Preliminary stock assessment of Indian Ocean yellowfin tuna using Statistical-Catch-At-Size (SCAS) (1950-2020)[1]

October 2021

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Abstract

- We conducted preliminary yellowfin tuna stock assessments (1950-2020) using the SCAS software(Nishida *et al*)(2021). The primary objective of our assessments is to evaluate the current YFT stock status (2020) as a reference for SS3.
- Major differences between SCAS vs. SS3 are the time unit (annual vs. quarter) and tagging data (without vs. with). Other input information is nearly identical.
- We investigated the current stock status (in 2020) using wide ranges of grids by combining 6 factors, i.e., (a) 2 types of area models, i.e., whole (one) area (9 fleets) model and 4 sub-areas (21 fleets) model, (b) 3 types of CPUE, i.e., LL (longline), PSA (Purse Seine Adult) and PSJ (Purse Seine Juvenile), (c) 3 steepness values (0.7, 0.8 and 0.9), (d) 3 values for σ for the recruitment deviation (0.4, 0.6 and 0.8) and (e) 2 values for the likelihood weighting for CAS (0.1 and 0.01). The total number of grids is 108, i.e., 54 each for the whole area (9 fleets) model and the 4 sub-areas (21 fleets) model.
- Only 9 girds out of 108 produced convergences, i.e., 3 for the whole area model and 6 for the 4 areas model. Even numbers (9 grids) are small, this implies that 4 areas (21 fleets) model is likely more plausible.
- The representative result (the median point of 9 grids) suggested that YFT stock status in 2020 is the overfished and overfishing situation (TB_{2020}/TBmsy=0.74 and F_{2020}/Fmsy=1.84).
- However, we consider that F_{2020}/Fmsy=1.84 is implausible under the current situation. Thus, the results should be looked with a caution.

Contents

[1] *Submitted to the IOTC WPTT23 (AS) (October 25-30, 2021) (online)*

1. INTRODUCTION

In WPTT20(2018), yellowfin tuna stock assessment was conducted by Stock Synthesis (SS3) and the stock status and management advice were provided. In addition, Statistical-Catch-At-Age (SCAA) was also conducted as a reference (supporting information). Due to large uncertainties in Kobe II Strategic Risk Matrix in SS3, no concrete management advices could be provided. To overcome this problem, WPTT21(2019), WPTT22(2020) and WPTT23(DP) (May 2021) discussed details to improve the situation by making number of suggestions. By incorporating these suggestions, SS3 was conducted with new information in WPTT23 by Fu *et al* (IOTC-2021-WPTT23-12).

During the WPTT23(DP), it was noted that other models (ASPIC, JABBA and SCAS) plan to be implemented as references and results will be compared with SS3 in this WPTT23(2021) meeting. Such comparisons among different models with different specifications may be useful to some extent to evaluate the results of SS3.

As mentioned above, SCAA was used in 2018. However, for this time, SCAS was used as the preferable model to SCAA because estimated CAA in SCAA includes biases and uncertainties (Nishida et al 2018). Thus, it is more appropriate to apply SCAS using raw size frequency data by avoiding such biases and uncertainties. SCAS is a simpler model of SS3.

Two major different specifications between SCAS and SS3 are (a) SCAS is the annual basis model, while SS3 is quarterly based, and (b) SCAS does not use the tagging data (no spatial components), while SS3 does. Thus, results of SCAS are more comparable to SS3 than ASPIC and JABBA based on only catch and CPUE. In addition, we developed the menu driven SCAS software and applied to this YFT stock assessment. For details of the SCAS software, refer to the other information document (IOTC-WPTT23-INF03).

We tried to use the same input information as in SS3 (2018 and 2021) as much as possible for meaningful comparisons.

2. INPUT INFORMATION

In this section, we briefly describe input information for SCAS runs. For detail description of the input information, refer to the SS3 document by Fu *et al* (IOTC-2021-WPTT23-12).

2.1 Assumption of the stock structure and definition of sub areas.

We assume that yellowfin tuna in the Indian Ocean is one single stock. As in SS3, we use four sub-areas (R1-R4), where R1 has two divisions (R1a and R1b) (Fig. 1).

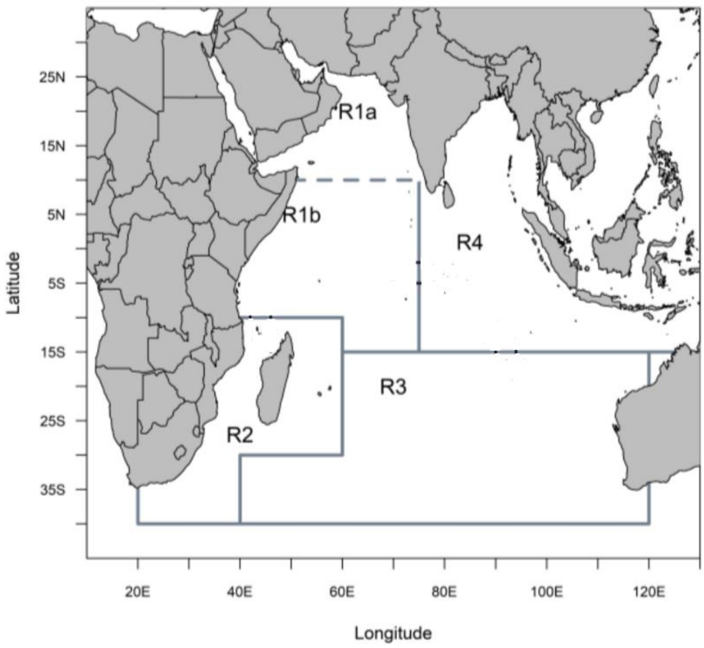


Fig.1 Four sub-areas in the Indian Ocean for YFT stock assessment defined by SS3 under the single stock structure hypothesis

2.2 Definition of fleets and catch trend by fleet

We set up 2 area models, (a) one (whole) with 9 fleets and (b) 4 sub-areas with 21 fleet as in SS3. The 4 sub areas model is the same as in SS3 (Fu *et al*, 2021). We used nominal catch from the published data (IOTC-2021-WPTT23(AS)-DATA03). Table 1 and 2 defines the fleet types and Figs.2-3 for annual catch trends by fleet for the one area model and the 4 sub areas models, respectively.

Table 1 Definition of 9 fleets used in the one (whole) area model

fleet #	gear type	code
f1	Pole and Line	BB
f2	Troll	TR
f3	Purse seine (Log school)	LS
f4	Others	OT
f5	Gillnet	GL
f6	Purse seine (Free school)	FS
f7	Handline	HD
f8	Longline (Fresh)	LF
f9	Longline (Frozen)	LL

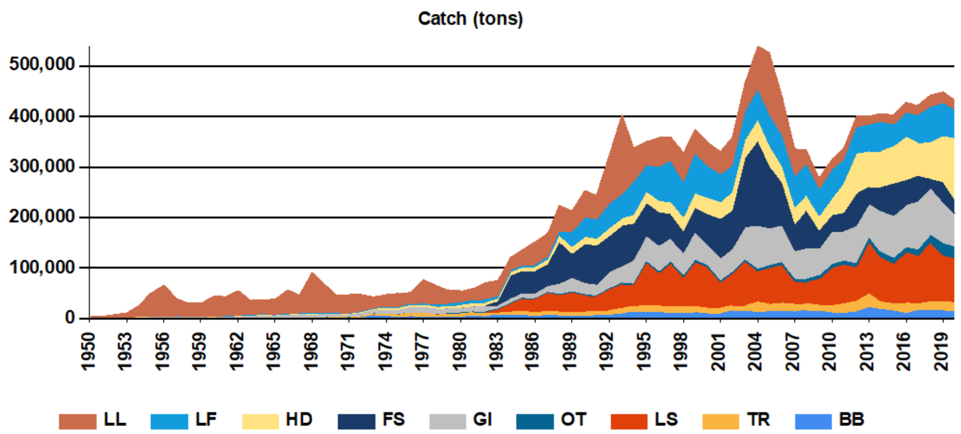


Fig. 2 Catch of 9 fleets in the one (whole) area model.

