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WESTERN ATLANTIC BLUEFIN TUNA STOCK ASSESSMENT 1950-2020 USING STOCK SYNTHESIS: PART I. MODEL SPECIFICATION AND INPUT DATA

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SUMMARY

This document describes a stock assessment model using Stock Synthesis (version 3.30) for the Western Atlantic population of Bluefin tuna. The model runs from 1950 to 2020 and was fit to length composition data, conditional length at age (otolith age-length pairs input as an age-length key), 12 indices and 13 fishing fleets. Growth was internally estimated in the model and natural mortality was scaled with a Lorenzen function. These input and model settings were slightly changed from those used in 2020 except relative abundance indices in accordance with the request from ICCAT Commission. Two models (early and late maturity) were used for advice in 2017 and the same are retained here. The shapes of most selectivity were changed from asymptotic to dome shape to improve the convergence of the models and to reduce the conflict among the data sources, which was mainly due to the conflict among the indices. The trend of spawning stock biomass and recruitment are similar to previous one, while the biomass level was obviously different. These results will combine with those came from VPA analysis for the management recommendation in this year.

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. Le modèle s'étend de 1950 à 2020 et s'est ajusté aux données de composition par taille, la taille conditionnelle par âge (paires d'otolithes âge-longueur saisies comme une clé âge-longueur), 12 indices et 13 flottilles de pêche. La croissance a été estimée en interne dans le modèle et la mortalité naturelle a été mise à l'échelle avec une fonction de Lorenzen. Ces entrées et configurations du modèle ont été légèrement modifiées par rapport à celles utilisées en 2020, à l'exception des indices d'abondance relative, conformément à la demande de la Commission de l'ICCAT. Deux modèles (maturité précoce et maturité tardive) ont été utilisés pour obtenir un avis en 2017 et les mêmes sont retenus ici. Les formes de la plupart des sélectivités ont été modifiées, passant d'une forme asymptotique à une forme de dôme, afin d'améliorer la convergence des modèles et de réduire le conflit entre les sources de données, qui était principalement dû au conflit entre les indices. Les tendances de la biomasse du stock reproducteur et du recrutement sont similaires aux précédentes, alors que le niveau de la biomasse était manifestement différent. Ces résultats seront combinés avec ceux issus de l'analyse de la VPA pour la recommandation de gestion de cette année.

RESUMEN

Este documento describe un modelo de evaluación de stock que utiliza Stock Synthesis (versión 3.30) para la población de atún rojo del Atlántico occidental. El modelo abarca desde 1950 hasta 2020 y se ajustó a los datos de composición por tallas, la talla por edad condicional (pares de otolitos edad-talla introducidos como clave de edad-talla), 12 índices y 13 flotas pesqueras. El crecimiento se estimó internamente en el modelo y la mortalidad natural se escaló con una función Lorenzen. Estos datos de entrada y especificaciones del modelo se cambiaron ligeramente respecto a los usados en 2020, excepto los índices de abundancia relativa, por petición de la Comisión. Se utilizaron dos modelos (madurez temprana y tardía) para el asesoramiento en 2017 y se mantienen los mismos aquí. Las formas de la mayoría de la selectividad se cambiaron de asintóticas a con forma de cúpula para mejorar la convergencia de los modelos y reducir el conflicto entre las fuentes de datos, que se debía

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principalmente al conflicto entre los índices. Las tendencias de la biomasa del stock reproductor y el reclutamiento eran similares a las anteriores, mientras que el nivel de biomasa era obviamente diferente. Estos resultados se combinarán con los del análisis VPA para la recomendación sobre ordenación de este año.

KEYWORDS

Stock assessment, bluefin tuna, Stock Synthesis

Introduction

Stock Synthesis (SS) 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). SS 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 SS is that they should be modeled together, which helps to ensure that uncertainties in the input data are properly accounted for in the assessment. SS 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 document describes the changes in 2021 assessment compared to 2020 assessment firstly. The basic settings and data which are same as those in 2020 assessment are also documented.

Major change from 2020 assessment

There was the three points of major change from last assessment. First and second points were the decision by WG, while third point regarding the selectivity assumption was the proposal to improve the results of diagnostics without so much change of model setting.

Indices used in the assessment

The poor fit to several relative abundance indices and reliability of indices themselves were discussed much in 2020 assessment meeting (Anon. 2020a). According to this discussion, WG established the small group to review and to improve the input data and standardization method for the abundance indices. In order to review and improve the indices, WG develop the technical sub-group (SG) which consist of data providers in each CPCs (Anon. 2020b). SG recommended that some indices used for the previous assessment should be revised mainly by the aggregation or separation of input dataset for the standardization and WG accepted the recommendation and decided to use new indices for the 2021 assessment up until 2020 data point (Anon. 2021). The details of each change were in the individual documents for 2021 April data preparatory meeting and comparison plots for old and new indices were in the meeting report (Anon 2021).

Fleet structure corresponding to the new indices

According to the aggregation or separation of indices, the fleet structure had to be changed to estimate the selectivity for vulnerable biomass of each index. For example, the index for Canadian Hook and Line fisheries used in 2020 assessment was split into two indices which were operated in off Northwest Nova Scotia or Gulf of St, Lawrence, respectively. Hence, catch fleet for Canadian fisheries had to be split into two fleets. This split enables to mirror selectivity came from recent size composition data by GSL fisheries to GSL Acoustic index. The detail of fleet structure for 2021 assessment is in Table 1.

Selectivity assumption
One of the issues in 2020 assessment was the strong conflict in the R0 profiles among data component. In order to reduce the conflict, assuming the dome shaped selectivity by 6 parameter double normal for all fleet except CAN_GSL fishery (**Table 1**). The reason why CAN GSL fishery is the only fleet with asymptotic selectivity was that the mean size of length composition is maximum among the fleets and was based on the empirical selectivity diagnostics by r4ss.selecitivity. This change will reduce the conflict among data and improve model diagnostics.

Some minor change from 2020 assessment

- Tuning on the estimation of initial F of US and CAN Harpoon fleet, which have an initial equilibrium catch but was not estimated in 2020 assessment because of the hit to the lower bound.

- Removing the one data point for Japanese longline index 1, which value was extremely lower in comparison with the other values. Probably that was because the narrowing down the area for the standardization in accordance with the shrinkage of operation area for recent year.

Basic Model Specification
Overview
Overall the WBFT SS model uses size composition information, conditional age at length data (essentially an age-length key using the age-length pair data available for WBFT), 12 indices and landings going back to 1950 (**Figure 1**). Catch at age for the Japan longline, as derived from cohort slicing is input in the model but not used in fitting for the purposes of evaluating the predicted CAA from SS with the assumed CAA for the VPA. Basic equations and technical specifications underlying Stock Synthesis can be found in Methot and Wetzel (2011). In this assessment, we use both SS version 3.30.14.

The model assumed the Western Atlantic Bluefin tuna stock structure (West of 45º longitude) with no spatial structure otherwise. Fleet structure was designed to generally alias spatial/temporal structure with fleets were separated according to whether they occurred in the Gulf of Mexico or the Atlantic and when there was a clear separation in size structure due to either selectivity or availability.

The model starts in 1950 and runs to 2020 (**Figure 1**). Conditions were assumed to be near-virgin in 1950 with two fleets, USA_ TRAP and USA_CAN_HARPOON, assumed to have equilibrium catches equal to the average of 1950-1955, respectively, 434.5 and 310 t and initial Fs estimated for one of the fleets. An annual time step was assumed for the model with 14 fleets assumed to take catch out continuously over the year. Individual 12 indices were adjusted to account for the timing within the year when the index occurs.

Key settings and Input data
Biology
A single sex was assumed for the model and spawning biomass was assumed to be the summed mass of all mature fish. Fish are born at age 0 and the model uses a plus group age of 35. Maturity at age was modeled with two vectors representing either early or late spawning (**Figure 2**). Natural mortality was modeled with a Lorenzen function scaled according to the growth model with a reference M of 0.1 applied to a reference age of 20. The M of 0.1 corresponds to the Hoenig (1983) estimator of Z for a maximum age of 35. Growth was modeled with a Richards 3 parameter formulation and initially input as the Ailloud et al (2017) growth parameters but then all growth parameters, except for length at age 0.5 (43 cm) which was fixed, were freely estimated in the model (Linf, K, Richards parameter and the CV on young and old fish). Fecundity was modeled as proportional to weight (eggs=a*Wt^b) and the overall Western Atlantic length weight relationship was used to convert size to weight (1.52E 05* length^3.05305). Biological vectors input or initial value for estimation in SS (italics) are shown in **Table 2**.

Stock-recruitment relationship.

A Beverton-Holt stock recruit relationship was assumed, and spawning biomass was equal to the biomass of the mature population according to the two maturity vectors outlined in the biology section. Parameters of the stock recruitment relationship (steepness and R0) were freely estimated. The variance in interannual recruitment deviations (sigmaR) was estimated between a range of 0.2 to 2 using the Method and Taylor bias correction ramping to facilitate estimability.

