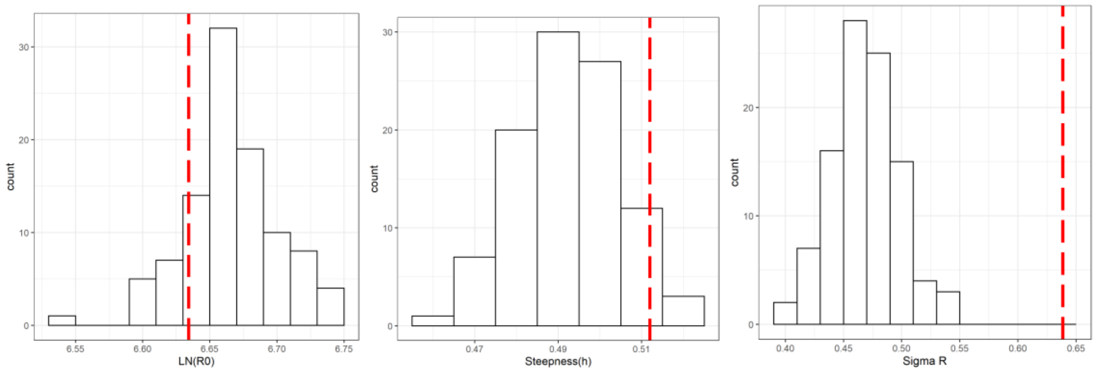


(b) Model 2

Figure 13. Results of SSB and recruitment trends came from original runs (red line) and 100 bootstrap replicates (gray line) for (a) model 1 and (b) model 2.