Table 2 Definition of 21 fleets used in the 4 sub-areas model

fleet #	area	gear type	code
f1	1	Gillnet	1_GI_1a
f2	1	Handline	2_HD_1a
f3	1	Longline (Frozen)	3_LL_1a
f4	1	Others	4_OT_1a
f5	1	Pole and Line	5_BB_1b
f6	1	Purse seine (Free school)	6_FS_1b
f7	1	Longline (Frozen)	7_LL_1b
f8	1	Purse seine (Log school)	8_LS_1b
f9	1	Troll	9_TR_1b
f10	2	Longline (Frozen)	10_LL_2
f11	3	Longline (Frozen)	11_LL_3
f12	4	Gillnet	12_GI_4
f13	4	Longline (frozen)	13_LL_4
f14	4	Others	14_OT_4
f15	4	Troll	15_TR_4
f16	2	Purse seine (Free school)	16_FS_2
f17	2	Purse seine (Log school)	17_LS_2
f18	2	Troll	18_TR_2
f19	4	Purse seine (Free school)	19_FS_4
f20	4	Purse seine (Log school)	20_LS_4
f21	4	Longline (Fresh)	21_LF_4

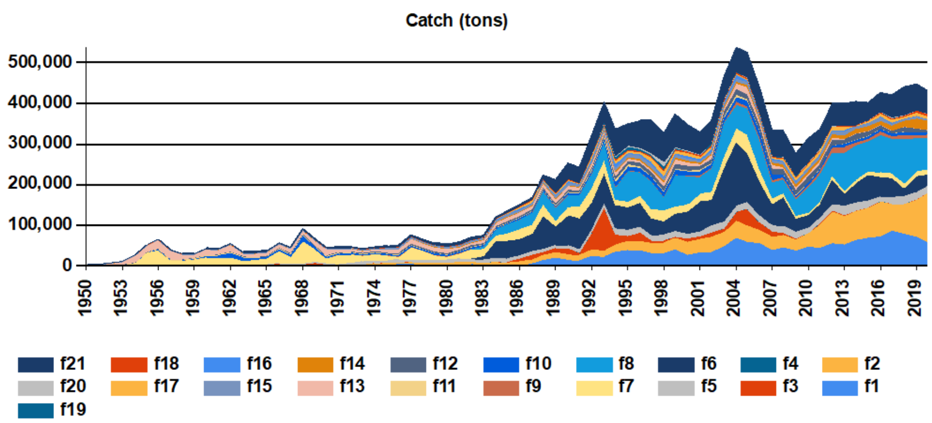


Fig. 3 Catch of 21 fleets used in the 4 sub-areas model

2.4 Standardized CPUE

Three types of standardized CPUE are available and published in the IOTC home page (IOTC-2021-WPTT23(AS)-DATA15-CPUE), i.e., Longline (1975-2020) by Kitakado et al (IOTC-2021-WPTT23(AS)-11), Purse seine (adult) (1991-20219) and Purse seine (juvenile) (1991-2018) by Guéry *et al* (IOTC-2021-WPTT23(AS)-10). Two outliers (2010 and 2018) in the PS (juvenile) CPUE were removed. Figs. 4 and 5 shows the trends of 3 CPUE for one area model and 4 sub-areas model respectively.

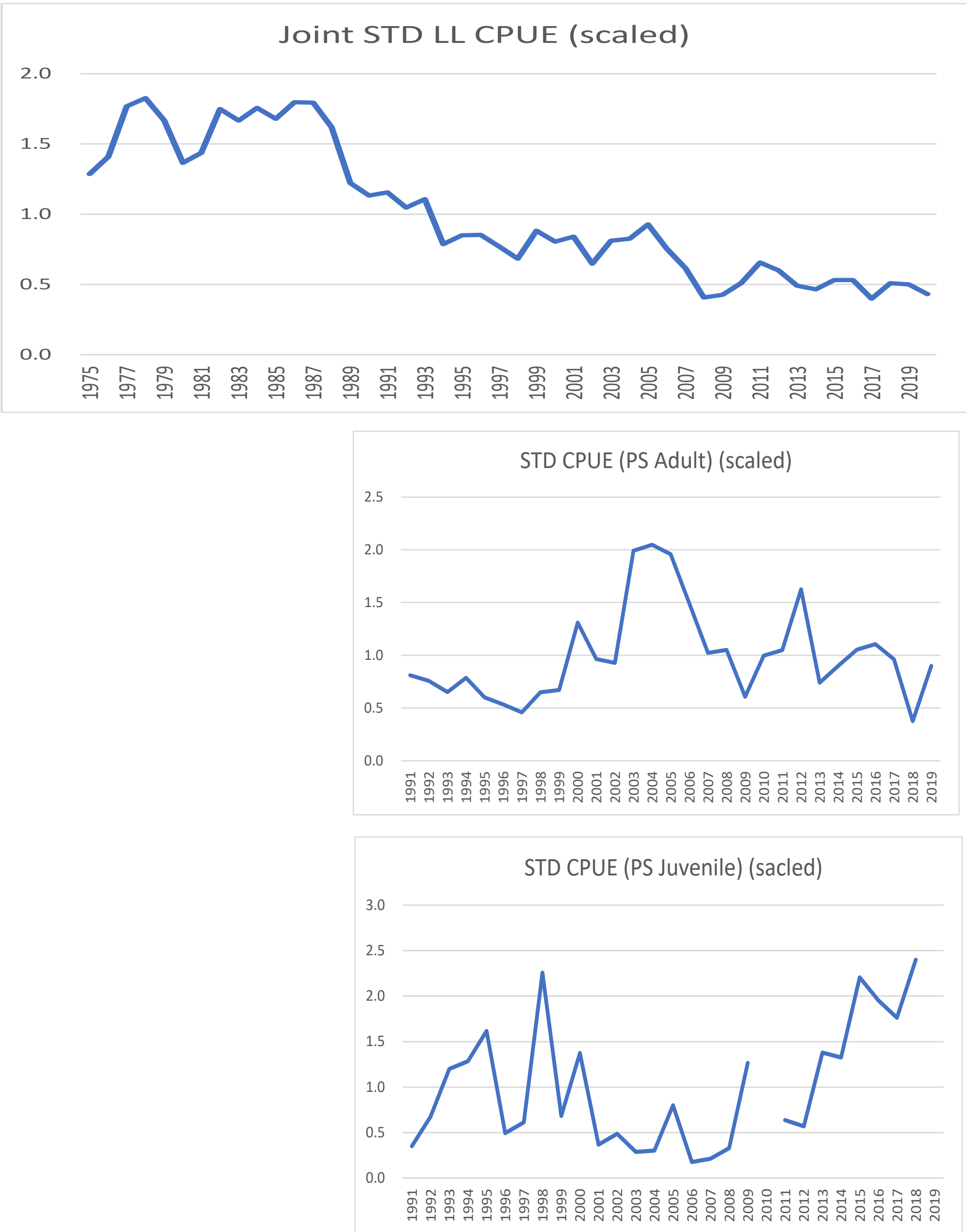
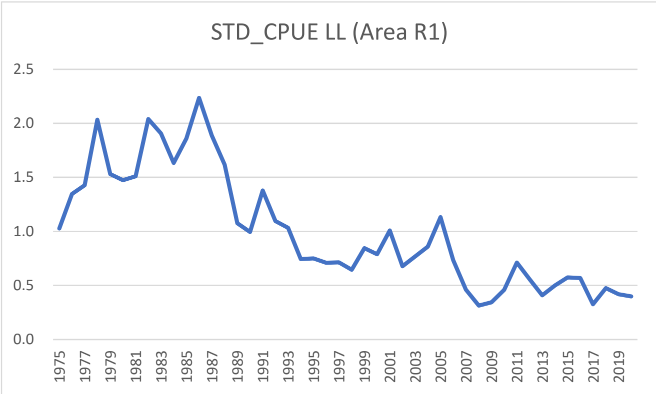
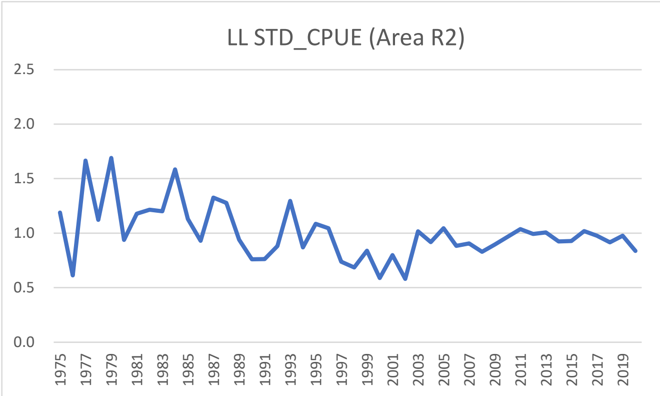
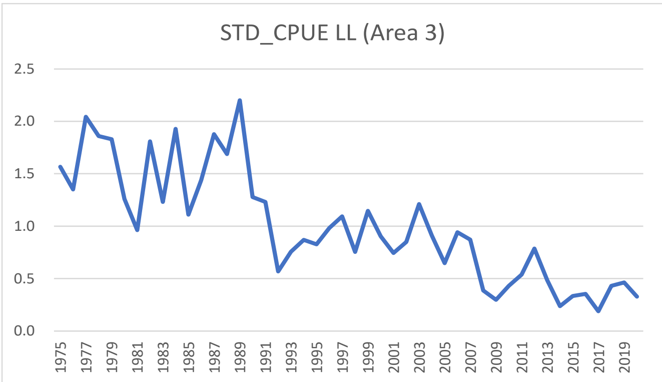