Deviations from the stock-recruitment relationship were assumed to follow a lognormal distribution estimated on a logscale as N(0, sigmaR) variates with a min and max of -5 and 5, respectively. Zero recruitment deviations were assumed until the start of informative data on age structure, i.e. annual deviates were only estimated from 1961-2019. The lognormal bias correction ($-0.5\sigma^2$) for the mean of the stock recruit relationship was applied during the period 1961-2018 with a bias correction ramp applied prior to 1971 and after 2016 according to the Methot and Taylor (2011) recommended bias correction ramping. This bias correction ramping was updated for the 2020 models and recruitment deviations extended to 2017.

Fleet and index definitions
Fleet definition for catch and index fleet was bit different as written above to in accordance with the change of indices. Overall the model consists of 14 fleets and 12 indices.

Total catch (task I)
The total catches were calculated by the Secretariat (**Table 3, Figure 3**) with some modifications as noted to the fleets, above. Catch in metric tons was used in the model for all fleets, and was assumed to be known essentially without error (standard error =0.05). Initial equilibrium catch was input for USA_trap and USA_CAN_Harpoon that had non-negligible catches in 1950. Initial F was estimated for these fleets but was assumed to be zero for all other fleets. To provide initial equilibrium catches for USA_TRAP and USA_CAN_HARPOON the average for 1950-1955 was input (434.5 and 310 t, respectively).

Catch per unit effort data
While retained in the data file the SS models exclude the Gulf of Mexico oceanographic index and the historic tagging index from likelihood component. All indices were input with a CV of 0.2 for each year (input as a log scale standard error in model). This decision was similar to the decisions made for the VPA and other models. CPUE indices were assumed to have a lognormal error structure. No time blocks on indices were modeled as indices that required splits were input as separate indices with unique catchabilities, while catchability for three indices, US_RR_GT177, i.e. CAN_GSLNS and CAN_ACOUSTIC, were linked with the Atlantic multidecadal oscillation (AMO) for July, August and September as an environmental factor (see SCRS 2020/. CPUE input data are shown here (**Figure 4**) but fits to CPUE data will be shown in the second paper that documents preliminary Results.

Conditional age at length inputs
Otolith age-length data was available from the same five labs that provided data in 2017, with substantial additional numbers of age-length pairs available (**Table 4**). Much of the data has gone through extensive re-evaluation and scrutiny of aging protocols (SCRS-2019-132) resulting in updates to several of the datasets used in 2017.

Consistent with the nature of this assessment as an update we include age data from 2016-2018 (terminal year of the model) and also to include the historical data from the years that it was originally used in the 2017 and 2020 assessment.

The data was screened for outlier length-weight pairs by noting observations +/- 3 empirical standard deviations from the mean size at age. In many cases these were due to length conversions from different units and could be corrected in the original files. The remaining outliers that could not be confidently identified as being due to size conversion errors were removed from the age dataset (**Figure 5**).

Similar to the treatment of the data in 2017 and 2020, when gear types were not recorded expert opinion was necessary to assign gear based on landing port and these remain the same fleets as in 2017 and 2020. In the Panama City dataset, a number of small fish without gear were assumed to be USA_RRFS as the samples likely came from the Large Pelagics Biological Survey that generally surveys the US recreational fleet.

This process of updating the years of data from 2019-2020 and replacing the previously used samples with the revised age reads resulted in a similar dataset as in 2017 and 2020 but with additional years of data (**Table 1**). It did result in removing a substantial amount of new ageing data from the time period 1973-83 from Canada DFO and from University of Maine from 2012-2015 but this would have been data not used in 2017. The total number of age-length pairs available were 9307 from years 1973-2018 with 6552 remaining following screening and following the strict update protocols.

Age-length data was assigned to 9 different fleets (**Figure 6**). Age information was input with an aging error vector assuming a CV of approximately 0.1 for most ages (SCRS/2014/038). In 2017 an aging bias vector derived from paired otolith-spine samples was used. However, a review of aging protocols (SCRS/2019/132) indicated that some of this bias may have been due to the previous assumption regarding the timing of opaque band formation. A revised adjustment criterion was proposed to convert the count of bands into ages and all historical reads (except the UMCES samples) were revised accordingly, obviating the need to input a bias in the aging vector. Hence only a vector of aging error was input to the update models (**Table 5**).

Ages were adjusted according to SCRS/2019/132. An additional adjustment to the ages for input to Stock Synthesis was to subtract one half of a year to the age to account for the assumed (within SS) January 1st birthdate so that SS correctly tracks cohorts. Age data was input as conditional age at length data (similar to an age-length key) where the main assumption is that the ages are randomly collected within a length bin e.g., within a 5 cm length bin all the samples a random sample. We also show histograms of the age composition by year for visual purposes (**Figure 7**). As the sampling is not representative of all fleets, across all sizes this greatly relaxes the assumption of random sampling across all size classes for a fishery.

Catch at age input
Similar to the 2017 and 2020 model, catch at age was input for the Japan longline fleet which did not have conditional age at length data. Catch at age data was not fit in the likelihood component but was input for diagnostic purposes to evaluate the consistency of decisions used to construct the CAA with internal modeling of growth and selectivity in SS. Catch at age was only updated to 2015 as it was not necessary to include later years simply for diagnostic purposes.

Size frequency information
Development of the raw size frequency input to SS followed the same process as in 2017 (*SCRS/2017/166*). Some data cleaning was conducted (removing outliers due to extreme skewness, kurtosis, or extremely small or large sizes for particular fleets) but the size composition information was used in its most raw format as provided by individual CPCs (**Figs 8 & 9**). In 2020 these outliers were removed which cleans up many of the Pearson residual plots allowing for the central patterns to emerge. Additionally, compress option for last 5 bin (325-250 cm) was used only for the US_MEX_GOM_LL to avoid the misfit by little observation around the largest bin. Data was input is straight fork length in centimeters and modeled with 5 cm length bins between 30 and 350 cm in the model.

Size frequencies for the remainder of the 13 fleets indicate relatively consistent size structure over time with the exception of several fleets with sparse data (**Figs 10, 11**). Length composition data is modeled assuming a multinomial distribution.

Selectivity
Selectivity was parameterized (**Table 1, Figures 12,13**) as length-based for most fleets/surveys as either 6 parameter double normal which could take on either dome or asymptotic shape as logistic on the basis of visual examination of the length composition data. There was time block selectivity for two fleet, Japan_LL, USA_RRFS and CAN_HL_GSL. For the Japan LL time varying selectivity with deviation was assumed from 2011 to 2015 to be aligned with the target change of this fishery because of fishery management. The selectivity deviations were not expanded for 2016-2018. Several surveys had a special selectivity parameterization with the larval survey assumed to have selectivity of the GOM_LL_US_MEX index and fishery. The oceanographic index was excluded in the likelihood component but was retained to evaluate the potential fit and was modeled with a selectivity equal to exp(rec devs). In several cases when the double normal selectivity showed either a steady increasing or decreasing limb these were modeled to allow for either a smooth increase or decrease to avoid sharp and unrealistic breaks.

Data weighting
Francis and Hilborn (2011) indicates that often in complex integrated models there is conflicting sources of information, stemming from fitting to either the length composition data, or abundance index data and often the numerically abundant length composition information dominates the likelihood. Length composition data was initially input with a sample size of 100 and conditional age at length data was input with the actual sample size. In most cases, the effective N was much higher than the input N indicating that that the effective sample should be reduced for most fleets. Input sample size for length and age data input was iteratively adjusted so that the harmonic mean effective N equaled the input N using variance adjustments (McAllister and Iannelli 1997). Input weights, as follow, generally substantially downweighted the length composition as well as the conditional length at age data. Age composition data input for the Japan_LL was not fit in the model likelihood and removed using the lambda emphasis factors. The iterative reweighting of the models was repeated for the 2020 update models but only for one maturity run and the same weights used for the other run.

No adjustment to index weighting was performed in the current iterations of the models.

Model Diagnostics
Model convergence was assessed using several means.

1. The first diagnostic was whether the Hessian, (i.e., the matrix of second derivatives of the likelihood with respect to the parameters) inverts.
2. The second measure is the maximum gradient component which, ideally, should be low. The third diagnostic was a 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).
3. Parameter coefficients of variation where the CV of the parameter estimate comes from the model estimated variance from the variance-covariance matrix
4. 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. Likelihood profiles elucidate conflicting information among various data sources, determine asymmetry around the likelihood surface surrounding point estimates and evaluate the precision of parameter estimation.
5. Evaluation of fits to residuals for indices and length composition,
6. Retrospective analyses. Retrospective analyses are also standard diagnostic practice and were conducted on models 1-2 with 5 year retrospective peels.
7. Sensitivity to different indices (index jackknife evaluation)

Another model diagnostic is parametric bootstrapping. Uncertainty in parameter estimates and derived quantities can as well bias between the maximum likelihood estimates and estimates obtained by bootstrapping were investigated using a parametric bootstrap approach. Bootstrapping is a standard technique used to estimate confidence intervals for model parameters or other quantities of interest and was used in 2017 to generate the kobe matrix. There is a built-in option to create bootstrapped data-sets using SS. This feature performs a parametric bootstrap using the error assumptions and sample sizes from the input data to generate new observations about the fitted model expectations. The model was refit to approximately 100 bootstrapped data-sets and the distribution of the parameter estimates was used to represent the uncertainty in the parameters and derived quantities of interest.