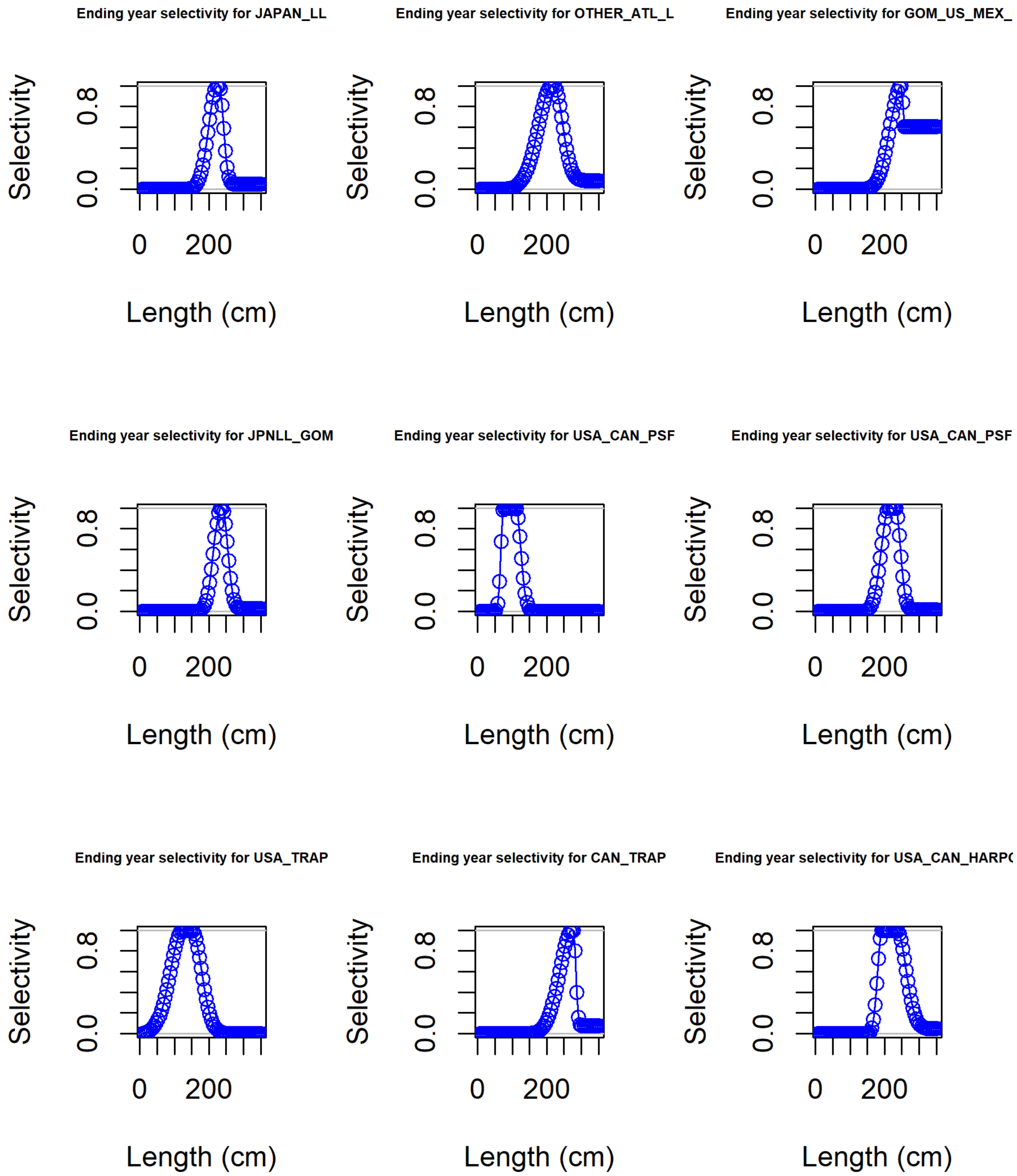


(a) Model 1



(b) Model 2

Figure 14. Results of the distribution of 3 parameter estimates related to SR relationship came from 100 bootstraps replicates for (a) model 1 and (b) model 2, ln(R0) (left), steepness (middle) and sigmaR (Right). Red line shows the estimates in original run without data pertuerbation.



Ending year selectivity for JAPAN_LL
Ending year selectivity for OTHER_ATL_L
Ending year selectivity for GOM_US_MEX_
Ending year selectivity for JPNLL_GOM
Ending year selectivity for USA_CAN_PSF
Ending year selectivity for USA_CAN_PSF
Ending year selectivity for USA_TRAP
Ending year selectivity for CAN_TRAP
Ending year selectivity for USA_CAN_HARP(
Selectivity
0.0
0.8
0
200
Length (cm)