Fig. 4 Annual trends of three types of standardized CPUE used for the one area model (top: LL, middle: PS-adult and bottom: PS-juvenile)







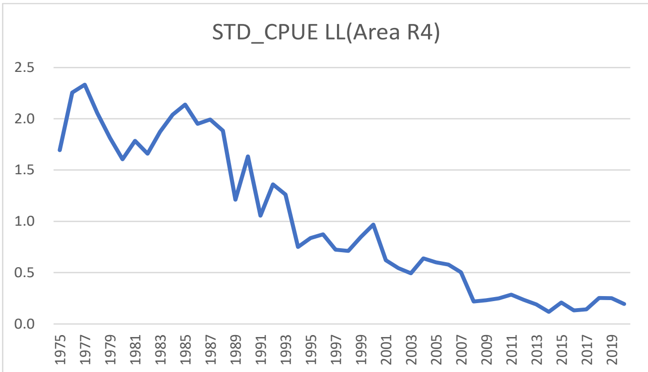


Fig. 5 Annual trends of standardized LL CPUE by area used for the 4 areas model

2.5 Biological information (Table 3)

Table 3 Summary on the biological input information to the SCAS.

Type	Input information to SCAS (annual based)	Sources
Size	10-198cm (4 cm class interval) by fleet ● For the one area (9 fleets) model, data for 9 fleets are available. ● For the 4 area (21 fleets) model, data for 19 fleets area available, while 2 TR fleets (9_TR_1b and 18_TR_2) are not available.	Secretariat IOTC-2021-WPTT23(AS)-DATA12
Selectivity	● LL and LF: Logistic model ● Other fleets: Double normal model *(Note) As the cubic spline model is not available in the current SCAS software, the double normal model is substituted for PSLS, while SS3 used cubic spline model.*	Fu et al (2018 & 2021) YFT SS3 assessment
LW relation	$W=aL^b$ where, a=2.9667 and b=2.459E-5	Secretariat IOTC-2016-WPDCS12-INF05
Growth equation	Ad hoc 2 stanza model based on the tag recapture data. Approximated by the von Bertalanffy growth equation (Loo=145cm, t0=0.024 and K＝0.438). This is because the current SCAS software cannot handle this ad hoc model,	Fonteneau, A. 2008. A working proposal for a Yellowfin growth curve to be used during the 2008 yellowfin stock assessment (IOTC-2008-WPTT-4).
Maturity-at-age	Age 0 0 Age 1 0.15 Age 2 0.79 Age 3 or older 1	Zudair, I., Murua, H., Grande, M., Bodin, N. (2013). Reproductive potential of yellowfin tuna in the western Indian Ocean. Fish. Bull. 111:252–264.
M (Natural mortality)	0 1.20 1 0.54 2 0.54 3 0.76 4 0.74 5 0.58 6 0.54 7+ 0.53	Fu et al (2018). Mid-point between M based on tagging data (IOTC) and M used by WCPFC.

2.6 Summary of catch, standardized CPUE and size data (Table 4)

Table 4 Summary of nominal catch, standardized CPUE and size data

Type	Fleet	Year	Authors	Source
Nominal catch	9 fleets (one area model) 21 fleets (4 area model)	1950-2020	Secretariat	● IOTC-2021-WPTT23(AS)-DATA03
Standardized CPUE	Longline	1975-2020	Kitakado et al (2021)	● IOTC-2021-WPTT23(AS)-DATA15-CPUE.
	Purse seine adult Purse seine juvenile	1991-2019	Guéry *et al (2021)*	
Size data	9 fleets (one area model) 21 fleets (4 area model)	1950-2020	Secretariat	● IOTC-2021-WPTT23(AS)-DATA11 Size frequency data - YFT ● IOTC-2021-WPTT23(AS)-DATA12 Size frequency data - reference file

2 Grids search

To search an optimum set of parameters, we set up 108 grids combining 5 parameters described as below:

(a) 2 areas (whole area model with 9 fleets and 4 sub-areas model with 21 fleets)
(b) 3 different standardized CPUE (LL, PS for adult and PS for Juvenile)
(c) 3 different σ for recruitment deviations (0.4, 0.6 and 0.8)
(d) 3 different steepness (0.7, 0.8 and 0.9)
(e) 2 different weightings for CAS (0.01 and 0.1)

Table 5a and 5b (first 4 columns) shows the grid list. In addition, we used the initial guess population size (male and female combined) as 270 (age 0) and 75 million fish (age 1) and 5.5 million tons (age 0 biomass). Default values for the other parameters were used as described in the SCAS manual (OTC-WPTT23-INF03).

3. Results

Using the SCAS software (IOTC-WPTT23-INF03), we conducted the batch jobs for the 108 grids(runs) to search parameters converged. Table 5a and 5b shows results of the grid searches. Only 9 grids(runs) were converged. We selected the median point (grid # A1-3 as the representative stock status in 2020 (Fig. 6). The result suggested that the stock status is overfished and overfishing situation, i.e., TB_{2020}/TBmsy=0.74 and F_{2020}/Fmsy=1.84. Fig.7 shows the Kobe plot, and Appendix 1 shows the results with some figures.

Table 5a Results the one area (9 fleets) model

(Note 1) Yellow makers indicate convergence (A and B), while no convergences, by “Warning – “ in Error Message.

(Note 2) Pink markers indicate that parameters are out of range.