Parameters Estimated
Overall 143 parameters are estimated in the model, consisting of 7 growth parameters 2 initial F parameter, 66 selectivity parameters, 8 catchability, 5 deviations, 3 stock recruitment parameters and 59 recruitment deviations. Several selectivity and catchability parameters were input with Bayesian priors to aid model stability.

Benchmark and fishing mortality calculations
For overall fishing mortality rate, an F0.1 proxy calculated from the yield per recruit curve was used in 2017 and 2020 and will also be used here. Given the substantial changes in overall selectivity over time the F01 and benchmarks will be estimated on a year-specific basis according to the fleet allocation in that year. Fishing mortality will be calculated as the average true (instantaneous) F over ages 10-20.

Uncertainty Quantification
In 2020 uncertainty in parameter estimates was quantified by the multivariate lognormal approximation approach (Winker et al., 2019) indicate little benefit from the added time involved in bootstrapping with greatly increased times to produce the K2SM and the BFT WG may want to consider using the approximation approach used for yellowfin tuna in 2019. Therefore, we will use the same method as that in 2020 to quantify the uncertainty for management advise.

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Table 1. Names and fishery definitions of the fleets used in the SS model.

Num.	Fleet/Index	Selectivity (all length based except fleet 15)	Time block Selectivity	use	start	end
1	JAPAN_LL	Double Normal	Y (1950-2009)	Y	1957	2020
2	OTHER_ATL_LL	Double Normal	N	Y	1957	2020
3	GOM_LL_US_MEX	Double Normal	N	Y	1971	2020
4	JLL_GOM	Double Normal	N	Y	1974	1981
5	USA_CAN_PSFS	Double Normal	N	Y	1950	1984
6	USA_CAN_PSFB	Double Normal	N	Y	1950	2015
7	USA_TRAP	Double Normal	Y (1950-1992)	Y	1950*	1974
8	CAN_TRAP	Double Normal	N	Y	1950*	2020
9	USA_CAN_HARPOON	Double Normal	N	Y	1950	2018
10	USA_HARPOON	Double Normal	N	N	1950	2020
11	USA_RRFS	Double Normal	N	Y	1950	1920
12	USA_RRFB	Double Normal	N	Y	1950	2020
13	CAN_CombinedHL	Double Normal	N	N	1988	2020
14	CAN_SWNS_HLnoHP	Double Normal	N	Y	1988	2020
15	CAN_SWNS_HLwithHP	Double Normal	N	N	1988	2020
16	CAN_GSL_HL	Logistic	Y (1950-2008)	Y	1988	2020
17	CAN_GSL_old	Mirror CAN_GSL_HL	N	Y	1950	1987
18	IND1_JAPAN_LL	mirror JAPAN_LL	N	Y	1976	2009
19	IDX2_JAPAN_LL2	mirror JAPAN_LL	N	Y	2010	2020
20	IDX3_USPLL_GOM	mirror GOM_LL	N	N	1987	1991
21	IDX4_USPLL_GOM2	mirror GOM_LL	N	N	1992	2020
22	IDX5_MEXUSLL_GOM_LL2	mirror GOM_LL	N	Y	1994	2019
23	IDX6_JPNLL_GOM	mirror JLL_GOM	N	Y	1974	1981
24	IDX7_US_RR_66_114	Double normal	N	N	1995	2020
25	IDX8_US_RR_115_144	Double normal	N	N	1995	2020
26	IDX9_US_RR_66_144	Mirror USRRFS	N	Y	1995	2020
27	IDX10_US_RR_LT145	Mirror USRRFS	N	Y	1980	1992
28	IDX11_US_RR_GT177	Mirror USRRFB	N	Y	1993	2020
29	IDX12_US_RR_GT195	Mirror USRRFB	N	Y	1983	1992
30	IDX13_CAN_combinedHL	Mirror Can combined HL	N	N	1984	2018
31	IDX14_CAN_SWNS	mirror Can_SWNS_HLnoHP	N	Y	1996	2020
32	IDX15_CAN_GSL	mirror Can_GSL_HL	N	Y	1988	2020
33	IDX16_CAN_ACOUSTIC	mirror Can_GSL_HL	N	Y	1994	2017
34	IDX17_GOMlarval	mirror GOM_LL	N	Y	1977	2019
35	IDX19_oceanographic	Exp(rec_dev)	N	N	1993	2011

*fishery starts with equilibrium catch

Table 2. Key biological parameters for the SS model.

Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	…	35
early spawning	0	0	0	0.25	0.5	1	1	1	1	1	1	1	1	1	…	1
late spawning	0	0	0	0	0	0	0	0.01	0.04	0.19	0.56	0.88	0.98	1	…	1
M (Lorenzen scaled)	*0.40*	*0.33*	*0.27*	*0.23*	*0.20*	*0.18*	*0.16*	*0.14*	*0.13*	*0.12*	*0.12*	*0.11*	*0.11*	*0.11*	…	0.10
Growth (mid year size)	43	*58*	*75*	*93*	*113*	*133*	*152*	*170*	*186*	*200*	*212*	*222*	*231*	*238*	....	*266*

Table 3. Task 1 landings input for SS3 only used fleets for the assessment.

	JAPAN_LL	OTHER_ATL_LL	GOM_US_MEX_LL	JPNLL_GOM	USA_CAN_PSFS	USA_CAN_PSFB	USA_TRAP	CAN_TRAP	USA_CAN_HARPOON	USA_RRFS	USA_RRFB	CAN_SWNS_HLnoHP	CAN_GSL_HL	CAN_GSL_old
Equ. Cat.	0	0	0	0	0	0	434.5	0	310	0	0	0	0	0
1950	0	0	0	0	0.85	0.15	346	10.3	459	38	88	0	0	75
1951	0	0	0	0	85	15	491	26.8	263	1	155	0	0	86
1952	0	0	0	0	0	0	135	64.5	323	0	95	0	0	69
1953	0	7	0	0	0	0	766	0	197	5	86	0	0	29
1954	0	1	0	0	46.75	8.25	531	0	129	13	46	0	0	49
1955	0	0	0	0	0	0	377	0	135	4	14	0	0	9
1956	0	5	0	0	0	0	181	0	47	2	14	0	0	3
1957	30	0	0	0	0	0	404	0	58	15	19	0	0	4
1958	32	16	0	0	117.3	20.7	869	0	61	3	64	0	0	0
1959	200	40	0	0	663.9	117.2	302	79	125	7	58	0	0	14
1960	339	83	0	0	235.5	41.55	204	32	119	9.55	45.45	0	0	5
1961	373	1	0	0	767.6	135.5	79	79	78	23.88	43.12	0	0	41
1962	1219	0	0	0	3203	565.2	87	137	44	135.4	236.7	0	0	40
1963	6191	132	0	0	4905	865.5	74	229	22	426.7	668.3	0	0	90
1964	12044	367	0	0	4378	772.5	161	318	24	199.8	309.2	0	0	99
1965	9147	303	0	0	2831	499.7	166	81	55	385.3	589.7	0	0	94
1966	2471	318	0	0	855.1	150.9	134	87	46	1439	2182	0	0	111
1967	694	604	0	0	1770	312.3	139	174	53	114.3	195.8	0	0	56
1968	272	2432	0	0	584	103.1	25	101	61	174.8	282.2	0	0	180
1969	116	1393	0	0	1118	0	38	193	30	113	757	0	0	170
1970	66	477	0	0	3335	953.2	53	130	72	57	447	0	0	151
1971	1375	202	0	0	3166	603.3	47	59	166	123	949	0	0	88
1972	321	15	23	0	1549	462	29	29	160	111	1058	0	0	188
1973	1097	18	29	0	1387	269.3	13	144	86	31	546	0	0	239
1974	824	30	39	80.98	891.6	68.45	20	256	214	2361	185	0	0	409
1975	237	41	24	1276	2009	310.7	0	144	233.3	122	460.7	0	0	206
1976	790.3	49.4	37	2112	1365	216.8	0	172	189	28	382	0	0	342
1977	1033	246	14	2625	1292	209.7	0	372	157	60	512	0	0	302
1978	708.5	118.4	28	2436	1117	113.2	0	221	158	51	645	0	0	208
1979	1298	80.07	22	2323	1012	369	0	31	143	95	647	0	0	214
1980	1420	101	10	2516	536.9	221.1	0	47	102	82.43	552.6	0	0	259
1981	1759	36.51	90	2012	515.7	394.3	0	41	109	72.87	460.1	0	0	279
1982	292	37	14	0	100.7	136.3	0	68	86	91.99	367	0	0	436
1983	711	68	12.24	0	108.8	275.2	0	7	159	121	616	0	0	426
1984	696	118	75.18	0	56.81	344.2	0	3	115	119.5	557.5	0	0	261
1985	1092	73	98.24	0	0	377	0	20	166	138.9	610.1	0	0	122
1986	584	50	124.2	0	0	360	0	0	127	97.36	418.8	0	0	41