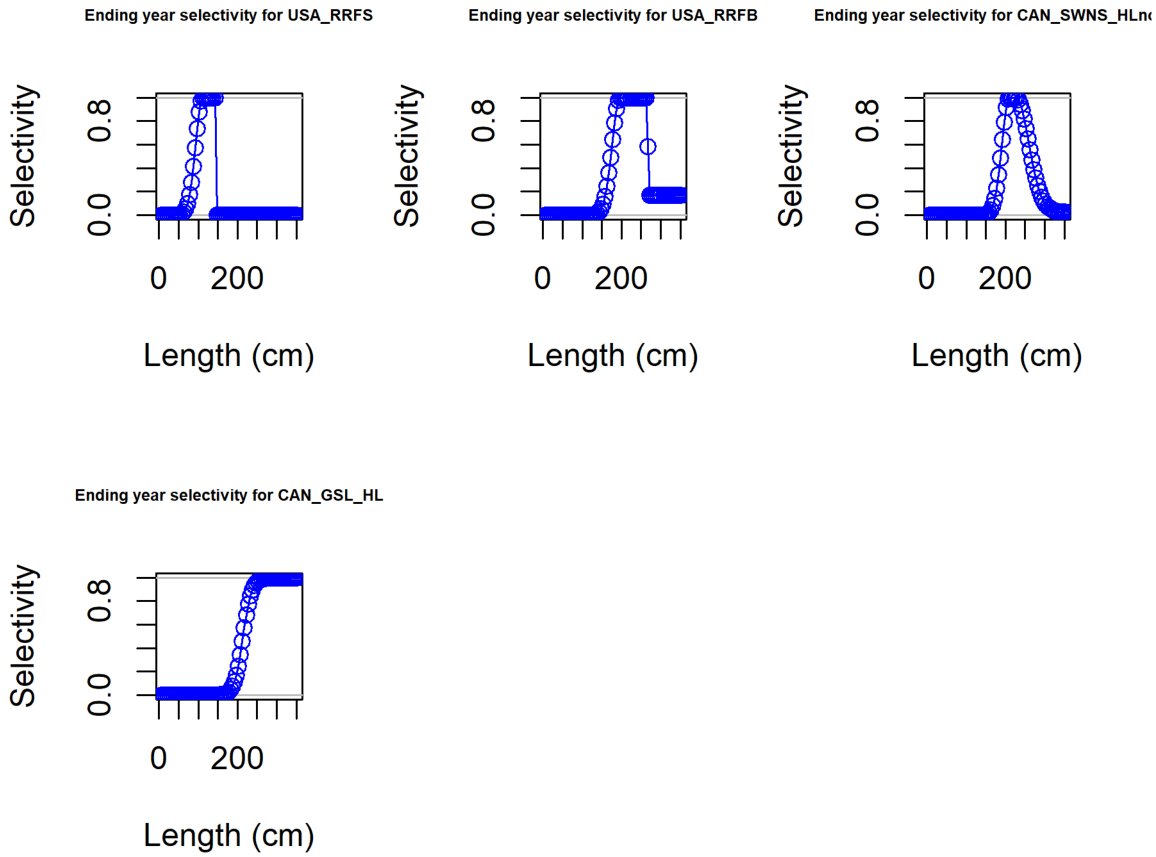
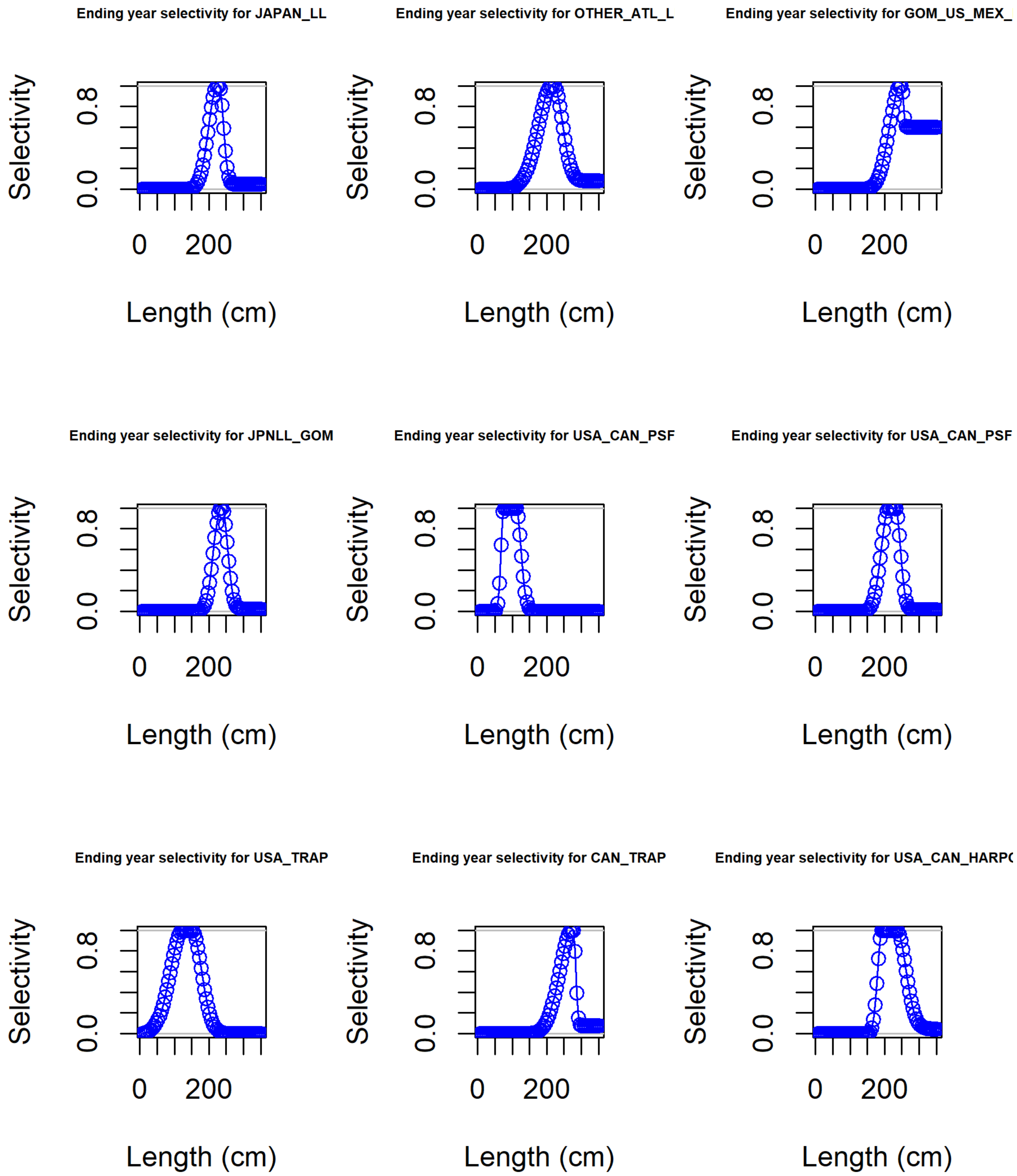