CPUE	Run no.	CAS weight	Sigma (SR)	h (steepness)	TB0	TBmsy	TB (current)	MSY	Catch (current)	Depletion	TB/TBmsy	F/Fmsy	Error Message
					1,000 tons								
LL	A1-1	0.1	0.4	0.7	> 10,000	> 10,000	3,507	< 1	433	0.25	0.25	0.94	Warning -- Hessian does not appear to be positive definite
	A1-2	0.1	0.4	0.8	> 10,000	4,319	3,321	609	433	0.28	0.77	1.59	Warning -- Hessian does not appear to be positive definite
	A1-3	0.1	0.4	0.9	8,324	3,285	2,445	474	433	0.29	0.74	1.84	A
	A1-4	0.1	0.6	0.7	> 10,000	> 10,000	5,077	< 1	433	0.36	0.36	0.39	Warning -- Hessian does not appear to be positive definite
	A1-5	0.1	0.6	0.8	> 10,000	> 10,000	5,978	< 1	433	0.35	0.35	0.91	Warning -- Hessian does not appear to be positive definite
	A1-6	0.1	0.6	0.9	> 10,000	> 10,000	8,014	< 1	433	0.46	0.46	0.22	Warning -- Hessian does not appear to be positive definite
	A1-7	0.1	0.8	0.7	> 10,000	> 10,000	8,980	2,081	433	0.20	0.64	0.86	Warning -- Hessian does not appear to be positive definite
	A1-8	0.1	0.8	0.8	> 10,000	> 10,000	> 10,000	3,207	433	0.18	0.76	0.77	Warning -- Hessian does not appear to be positive definite
	A1-9	0.1	0.8	0.9	> 10,000	> 10,000	4,707	< 1	433	0.32	0.32	0.35	Warning -- Hessian does not appear to be positive definite
	A1-10	0.01	0.4	0.7	6,693	2,441	1,737	471	433	0.26	0.71	2.06	B
	A1-11	0.01	0.4	0.8	6,289	2,167	1,501	446	433	0.24	0.69	2.08	Warning -- Hessian does not appear to be positive definite
	A1-12	0.01	0.4	0.9	> 10,000	> 10,000	2,724	< 1	433	0.27	0.27	1.26	Warning -- Hessian does not appear to be positive definite
	A1-13	0.01	0.6	0.7	7,880	2,900	1,875	555	433	0.24	0.65	2.22	Warning -- Hessian does not appear to be positive definite
	A1-14	0.01	0.6	0.8	> 10,000	4,044	2,649	704	433	0.22	0.65	1.71	Warning -- Hessian does not appear to be positive definite
	A1-15	0.01	0.6	0.9	> 10,000	5,060	4,809	1,395	433	0.20	0.95	1.01	Warning -- Hessian does not appear to be positive definite
	A1-16	0.01	0.8	0.7	> 10,000	> 10,000	2,045	< 1	433	0.20	0.20	1.02	Warning -- Hessian does not appear to be positive definite
	A1-17	0.01	0.8	0.8	9,366	3,259	1,897	649	433	0.20	0.58	1.87	Warning -- Hessian does not appear to be positive definite
	A1-18	0.01	0.8	0.9	> 10,000	5,022	3,798	1,291	433	0.17	0.76	1.07	Warning -- Hessian does not appear to be positive definite
LL+PS(Adult)	A1-19	0.1	0.4	0.7	6,714	6,714	1,900	< 1	433	0.28	0.28	0.85	Warning -- Hessian does not appear to be positive definite
	A1-20	0.1	0.4	0.8	> 10,000	> 10,000	8,871	< 1	433	0.26	0.26	0.92	Warning -- Hessian does not appear to be positive definite
	A1-21	0.1	0.4	0.9	9,214	3,837	2,583	428	433	0.28	0.67	2.04	Warning -- Hessian does not appear to be positive definite
	A1-22	0.1	0.6	0.7	> 10,000	> 10,000	5,681	< 1	433	0.36	0.36	0.30	Warning -- Hessian does not appear to be positive definite
	A1-23	0.1	0.6	0.8	> 10,000	> 10,000	3,378	< 1	433	0.23	0.23	0.74	Warning -- Hessian does not appear to be positive definite
	A1-24	0.1	0.6	0.9	> 10,000	> 10,000	7,130	< 1	433	0.20	0.20	1.13	Warning -- Hessian does not appear to be positive definite
	A1-25	0.1	0.8	0.7	> 10,000	> 10,000	3,970	< 1	433	0.29	0.29	0.45	Warning -- Hessian does not appear to be positive definite
	A1-26	0.1	0.8	0.8	> 10,000	> 10,000	5,115	< 1	433	0.31	0.31	0.30	Warning -- Hessian does not appear to be positive definite
	A1-27	0.1	0.8	0.9	> 10,000	5,416	3,922	850	433	0.27	0.72	1.39	Warning -- Hessian does not appear to be positive definite
	A1-28	0.01	0.4	0.7	> 10,000	5,595	4,108	863	433	0.23	0.73	1.56	Warning -- Hessian does not appear to be positive definite
	A1-29	0.01	0.4	0.8	> 10,000	> 10,000	2,422	< 1	433	0.22	0.22	1.39	Warning -- Hessian does not appear to be positive definite
	A1-30	0.01	0.4	0.9	> 10,000	2,997	2,660	756	433	0.23	0.89	1.33	Warning -- Hessian does not appear to be positive definite
	A1-31	0.01	0.6	0.7	> 10,000	3,910	2,426	649	433	0.22	0.62	1.96	Warning -- Hessian does not appear to be positive definite
	A1-32	0.01	0.6	0.8	6,600	6,600	1,445	< 1	433	0.22	0.22	1.35	Warning -- Hessian does not appear to be positive definite
	A1-33	0.01	0.6	0.9	> 10,000	> 10,000	2,725	< 1	433	0.24	0.24	1.34	Warning -- Hessian does not appear to be positive definite
	A1-34	0.01	0.8	0.7	> 10,000	4,747	2,560	797	433	0.19	0.54	1.79	Warning -- Hessian does not appear to be positive definite
	A1-35	0.01	0.8	0.8	7,896	7,896	1,670	< 1	433	0.21	0.21	1.18	Warning -- Hessian does not appear to be positive definite
	A1-36	0.01	0.8	0.9	8,165	8,165	1,788	< 1	433	0.22	0.22	1.27	Warning -- Hessian does not appear to be positive definite
LL+PS(Adult) +PS(Juvenile)	A1-37	0.1	0.4	0.7	> 10,000	3,728	3,386	642	433	0.33	0.91	1.29	Warning -- Hessian does not appear to be positive definite
	A1-38	0.1	0.4	0.8	> 10,000	4,671	3,402	542	433	0.28	0.73	2.01	Warning -- Hessian does not appear to be positive definite
	A1-39	0.1	0.4	0.9	> 10,000	> 10,000	8,649	< 1	433	0.24	0.24	1.20	Warning -- Hessian does not appear to be positive definite
	A1-40	0.1	0.6	0.7	> 10,000	4,529	3,296	625	433	0.28	0.73	1.78	Warning -- Hessian does not appear to be positive definite
	A1-41	0.1	0.6	0.8	> 10,000	8,700	8,162	1,652	433	0.24	0.94	0.82	Warning -- Hessian does not appear to be positive definite
	A1-42	0.1	0.6	0.9	> 10,000	> 10,000	9,318	< 1	433	0.26	0.26	0.92	Warning -- Hessian does not appear to be positive definite
	A1-43	0.1	0.8	0.7	> 10,000	5,382	3,603	803	433	0.26	0.67	1.37	Warning -- Hessian does not appear to be positive definite
	A1-44	0.1	0.8	0.8	> 10,000	5,760	4,994	832	433	0.33	0.87	1.43	Warning -- Hessian does not appear to be positive definite
	A1-45	0.1	0.8	0.9	> 10,000	4,121	3,019	797	433	0.26	0.73	1.28	Warning -- Hessian does not appear to be positive definite
	A1-46	0.01	0.4	0.7	> 10,000	4,209	3,072	653	433	0.24	0.73	1.79	Warning -- Hessian does not appear to be positive definite
	A1-47	0.01	0.4	0.8	4,810	1,778	1,387	395	433	0.29	0.78	2.20	C
	A1-48	0.01	0.4	0.9	8,158	3,260	2,038	402	433	0.25	0.63	3.29	Warning -- Hessian does not appear to be positive definite
	A1-49	0.01	0.6	0.7	> 10,000	7,436	5,914	1,094	433	0.24	0.80	1.54	Warning -- Hessian does not appear to be positive definite
	A1-50	0.01	0.6	0.8	> 10,000	4,810	4,160	915	433	0.24	0.86	1.45	Warning -- Hessian does not appear to be positive definite
	A1-51	0.01	0.6	0.9	7,939	7,939	1,899	< 1	433	0.24	0.24	2.45	Warning -- Hessian does not appear to be positive definite
	A1-52	0.01	0.8	0.7	> 10,000	5,220	3,057	769	433	0.20	0.59	1.94	Warning -- Hessian does not appear to be positive definite
	A1-53	0.01	0.8	0.8	> 10,000	3,495	2,602	645	433	0.21	0.74	2.37	Warning -- Hessian does not appear to be positive definite
	A1-54	0.01	0.8	0.9	> 10,000	3,095	2,786	726	433	0.21	0.90	2.05	Warning -- Hessian does not appear to be positive definite

Table 5b Results of the four sub-areas (21 fleets) model

(Note 1) Yellow makers indicate convergence (C-I), while no convergences, by "Warning – " in Error Message.

(Note 2) Pink markers indicate that parameters are out of range.