1987	960	577	141.9	0	0	367	0	17	122	160.7	564.6	0	0	33
1988	1109	135.7	173	0	0	383	0	14	151	129	471	268	7	0
1989	468	197	101.4	0	0	385	0	1	187	166.4	621.7	579	0	0
1990	550	255.1	155.7	0	0	384	0	2	129	476	501	404	28.03	0
1991	688	150.7	192.9	0	0	237	0	0	129	483	570	438.6	40.38	0
1992	512	150.1	126.8	0	0	300	0	1	105	116.3	441.3	352.3	80.69	0
1993	581	261	71.1	0	0	295	0	29	121	209	558	218	154	0
1994	427	148	56	0	0	301	0	79	102	93	642.2	171.2	102.8	0
1995	387	138.7	57.52	0	0	249	0	72	120	260	661	219.3	237.7	0
1996	436	184.4	54.6	0	0	245	0	90	128	355	529	352.7	100.3	0
1997	330	221	26	0	0	250	0	59	153	190	762.3	283.9	99.12	0
1998	691	181	26	0	0	249	0	68	169	169	640	362.9	112.1	0
1999	365	170	62	0	0	248	0	44.49	154.2	103.5	673.1	308.4	164.5	0
2000	492	648.5	71.97	0	0	275.2	0	16.05	202	50.4	637.2	278	236.5	0
2001	506	515.6	29.92	0	0	195.9	0	15.79	121.9	249.3	1006	332.4	148.8	0
2002	575	178.8	44.75	0	0	207.7	0	28.13	68.49	519.5	1008	343	203.5	0
2003	57	320.3	75.95	0	0	265.4	0	83.99	97.57	314.6	676.6	256	193.1	0
2004	470	285.2	160.1	0	0	31.79	0	32.03	48.04	329	388.9	231.3	238.8	0
2005	265	194.7	128.6	0	0	178.3	0	8.43	45.51	170.4	256.7	290.3	250.7	0
2006	376	162.6	102.2	0	0	3.59	0	3	49.91	158.2	218.2	350.9	313.2	0
2007	277	236.2	88.44	0	0	27.95	0	3.59	39.8	398.6	235.4	198.9	213.3	0
2008	491.6	154.9	118.9	0	0	0	0	23.01	53.83	352.2	306.6	233.5	265.7	0
2009	162.2	154.2	121.6	0	0	11.44	0	23.46	83.8	143.3	717.2	160.4	266.6	0
2010	352.8	289.7	70.31	0	0	0	0	38.79	66.4	111.4	573.5	169.2	195	0
2011	577.6	280	26.88	0	0	0	0	26.26	100.3	173.4	419.8	141	200.6	0
2012	289.2	341	152.9	0	0	1.68	0	16.58	83.05	148.7	421.3	149.5	231.5	0
2013	316.7	259.6	55.12	0	0	42.54	0	11.37	69.56	115.3	250.8	150.3	226.7	0
2014	301.5	243.1	92.45	0	0	41.84	0	19.54	78.86	100	378.5	107.8	263.6	0
2015	346.6	242.4	62.4	0	0	38.85	0	6.47	102.9	112.1	582.3	115.2	311.8	0
2016	345.4	163.2	65.83	0	0	0	0	9.52	77.89	145.3	723.2	76.36	277.5	0
2017	345.8	180	45.64	0	0	0	0	12.63	98.98	141.8	657.9	87.52	281.3	0
2018	407	178.1	87.68	0	0	0	0	2.8	74.14	114	767.3	95.95	291	0
2019	406.3	186.7	43.87	0	0	0	0	3.91	155.8	181.8	798.6	119.3	364.5	0
2020	407.6	231.2	33.04	0	0	0	0.78	3.5	128	192.6	848.8	85.97	341.5	0

Table 5. Age specific error information in SS model.

Age class	*Age*	*Standard error*	*Cv*
0	0.5	0.14	0.28
1	1.5	0.41	0.27
2	2.5	0.54	0.22
3	3.5	0.62	0.18
4	4.5	0.73	0.16
5	5.5	0.75	0.14
6	6.5	0.89	0.14
7	7.5	1.07	0.14
8	8.5	1.09	0.13
9	9.5	1.14	0.12
10	10.5	1.22	0.12
11	11.5	1.34	0.12
12	12.5	1.52	0.12
13	13.5	1.85	0.14
14	14.5	2.04	0.14
15	15.5	1.76	0.11
16	16.5	1.66	0.10
17	17.5	1.44	0.08
18	18.5	1.53	0.08
19	19.5	2.2	0.11
20	20.5	2.31	0.11
21	21.5	2.42	0.11
22	22.5	2.54	0.11
23	23.5	2.65	0.11
24	24.5	2.76	0.11
25	25.5	2.87	0.11
26	26.5	2.99	0.11
27	27.5	3.10	0.11
28	28.5	3.21	0.11
29	29.5	3.32	0.11
30	30.5	3.44	0.11
31	31.5	3.55	0.11
32	32.5	3.66	0.11
33	33.5	3.77	0.11
34	34.5	3.89	0.11

Table 4. Table of otolith age-length pairs by sampling laboratory (DFO: Canada Department of Ocean and Fisheries, St Andrews Biological Station; PC: US NMFS Panama City Lab; UMaine: University of Maine; UMCES: University of Maryland Center for Environmental Sciences).

	WBFTagesAll.4.27 (full 2020 dataset, no exclusions or outliers removed)				WBFTagesWithSSgear (2017 dataset)				WBFTagesStrictUpdateRemoveEarly (Strict update dataset)			
year	DFO	PC	UMaine	UMCES	DFO	PC	UMaine	UMCES	DFO	PC	UMaine	UMCES
1973	1											
1974				2				2				2
1975	180			154				154				154
1976	342			68				68				68
1977	269			26				26				25
1978	315			97				97				96
1979	72											
1980	137											
1981	170											
1982	33											
1983	347											
1996				75				75				75
1997				34				34				33
1998				43				43				43
1999				21				21				21
2000				6				6				6
2002				54				54				54
2009		80				77	35			79		
2010	63	60	293		63	60	293		62	60	292	
2011	292	276	342	108	288	271	328	108	288	273	339	106
2012	288	237	147	143	289	235		143	284	235		142
2013	327	135	247	114	330	134		114	321	135		114
2014	298	207	290		297	205			296	206		
2015	254	169	144		245	164			254	169		
2016	338	274	293						338	272	287	
2017	512	243							499	240		
2018	439	248							437	247		
total	4677	1929	1756	945	1512	1146	656	945	2779	1916	918	939

not included in strict update dataset

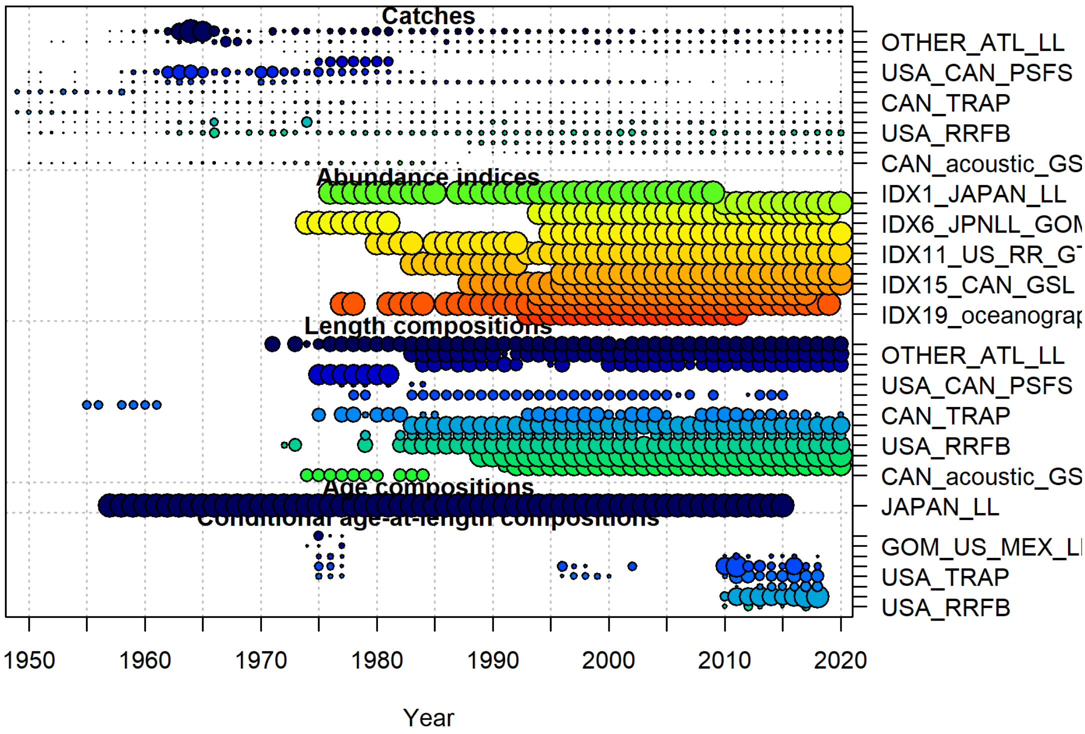

Figure 1. Time series of data inputs to the WBFT SS model.