Figure 15. Estimated selectivity at end year for model 1


Ending year selectivity for JAPAN_LL
Ending year selectivity for OTHER_ATL_L
Ending year selectivity for GOM_US_MEX_
Ending year selectivity for JPNLL_GOM
Ending year selectivity for USA_CAN_PSF
Ending year selectivity for USA_CAN_PSF
Ending year selectivity for USA_TRAP
Ending year selectivity for CAN_TRAP
Ending year selectivity for USA_CAN_HARP(
Selectivity
0.0
0.8
0
200
Length (cm)

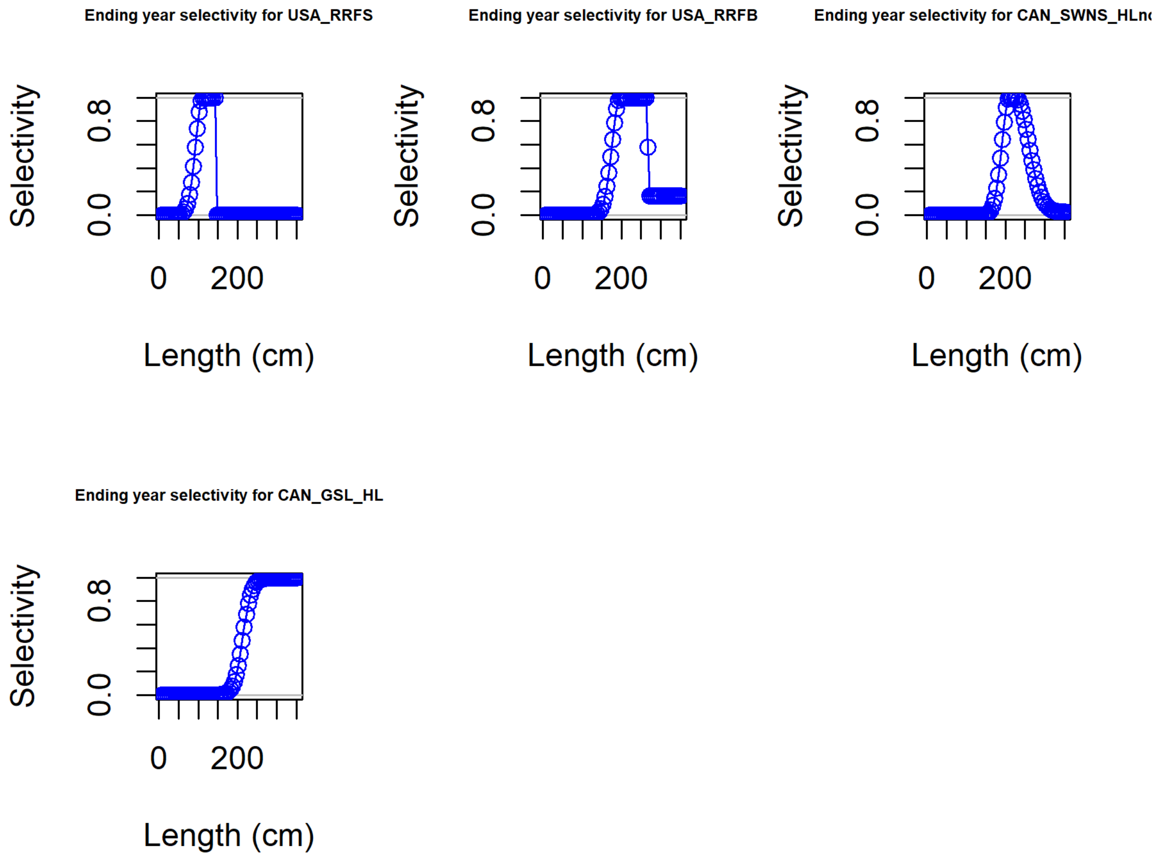


Figure 16. Estimated selectivity at end year for model 2

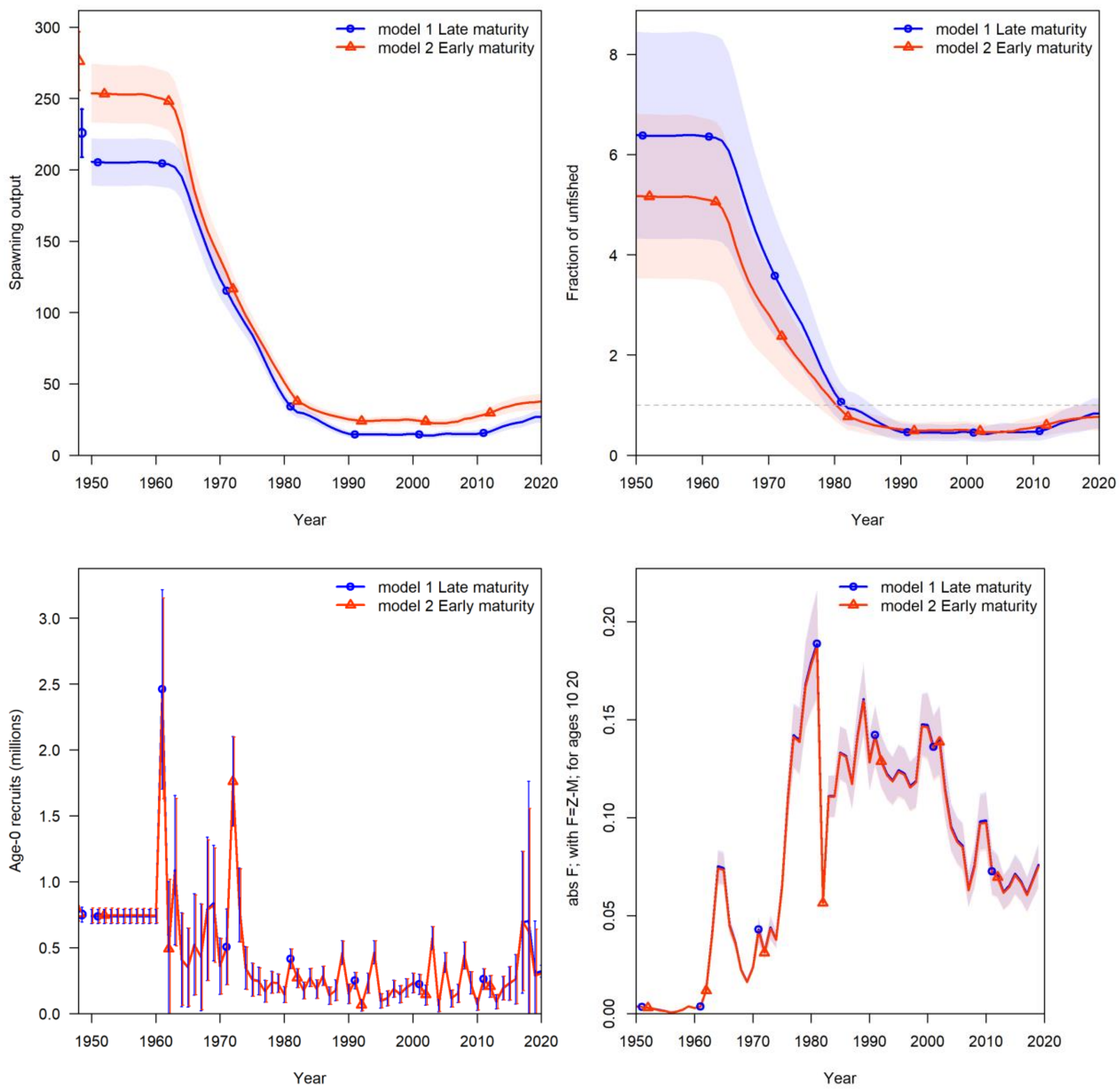


Figure 17. The comparison plot of time series of SSB (top left), recruitment (top right), biomass ratio to unfished levels (bottom left) and fishing mortality (bottom right) between model 1 and model 2, i.e. maturity schedule.