CPUE	Run no.	CAS weight	Sigma (SR)	h (steepness)	TB0	TBmsy	TB (current)	MSY	Catch (current)	Depletion	TB/TBmsy	F/Fmsy	Error Message
					1,000 tons								
LL	A4-1	0.1	0.4	0.7	> 10,000	6,857	3,414	1,144	433	0	0.50	1.20	Warning -- Hessian does not appear to be positive definite
	A4-2	0.1	0.4	0.8	> 10,000	5,431	3,001	900	433	0	0.55	1.49	Warning -- Hessian does not appear to be positive definite
	A4-3	0.1	0.4	0.9	7,593	2,783	1,838	562	433	0	0.66	2.39	Warning -- Hessian does not appear to be positive definite
	A4-4	0.1	0.6	0.7	7,854	2,972	2,176	597	433	0	0.73	1.57	Warning -- Hessian does not appear to be positive definite
	A4-5	0.1	0.6	0.8	> 10,000	6,963	3,175	1,272	433	0	0.46	1.22	Warning -- Hessian does not appear to be positive definite
	A4-6	0.1	0.6	0.9	8,110	2,967	2,025	602	433	0	0.68	2.07	Warning -- Hessian does not appear to be positive definite
	A4-7	0.1	0.8	0.7	> 10,000	3,867	2,324	745	433	0	0.60	1.70	Warning -- Hessian does not appear to be positive definite
	A4-8	0.1	0.8	0.8	> 10,000	3,875	2,476	841	433	0	0.64	1.29	Warning -- Hessian does not appear to be positive definite
	A4-9	0.1	0.8	0.9	9,737	3,355	2,019	790	433	0	0.60	1.72	D
	A4-10	0.01	0.4	0.7	4,701	1,704	810	577	433	0	0.47	1.32	Warning -- Hessian does not appear to be positive definite
	A4-11	0.01	0.4	0.8	5,130	1,788	829	595	433	0	0.46	1.68	Warning -- Hessian does not appear to be positive definite
	A4-12	0.01	0.4	0.9	> 10,000	4,255	1,799	1,056	433	0	0.42	2.73	Warning -- Hessian does not appear to be positive definite
	A4-13	0.01	0.6	0.7	4,836	3,171	696	201	433	0	0.22	1.17	Warning -- Hessian does not appear to be positive definite
	A4-14	0.01	0.6	0.8	5,502	1,877	722	657	433	0	0.38	2.05	Warning -- Hessian does not appear to be positive definite
	A4-15	0.01	0.6	0.9	5,545	5,545	699	< 1	433	0	0.13	2.90	Warning -- Hessian does not appear to be positive definite
	A4-16	0.01	0.8	0.7	6,545	2,447	617	709	433	0	0.25	2.13	Warning -- Hessian does not appear to be positive definite
	A4-17	0.01	0.8	0.8	5,189	1,815	595	631	433	0	0.33	1.61	Warning -- Hessian does not appear to be positive definite
	A4-18	0.01	0.8	0.9	8,158	2,793	756	902	433	0	0.27	1.93	E
LL+PS(Adult)	A4-19	0.1	0.4	0.7	6,447	2,555	1,773	400	433	0	0.69	3.51	Warning -- Hessian does not appear to be positive definite
	A4-20	0.1	0.4	0.8	6,691	2,597	1,778	441	433	0	0.68	3.14	Warning -- Hessian does not appear to be positive definite
	A4-21	0.1	0.4	0.9	> 10,000	5,203	3,078	1,162	433	0	0.59	1.09	Warning -- Hessian does not appear to be positive definite
	A4-22	0.1	0.6	0.7	> 10,000	7,883	3,568	1,798	433	0	0.45	1.97	Warning -- Hessian does not appear to be positive definite
	A4-23	0.1	0.6	0.8	> 10,000	3,998	1,907	707	433	0	0.48	2.57	Warning -- Hessian does not appear to be positive definite
	A4-24	0.1	0.6	0.9	> 10,000	6,767	3,345	1,676	433	0	0.49	0.93	Warning -- Hessian does not appear to be positive definite
	A4-25	0.1	0.8	0.7	> 10,000	> 10,000	> 10,000	< 1	433	> 10	> 10	0.00	Warning -- Hessian does not appear to be positive definite
	A4-26	0.1	0.8	0.8	8,612	8,612	2,135	< 1	433	0	0.25	0.84	Warning -- Hessian does not appear to be positive definite
	A4-27	0.1	0.8	0.9	> 10,000	6,017	2,607	1,454	433	0	0.43	1.12	Warning -- Hessian does not appear to be positive definite
	A4-28	0.01	0.4	0.7	> 10,000	> 10,000	8,158	5,056	433	0	0.46	2.30	Warning -- Hessian does not appear to be positive definite
	A4-29	0.01	0.4	0.8	7,328	4,035	1,956	999	433	0	0.48	2.21	Warning -- Hessian does not appear to be positive definite
	A4-30	0.01	0.4	0.9	> 10,000	> 10,000	5,110	3,304	433	0	0.37	2.16	Warning -- Hessian does not appear to be positive definite
	A4-31	0.01	0.6	0.7	6,446	2,431	924	815	433	0	0.38	1.68	Warning -- Hessian does not appear to be positive definite
	A4-32	0.01	0.6	0.8	> 10,000	> 10,000	6,586	4,490	433	0	0.40	2.17	Warning -- Hessian does not appear to be positive definite
	A4-33	0.01	0.6	0.9	5,570	3,003	1,499	722	433	0	0.50	1.45	Warning -- Hessian does not appear to be positive definite
	A4-34	0.01	0.8	0.7	4,017	1,438	622	527	433	0	0.43	2.26	Warning -- Hessian does not appear to be positive definite
	A4-35	0.01	0.8	0.8	8,792	3,319	998	966	433	0	0.30	3.54	Warning -- Hessian does not appear to be positive definite
	A4-36	0.01	0.8	0.9	> 10,000	8,686	2,652	1,853	433	0	0.31	2.45	Warning -- Hessian does not appear to be positive definite
LL+PS(Adult) +PS(Juvenile)	A4-37	0.1	0.4	0.7	7,671	3,137	1,979	414	433	0	0.63	3.03	Warning -- Hessian does not appear to be positive definite
	A4-38	0.1	0.4	0.8	5,800	2,189	1,637	436	433	0	0.75	2.52	Warning -- Hessian does not appear to be positive definite
	A4-39	0.1	0.4	0.9	5,592	2,107	1,600	391	433	0	0.76	3.31	F
	A4-40	0.1	0.6	0.7	7,102	2,820	2,168	459	433	0	0.77	2.20	G
	A4-41	0.1	0.6	0.8	9,481	3,409	2,013	639	433	0	0.59	2.24	Warning -- Hessian does not appear to be positive definite
	A4-42	0.1	0.6	0.9	5,627	2,070	1,557	472	433	0	0.75	1.91	Warning -- Hessian does not appear to be positive definite
	A4-43	0.1	0.8	0.7	> 10,000	7,283	2,676	1,167	433	0	0.37	1.61	Warning -- Hessian does not appear to be positive definite
	A4-44	0.1	0.8	0.8	6,841	2,487	1,655	632	433	0	0.67	1.30	Warning -- Hessian does not appear to be positive definite
	A4-45	0.1	0.8	0.9	7,607	2,659	1,886	701	433	0	0.71	1.27	H
	A4-46	0.01	0.4	0.7	> 10,000	7,025	4,014	1,622	433	0	0.57	2.22	Warning -- Hessian does not appear to be positive definite
	A4-47	0.01	0.4	0.8	5,402	2,782	1,459	728	433	0	0.52	1.58	Warning -- Hessian does not appear to be positive definite
	A4-48	0.01	0.4	0.9	7,242	4,041	2,439	1,046	433	0	0.60	1.45	I
	A4-49	0.01	0.6	0.7	> 10,000	> 10,000	5,801	2,486	433	0	0.49	2.03	Warning -- Hessian does not appear to be positive definite
	A4-50	0.01	0.6	0.8	5,635	2,126	1,383	863	433	0	0.65	1.51	J
	A4-51	0.01	0.6	0.9	7,803	3,202	2,127	1,245	433	0	0.66	1.57	Warning -- Hessian does not appear to be positive definite
	A4-52	0.01	0.8	0.7	8,292	8,292	1,619	< 1	433	0	0.20	2.30	Warning -- Hessian does not appear to be positive definite
	A4-53	0.01	0.8	0.8	> 10,000	5,899	2,567	1,809	433	0	0.44	2.14	Warning -- Hessian does not appear to be positive definite
	A4-54	0.01	0.8	0.9	> 10,000	> 10,000	8,328	4,491	433	0	0.51	1.95	Warning -- Hessian does not appear to be positive definite

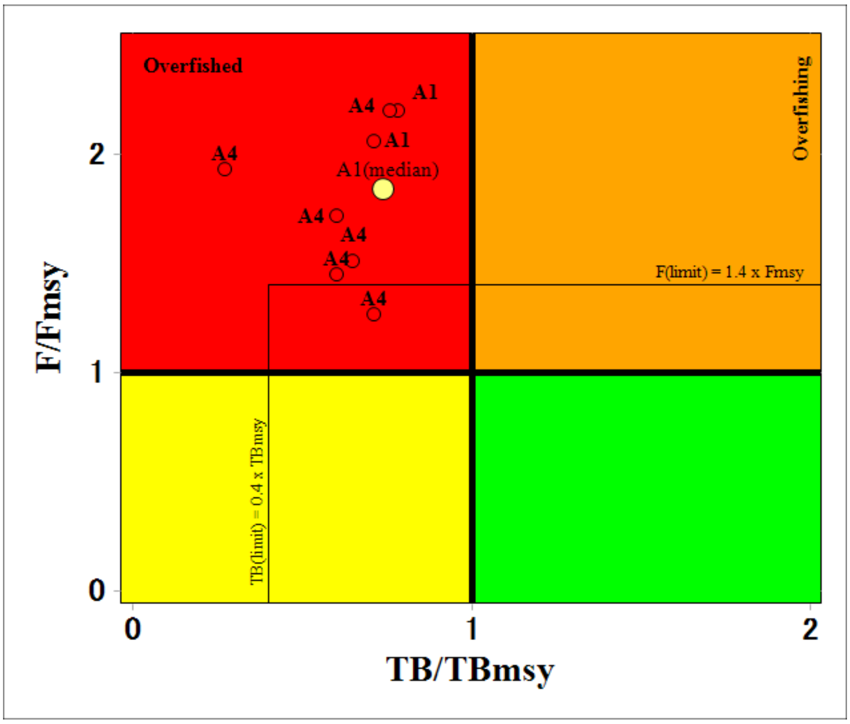


Fig. 6 YFT stock status (Kobe plot) (2020) showing 9 converged grids(runs) and the median point by the yellow dot.

(Note) Area model A1: One area (9 fleets) model and A4: 4 sub-areas (21 fleets) model.