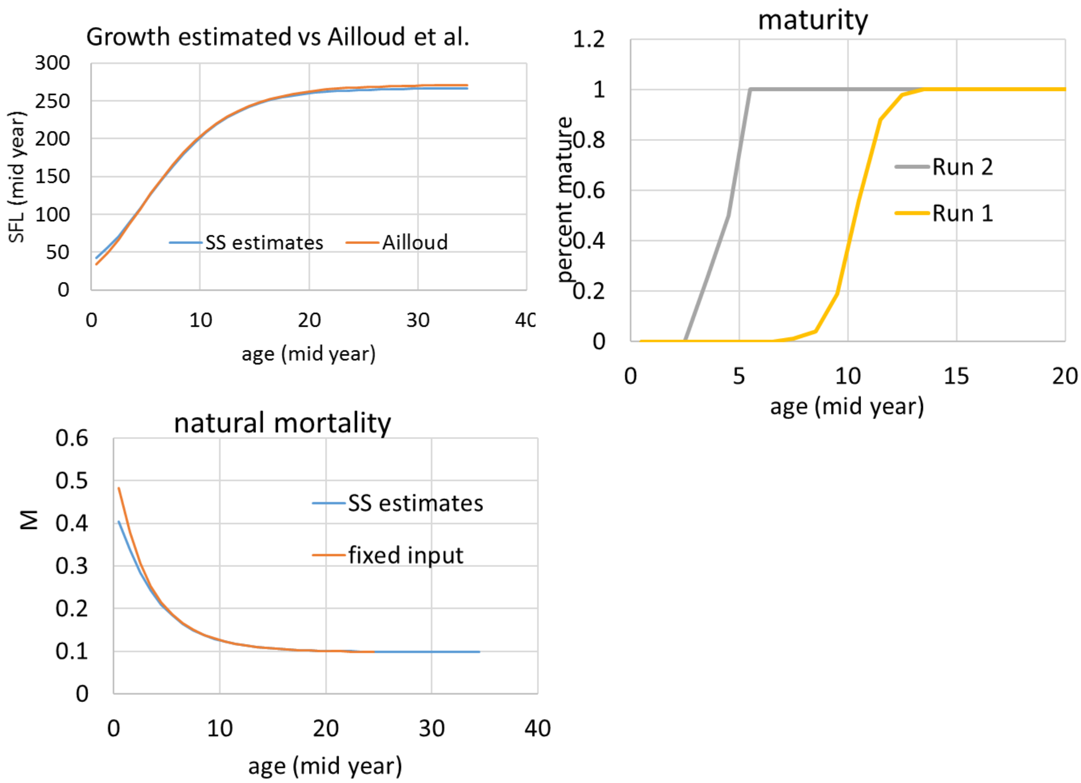

Figure 2. Estimated growth (from 2021 model) using a Richards function compared with Ailloud *et al* (2017) growth estimate, maturity and mortality at age vector as scaled by SS using M=0.01 on age 20 and scaled by the growth curve.

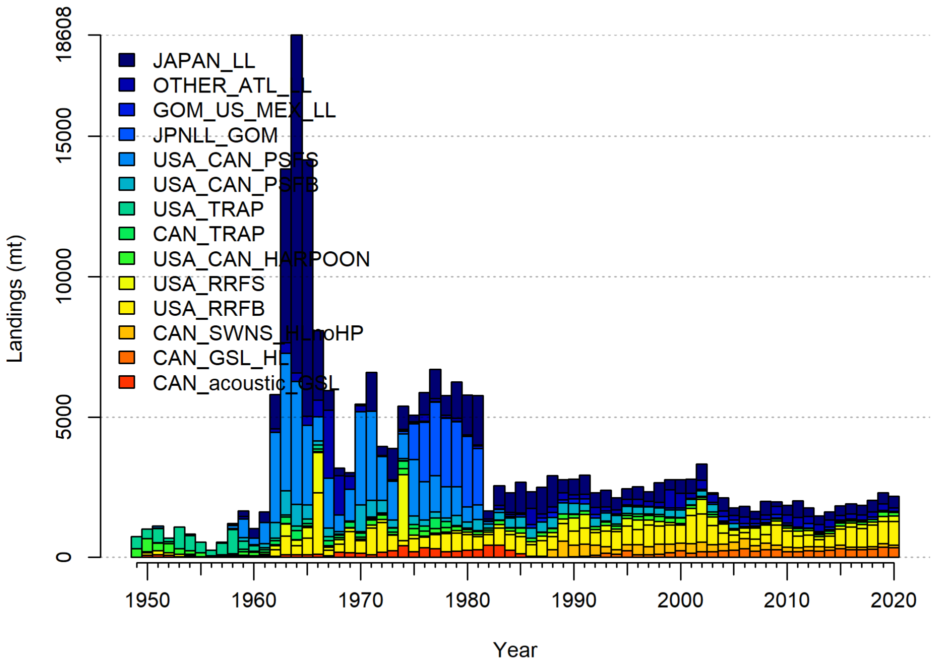

Figure 3. Task 1 catch by SS fleet by 2020.

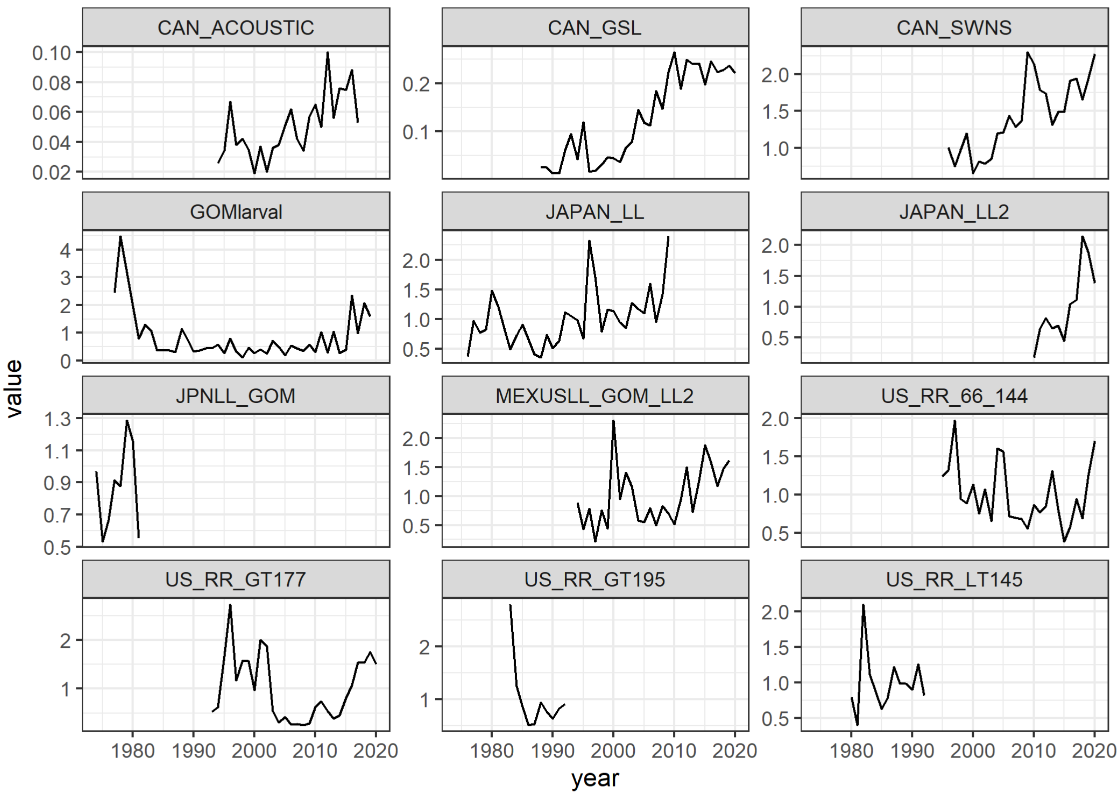

Figure 4. Indices used in 2021 assessment.