Appendix

Introduction

One of the major features of the integrated fishery stock assessment model (e.g., stock synthesis) is the joint likelihood function that enables to use several different data sources and estimate numerous parameters regarding the population dynamics simultaneously. In the case of the Atlantic bluefin tuna western stock (ABFT-W) assessment using the Stock Synthesis, more than 120 parameters regarding the growth, stock-recruitment relationship, recruitment deviations, catchability coefficient, initial condition (initial equilibrium fishing mortality), and selectivity were estimated from the data set combined abundance index, catch including the equilibrium catch before the assessment period, size composition and conditional age at length. The management advise is developed based on the short-term projections to compare the future fishing mortality with F0.1 reference point for the scenarios of several levels of constant catch and a constant recruitment, which is calculated as an average of recent recruitments. Thus, for the management advise of this stock, the population scale (log R0) and recruitment deviations (Rdevs) were particularly important to be estimated appropriately in the assessment.

There is reasonable quantity of the data for the ABT-W stock assessment using the Stock Synthesis. However, given the complexity of integrated model, it is difficult to understand how each data component contribute to the model estimates of those parameters. To elucidate how those parameters were informed by the data, we performed a series of diagnostics attempting simpler model process such as the Age Structured Production Model (ASPM) and Catch Curve analysis (CCA).

Models

Either of the ASPM and CCA are developed based on the 2021 ABT-W candidate assessment model (Tsukahara et al., 2021) with several modifications.

We used the following workflow to compute the ASPM (Minte-Vera et al., 2017; Carvalho et al., 2020): (1) run the candidate base case model, (2) fix the selectivity parameters and biological process parameters (growth, steepness of the Beverton-Holt spawner-recruit relationship, and the variability of the recruitment deviations) at the maximum likelihood estimates (MLEs), (3) turn off estimation of all parameters except logR0 and the initial fishing mortality parameters), (4) set the recruitment (and the initial age structure) deviates to zero, and (5) fit the model to the catch only, or catch and an index of abundance only (not fitting to the size/age composition data). If catch at age alone explains the trend of the indices of abundance with good contrast, it suggests that a production function is apparent in the data, therefore providing evidence that the index is a reasonable proxy of stock trend (Maunder and Piner, 2015).

CCA was also performed to elucidate how the composition data contributes to the estimation of the population scale and recruitment variability. The following workflow to compute the CCA (Minte-Vera et al., 2017; Carvalho et al., 2017): (1) run the candidate base case model, (2) fix the biological process parameters (growth, steepness of the Beverton-Holt spawner-recruit relationship, and the variability of the recruitment deviations) at the maximum likelihood estimates (MLEs), (3) turn off estimation of all parameters except logR0, the initial fishing mortality parameters, and Recruitment deviations, and (4) fit the model to the catch and size composition only (not fitting to the index of abundance data). In this analysis, the size composition data directory contributed to the estimates of absolute abundance and trend, then, it becomes important to verify that the trend in the CAA over time is consistent with the trend in the index of abundance.

Additionally, an ASPM with annual recruitment deviations specified (fixed) at those estimated in the CCA or in the full data model which were strongly implied by the juvenile index (lambda =100 for US Rod & Real from 66 to 144 cms; Index 9), were also performed to evaluate if the addition of information about the recruitment implied by the size composition data or juvenile index can improve the fits to the adult indices. If the fixed recruitments improve fits to the adult indices, this is evidence that the recruitment index is consistent with the other data sources in the model and provide good information on recruitment variability.

Results

For the sake of fair comparisons, we chose 7 indices of adult abundance (Japan_LL, MEX_US_LL_GOM, US_RR_GT177, CAN_SWNS, CAN_GSL, CAN_Acoustic, GOM_Larval), which have long time series (i.e., Generally model can fit to the short time series easier than long time series). SPM fitting to the catch alone model (Catch-ASPM) shows a fairly good fit to the Japanese longline index with some contrast although there is a certain time lag between the observed index and model predicted value (Fig. 1). Also, this model traces a general increasing trend from MEX_US_LL_GOM index (Fig. 2). As for the rest of the indices, it is difficult to explain their trend by catch alone (Table 1).