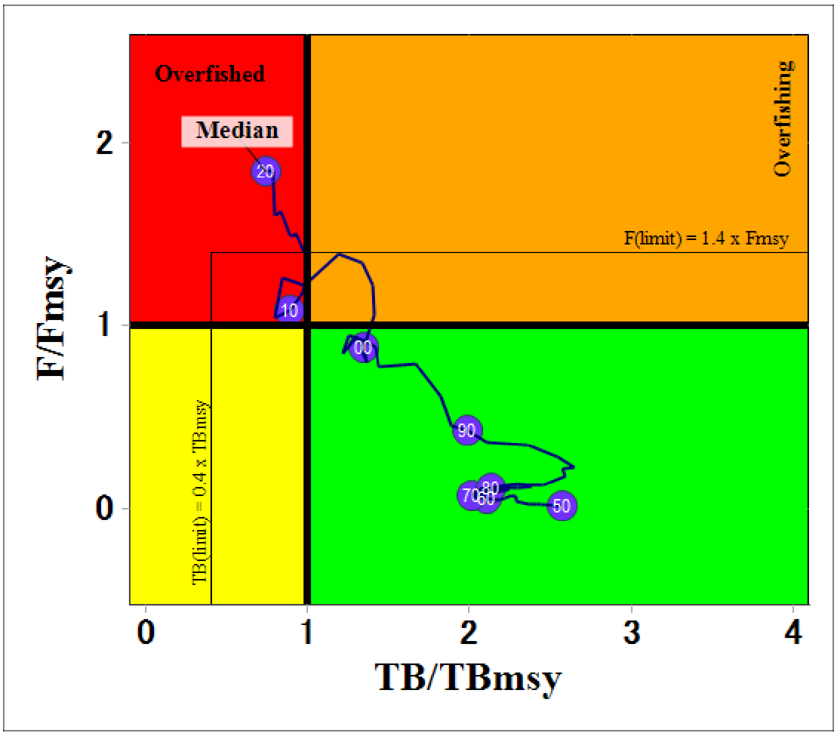


Fig. 7 YFT Stock status trajectories (Kobe plot) of the median among the 9 converged runs (grids)

4. Discussion

The aim of our stock assessment is to provide plausible stock status as reference for SS3. Thus we tries to use the same data as in SS3 and mainly explored the stock status (point estimate) using large grids (108) by combining 5 factors (area, CPUE, σ , steepness and weighting for CAS). However, only 9 grids produced convergences and we define the median point as the representative stock status in 2020, i.e., F_{2020}/Fmsy=1.84 with TB_{2020}/TBmsy=0.74 (situation of overfished and overfishing).

We consider that F_{2020}/Fmsy=1.84 is implausible under the current situation. We consider that there are likely four potential causes on "less numbers of convergences" and "high F_{2020}/Fmsy", i.e., (a) usages of one set of initial population seeding values, (b) underestimated MSY (see the 2nd graph, page 15), (c) fitness problems of size frequency data on three fleets (f5_Gillnet, f6_PSFS and f7_handline, see page 21) and/or (d) other unforeseen reasons. (b) and (c) may be caused by (a). Thus, usages of different seeding values may solve these problems. Therefore, the SCAS results for this time need be looked at a caution.

ACKNOWLEDGEMENTS

We sincerely thank to the IOTC Secretariat to provide the data used in the SCAS. We also appreciate Dan Fu (Secretariat) to assist relevant input information in SS3.

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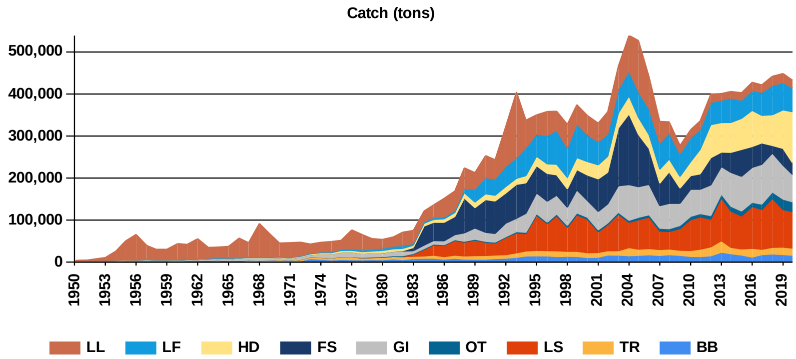
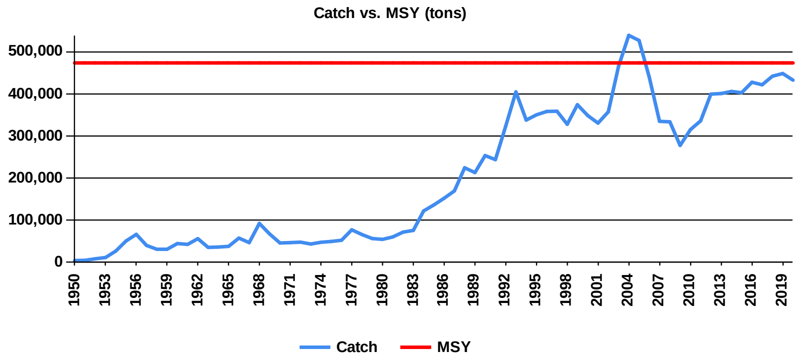
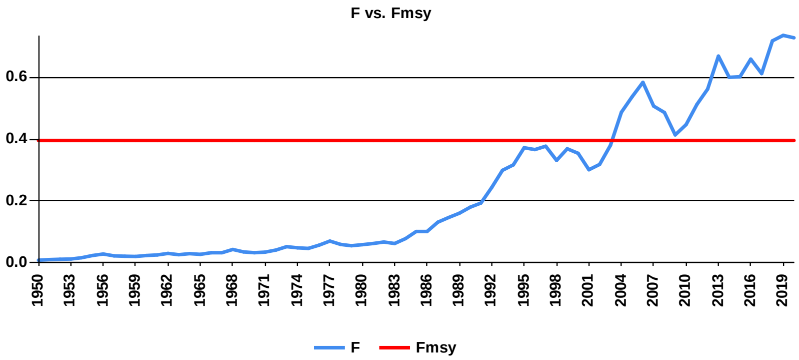
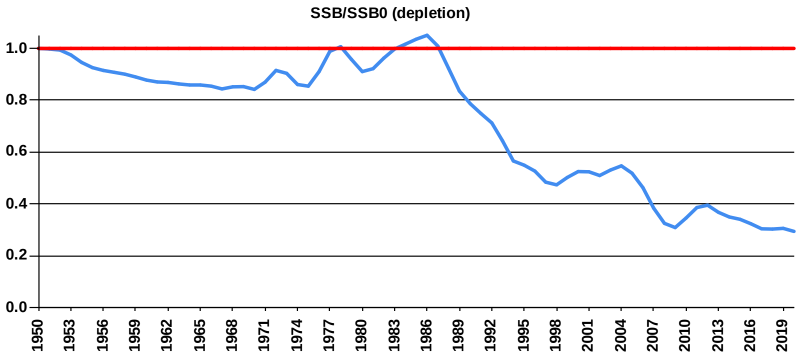
APPENDIX A. Results of the SCAS stock assessment

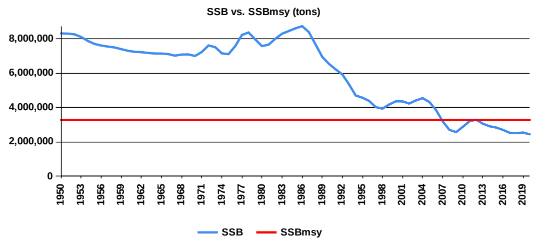
(Median of 9 converged grids) (refer to Figs. 5 and 6)