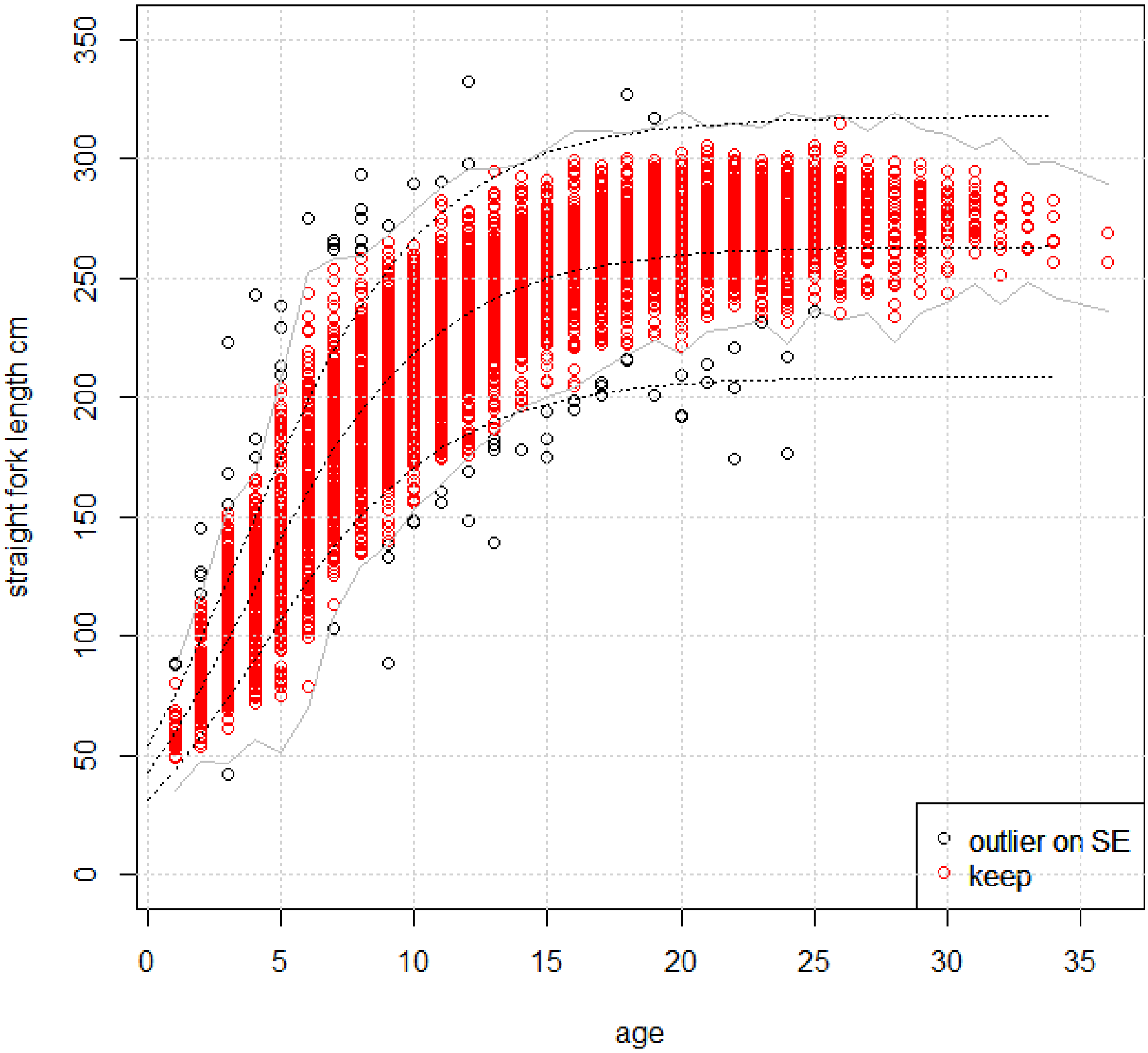

Figure 5. Straight fork length to age data. Black dots are observations that are +/- 3 standard deviations (gray lines) from the mean size at age. The dashed black lines are the mid year size at age as estimated by Stock Synthesis in 2017 +/- 3 standard deviations using the Richards growth function.

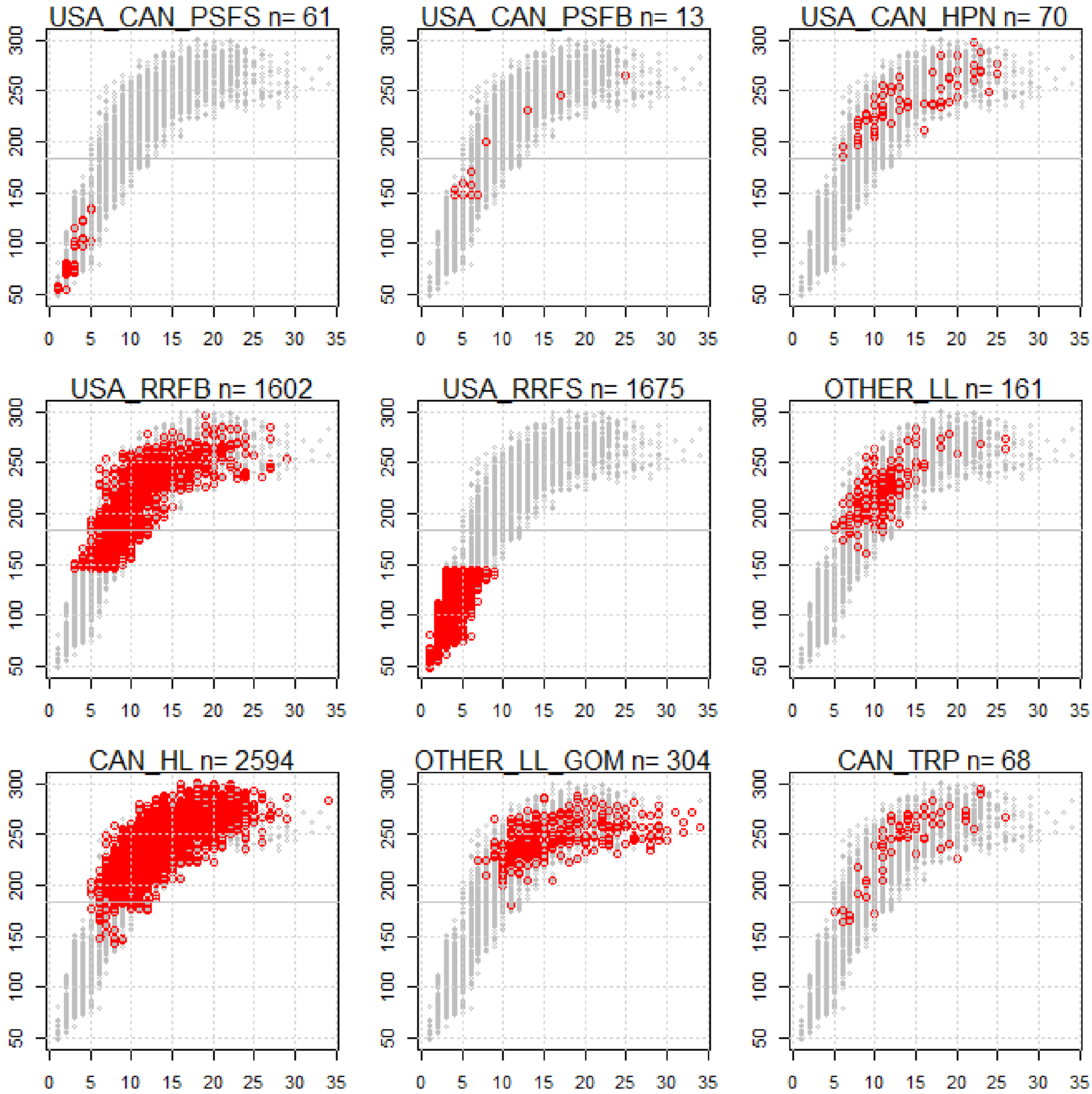

Figure 6. WBFT age-length data assigned (outliers exclude and only strict update data) to each fleet (red dots). Total age-length data are represented by the gray dots).