When the ASPM includes those indices, which are explained their trend by catch alone (IDX1_JLL, IDX_5_MEXUSLL_GOM_LL), in the likelihood function, only the JLL index shows an improvement of fit (Table 1).

Although the simple ASPM could not get the adequate fit the juvenile index (IDX9; US_RR_66_144), an ASPM with recruitment deviations specified at levels that exactly matched the juvenile index (ASPM-R_) further improves the model fits the JLL index (Figure 1 and Table 1). This result indicate that the information provided by the juvenile index (IDX9: US_RR_66_144) are consistent with those of the JLL index and likely provide good information on recruitment (and/or migrants from the eastern stock) variability.

The CCA shows a declining and increasing trend of the SSB. This indicates that the size composition is also a part of the driver of absolute biomass and its trend, however, the model fits to the Index1: JLL and Index5: Mex_US_LL_GOM are degraded from Catch-ASPM (Table 1). The ASPM-R with annual recruitment deviations specified (fixed) at those estimated in the CCA (ASPM_CCA) showed an improvement to the fits to the JLL index, but not to the juvenile index (Table 1).

Discussion

A consistency of the information between catch and an adult index from Japanese longline fishery (IDX 1) is elucidated by the ASPM diagnostics. Also ASPM-R diagnostics indicates that juvenile index (IDX 9) provided a good information about the recruitment (and/or migrants from the eastern stock), which is consistent with the JLL index. Those indicates obvious production relationship, and we can use this relationship to evaluate any changes to model structure when we develop the base case. Changes that improve the relationship among catch and those juvenile/adult indices is considered consistent with the production relationship in the model.

The CCA shows a contribution of size composition data to the estimation of the absolute biomass, although it does not seem to be consistent with the production relationship above. This may be caused by a misspecification of the selectivity or other biological process. Since the ASPM-R also shows an improvement to an adult index, this data component also would have some information about the recruitment deviation. But it should be noted that the size composition alone can not explain the trend of any index. It may be better to regulate the contribution of the size composition data to the estimation of the absolute biomass (e.g. down-weight to the composition data) unless the cause of inconsistency between the composition data and indices were understood.

Reference Papers

Carvalho, F., Punt, A., Chang, Y.J., Maunder, M., Piner, K. 2017. Can diagnostic tests help identify model misspecification in integrated stock assessments? Fisheries Research, Vol 192, Pages 28-40.

Carvalho, F., Winker, H., Courtney, D., Kapur, M., Kell, L., Cardinale, M., Schirripa, M., Kitakado, T., Yemane, D., Piner, K., Maunder, M., Taylor, I., Wetzel, C., Doering, K., Johnson, K., Methot, R. 2020. A cookbook for using model diagnostics in integrated stock assessments. Fisheries Research, Vol 240, 105959.

Minte-Vera, C., Maunder, M., Aires-da-Silva, A., Satoh, K., Uosaki, K. 2017. Get the biology right, or use size-composition data at your own risk. Fisheries Research, Vol 192, Pages 114-125.

Maunder, M., Piner, K. 2015. Contemporary fisheries stock assessment: many issues still remain. ICES Journal of Marine Science, 72(1), pages 7–18. doi:10.1093/icesjms/fsu015.

Table A1. Root Mean Square Error (RMSE) of the Index for each model. Shaded cells indicate that data is not included in the likelihood function of the model.

Index_Name	Fleet	Catch-ASPM	ASPM_IDX1_IDX5	ASPMR_IDX1_IDX5	CCA	ASPMR_CCA_IDX1_IDX5
IDX1_JAPAN_LL	18	0.48	0.43	0.37	0.55	0.39
IDX5_MEXUSLL_GOM	22	0.47	0.49	0.49	0.62	0.46
IDX9_US_RR_66_144	26	0.45	0.40	0.22	0.58	0.53
IDX11_US_RR_GT177	28	1.05	2.04	1.93	0.98	1.71
IDX14_CAN_SWNS	31	0.80	2.06	1.94	0.84	1.68
IDX15_CAN_GSL	32	0.98	2.41	2.17	1.15	1.98
IDX16_CAN_ACOUSTIC	33	1.00	2.46	2.25	0.92	2.03
IDX17_GOMlarval	34	0.80	0.83	0.84	0.75	0.79