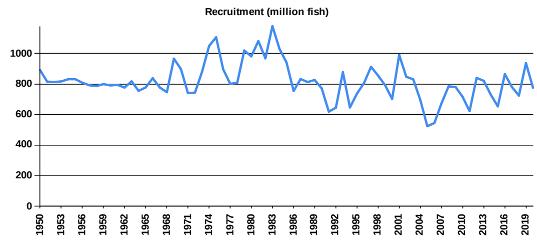


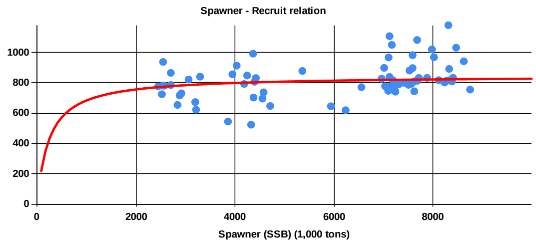


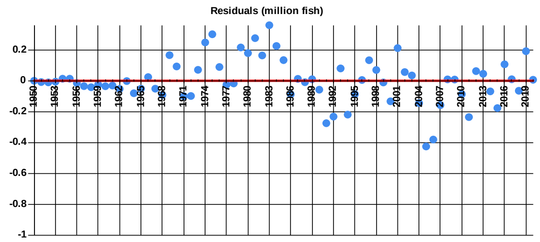


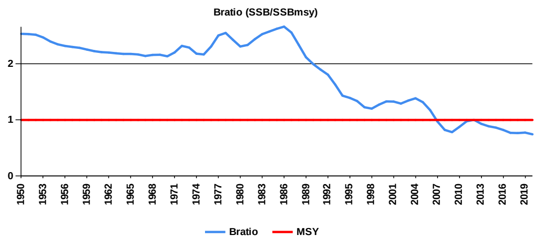


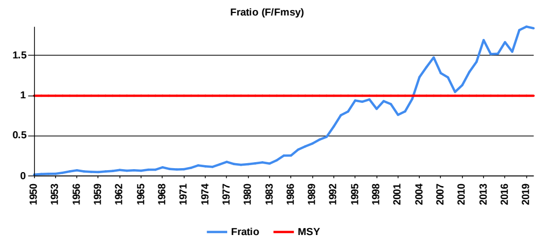

SSB vs. SSBmsy (tons)
SSB
SSBmsy

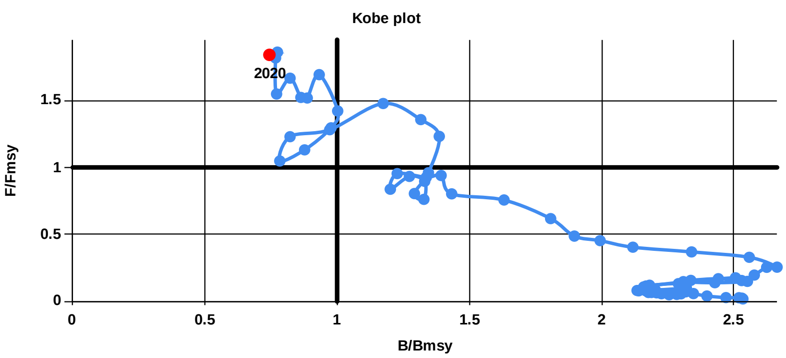

Recruitment (million fish)


Spawner - Recruit relation
Spawner (SSB) (1,000 tons)

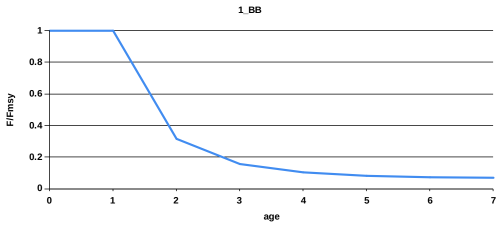

Residuals (million fish)

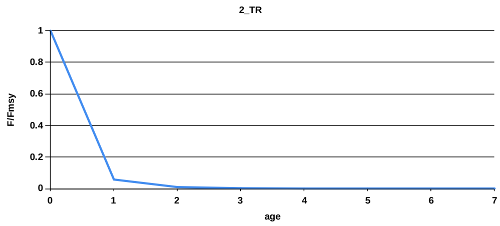

Bratio (SSB/SSBmsy)
Bratio
MSY

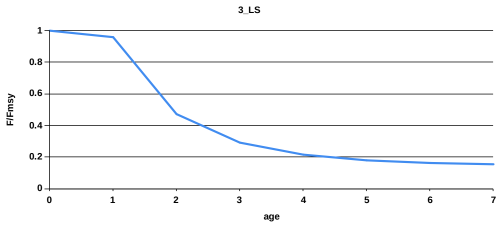

Fratio (F/Fmsy)
Fratio
MSY

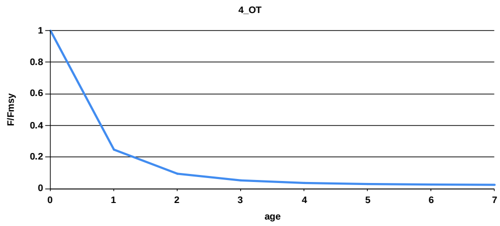

Kobe plot
2020
F/Fmsy
B/Bmsy

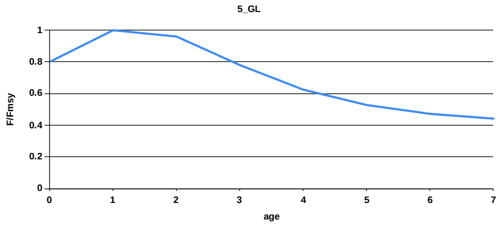
Selectivity

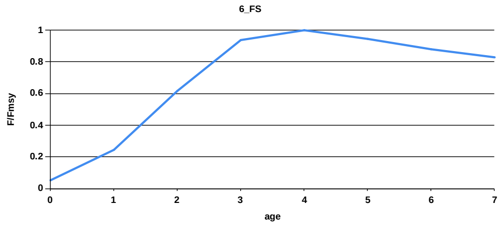


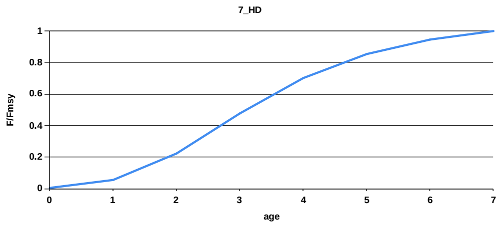


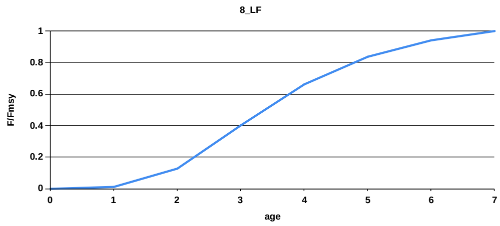


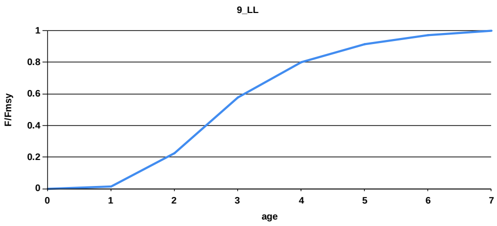






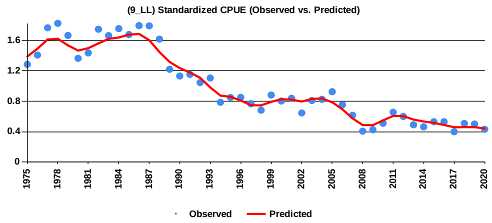


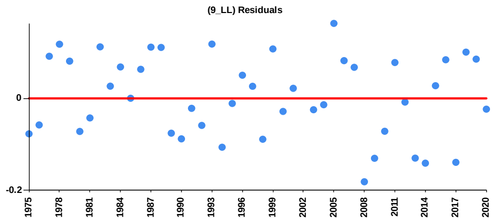




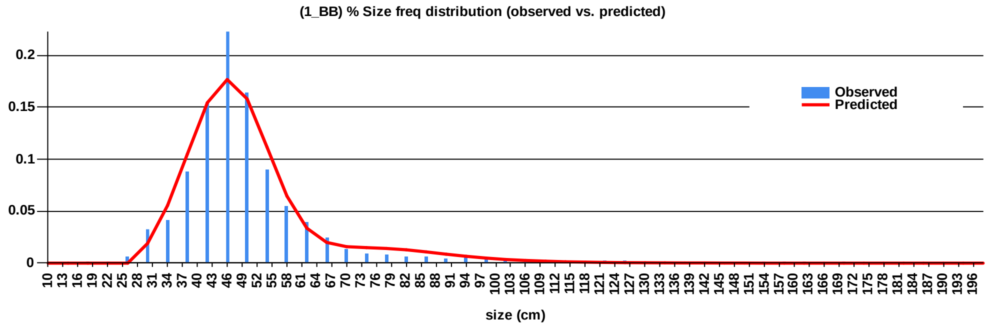
9_LL
F/Fmsy
1
0.8
0.6
0.4
0.2
0
0
1
2
3
4
5
6
7
age