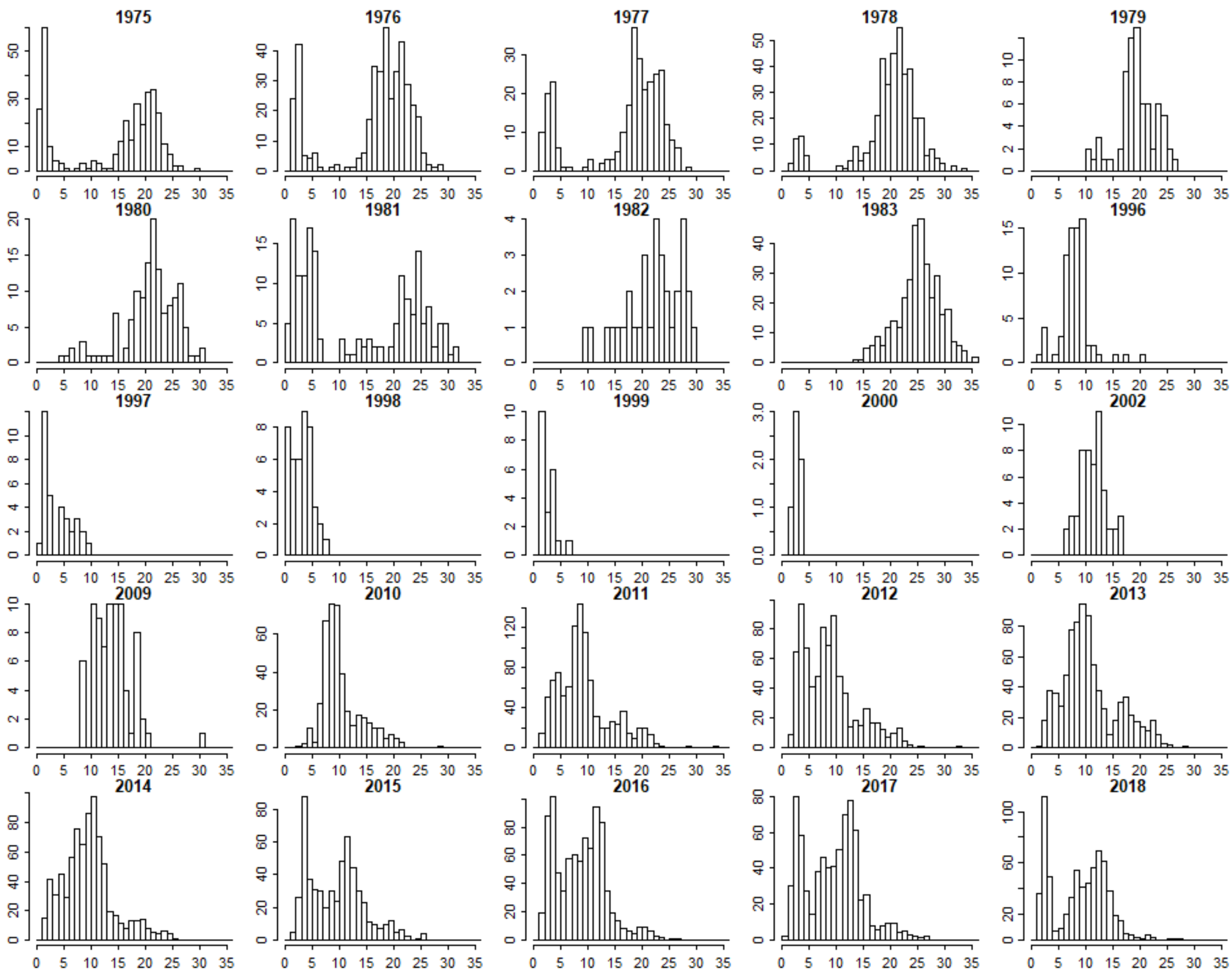

Figure 7. Histograms of age (Not just strict update dataset) data by year. Note that this is all gears and not necessarily representative of the all fleets and is not how the data are input to Stock Synthesis.

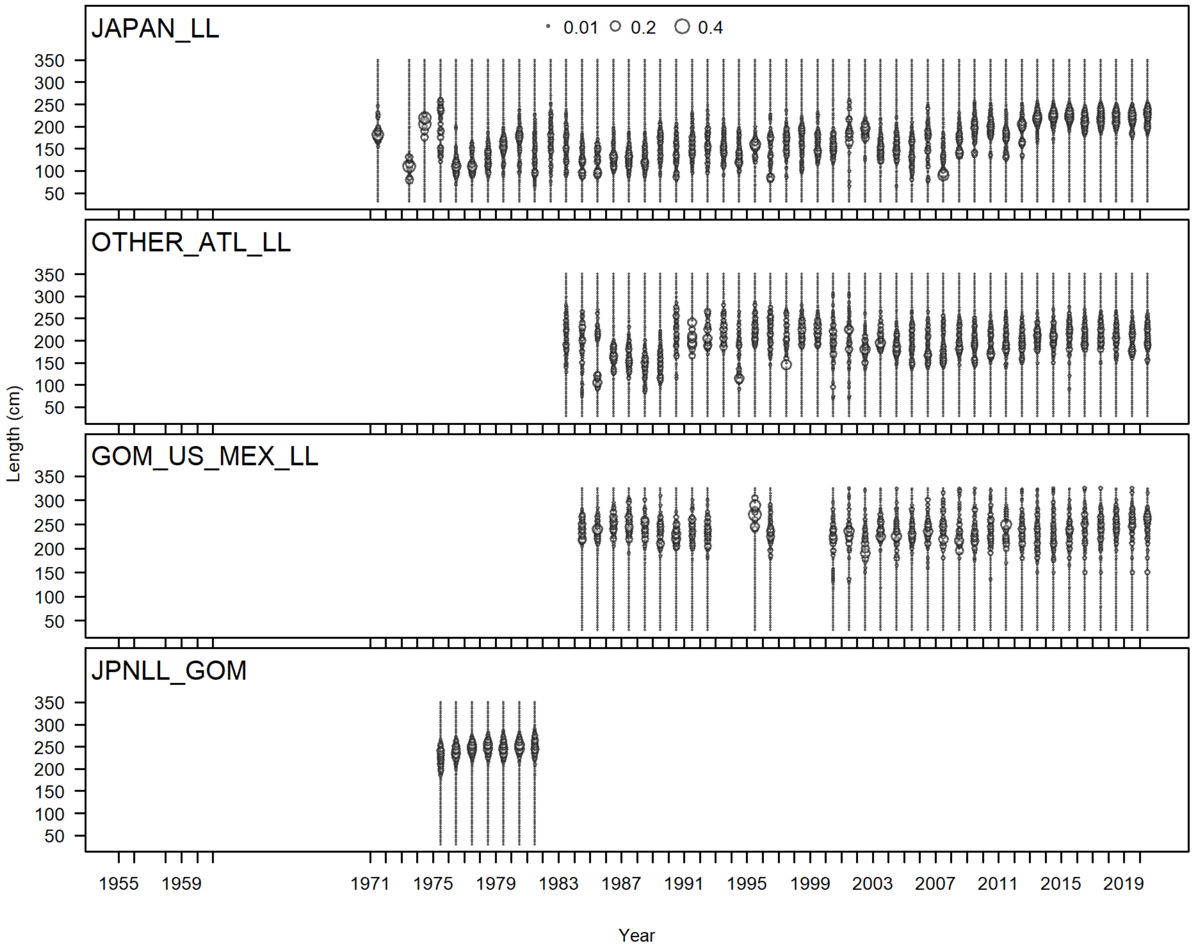

Figure 8. Length composition data, comparing across fleets (plot 1 of 4).