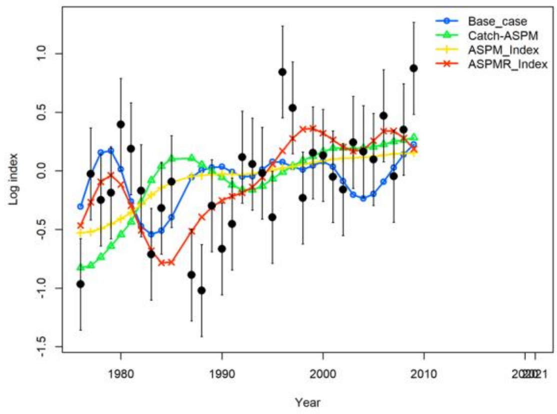


Fig. A1 Comparisons of the predicted abundance index (IDX 1: Japanese longline index) for the base-case model (blue lines), age structured production model with/without adult indices (ASPM; green and yellow lines), and age structured production model with the recruitment deviations (ASPM-R; red lines), where black closed circles with vertical lines represent the observed abundance indices with 95% CI.

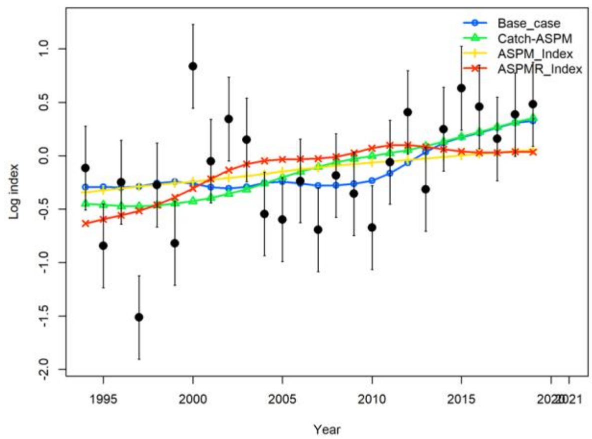


Fig. A2 Comparisons of the predicted abundance index (IDX 5: Mexico US longline in GOM index) for the base-case model (blue lines), age structured production model with/without adult indices (ASPM; green and yellow lines), and age structured production model with the recruitment deviations (ASPM-R; red lines), where black closed circles with vertical lines represent the observed abundance indices with 95% CI.

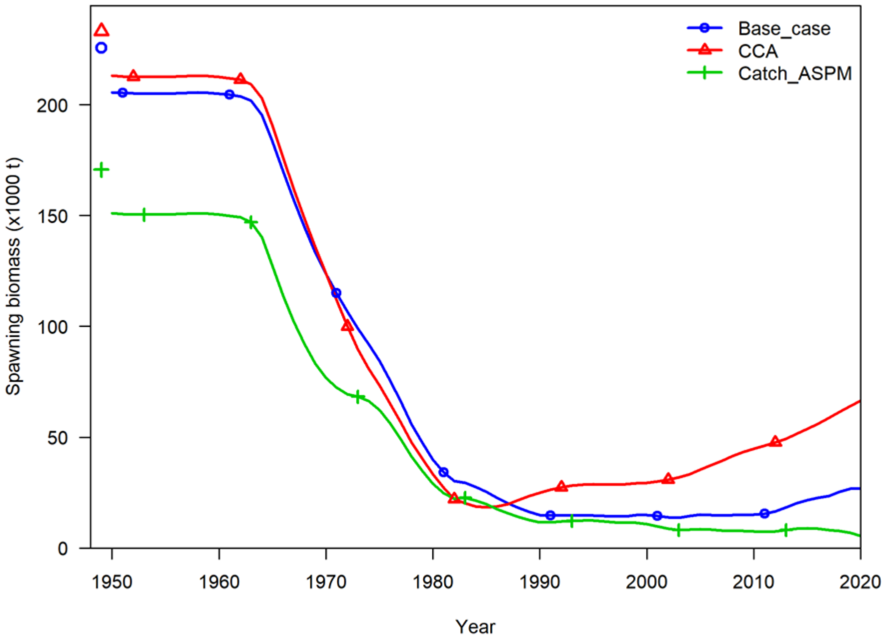


Fig. A3 Unfished spawning stock biomass (open plots) and spawning stock biomass of ABT western stock with old maturation scenario for the candidate base-case model (blue), Catch Curve analysis model (CCA; red) and age structured production model (Catch-ASPM; green).