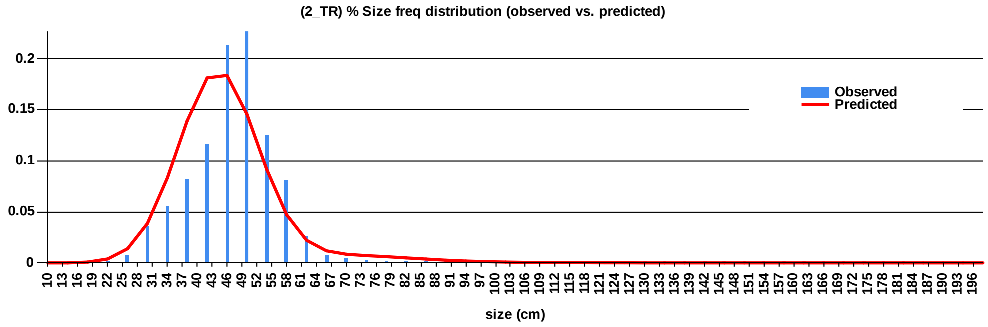
CPUE

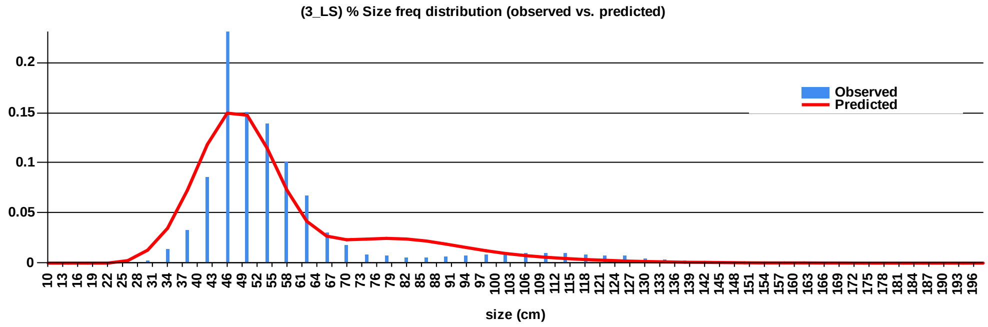

(9_LL) Standardized CPUE (Observed vs. Predicted)
Observed
Predicted

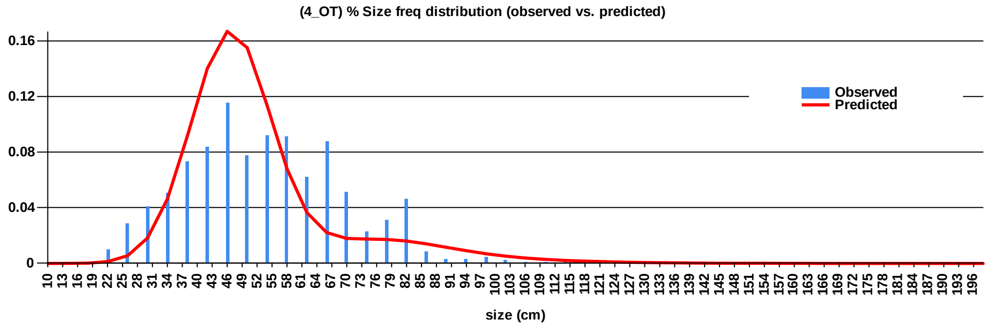

(9_LL) Residuals

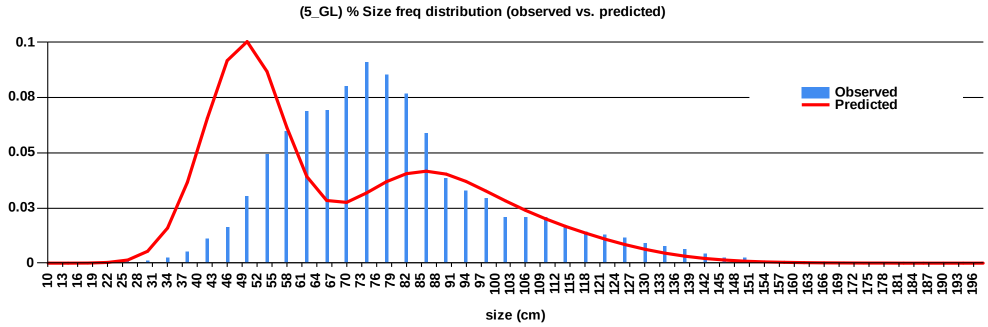
Fitness of size frequency distribution

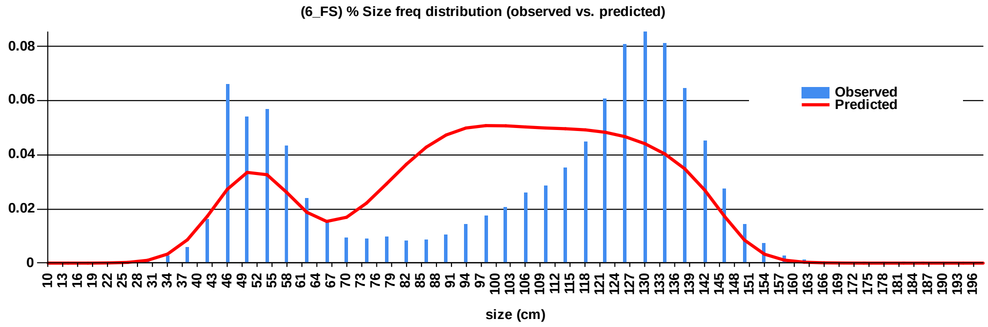


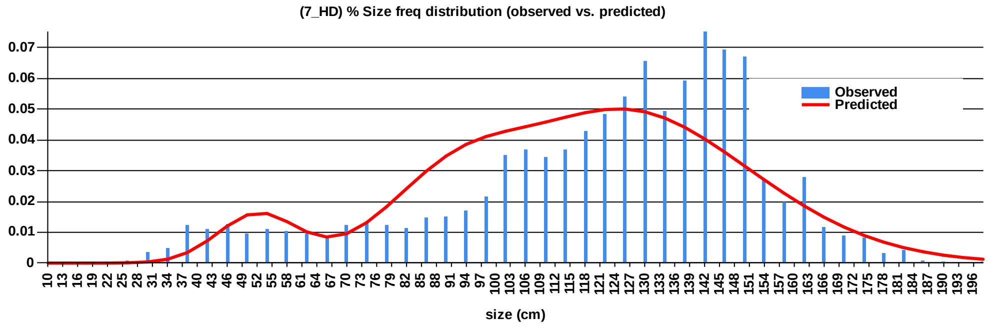


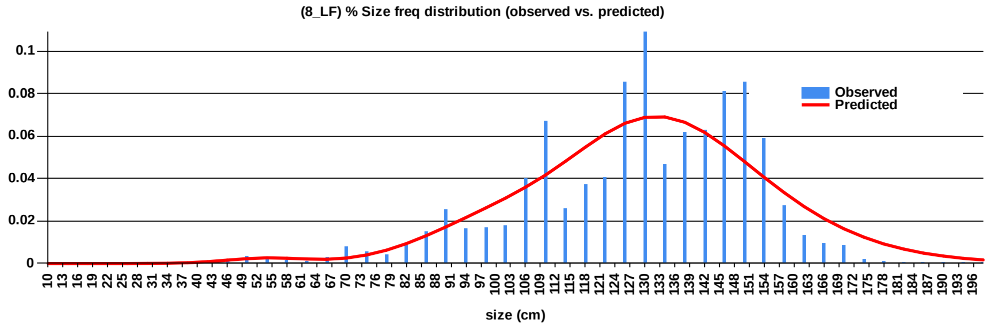


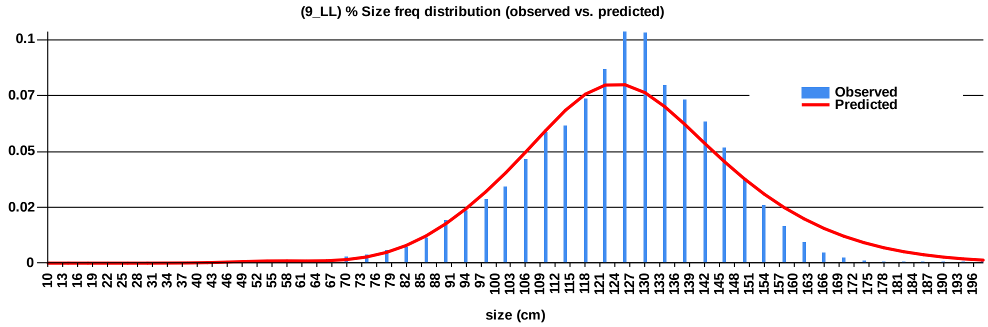



(5_GL) % Size freq distribution (observed vs. predicted)
Observed
Predicted
size (cm)


(6_FS) % Size freq distribution (observed vs. predicted)
Observed
Predicted
size (cm)


(7_HD) % Size freq distribution (observed vs. predicted)
Observed
Predicted
size (cm)


(8_LF) % Size freq distribution (observed vs. predicted)
Observed
Predicted
size (cm)


(9_LL) % Size freq distribution (observed vs. predicted)
0.1
0.07
0.05
0.02
0
Observed
Predicted
10 13 16 19 22 25 28 31 34 37 40 43 46 49 52 55 58 61 64 67 70 73 76 79 82 85 88 91 94 97 100 103 106 109 112 115 118 121 124 127 130 133 136 139 142 145 148 151 154 157 160 163 166 169 172 175 178 181 184 187 190 193 196
size (cm)