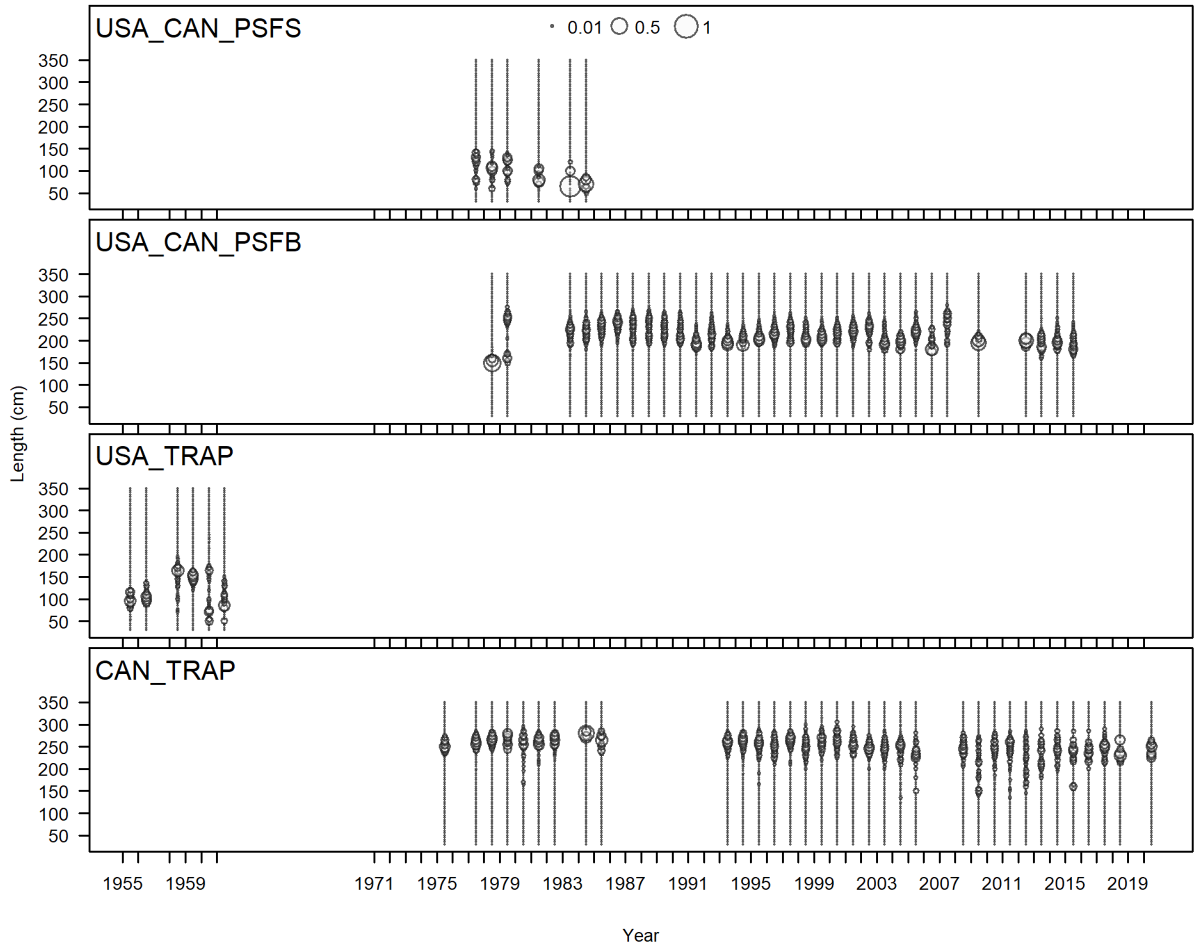

Figure 9. Length composition data, comparing across fleets (plot 2 of 4).

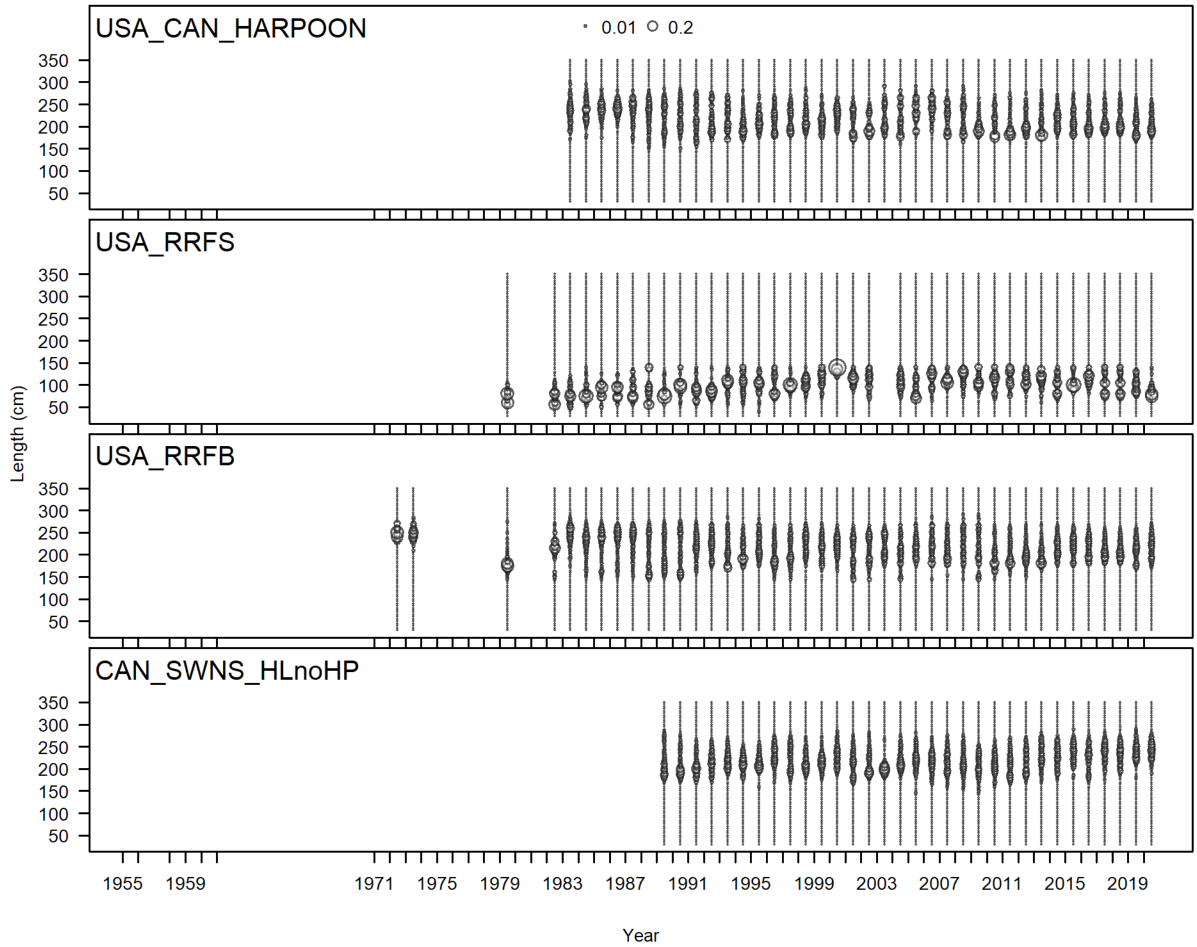

Figure 10. Length composition data, comparing across fleets (plot 3 of 4).

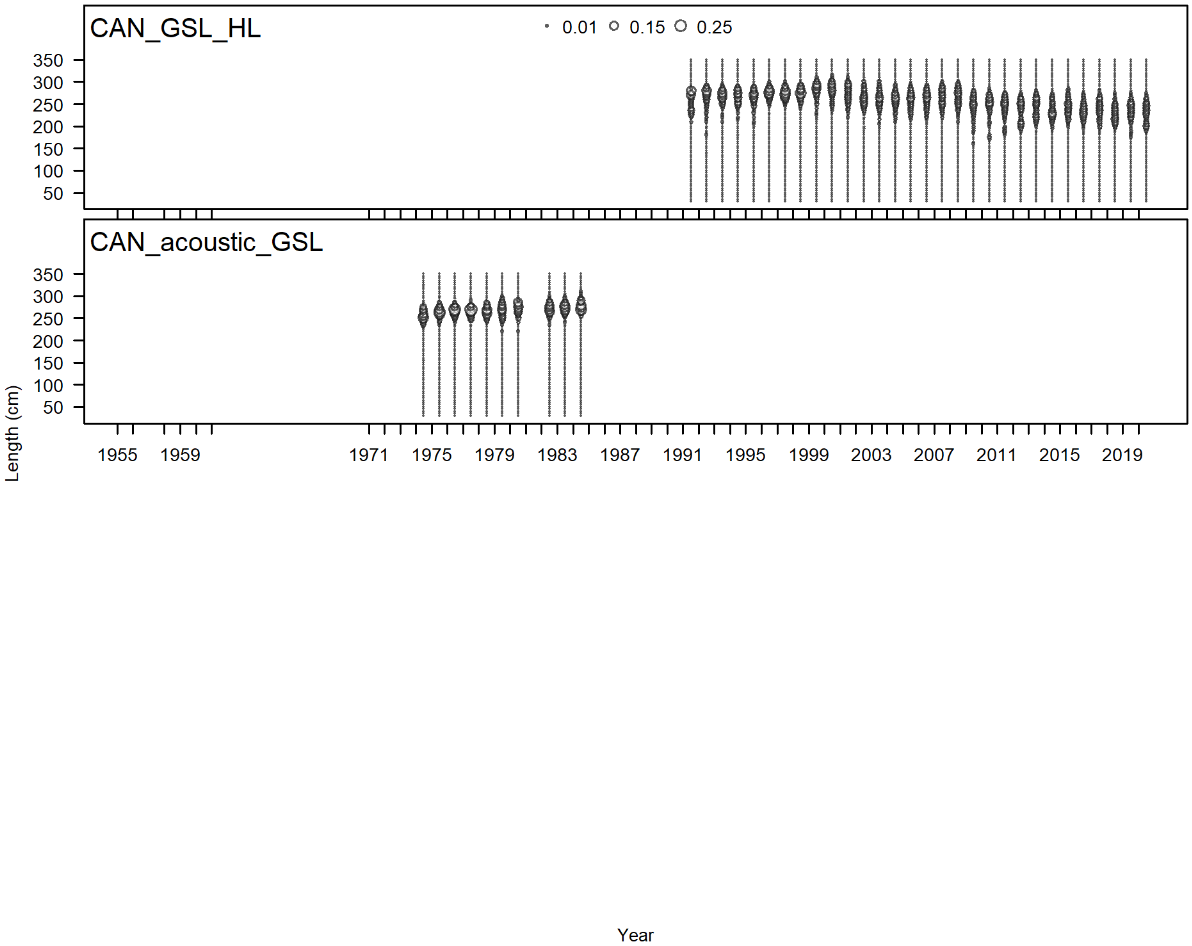

Figure 11. Length composition data, comparing across fleets (plot 4 of 4).