2019 Updated horse mackerel assessments and projections

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Summary

This document reports updated 2019 horse mackerel assessments, along with some initial projections. The updated assessments provide indications of improved resource status, with consequent implications for management advice. However, before final calculations to facilitate development of such advice are specified and conducted, the DWG needs first to give attention to whether this updated information as yet provides a sufficiently strong scientific basis to allow firm conclusions to be drawn concerning such improvement in status.

INTRODUCTION

This document reports the 2019 updated horse mackerel assessments, along with some initial projections. The input data, which include updates to the catch, survey and CPUE series, are reported in Fairweather (2019).

OPERATING MODELS

FISHERIES/2018/SEP/SWG-DM/54_rev provided results of the assessment models for Horse Mackerel for 2018 taking the then most recent data (to 2018) into account. These assessment models omitted the 2015 *Desert Diamond* (DD) CPUE value. Two main model variants were recommended – these two models explain the very low 2014 to 2016 observed CPUE *Desert Diamond* values in very different ways. The inclusion of the Dual Rights vessels' (DR) CPUE series was also recommended. In the light of the suggestions made in 2018, and consideration of fits to the updated data, the set of 2019 updated assessment models presented here are as follows.

Model 3a: $q = q_1$ for all years,

This model does **not** allow for a reduced fishing catchability to explain the recent (2014-2016) low *Desert Diamond* CPUE values.

Model 3b: $q = q_1$ for years up to and including 2013,

$q = q_2$ for year 2014,

$q = q_1$ for year 2017+ ,

q is linearly interpolated between q_2 (in 2014) and q_1 (in 2017) to obtain the q values for 2015 and 2016 (although note that the observed 2015 CPUE value is omitted in the model fit, as decided earlier by the DWG).

This model thus assumes that recent (2014-2016) low CPUE values could be a result of reduced fishing catchability.

Model 3c: $q = q_1$ for years up to and including 2013,

$q = q_2$ for year 2014,

$q = q_1$ for year 2016+ ,

This model thus assumes that the 2014 low CPUE value could be a result of reduced fishing catchability, but only for two rather than three years as in Model 3b.

Model 3c*: Model 3c but forcing the 2015 and 2016 stock-recruit residuals to equal zero to examine their influence on estimated abundance trends.

Model 5: An extra mortality event occurs at the start of 2014 (numbers-at-age in 2014 are all reduced by an estimated additional proportion M^{extra}). This extra mortality is a one-off event.

PROJECTIONS

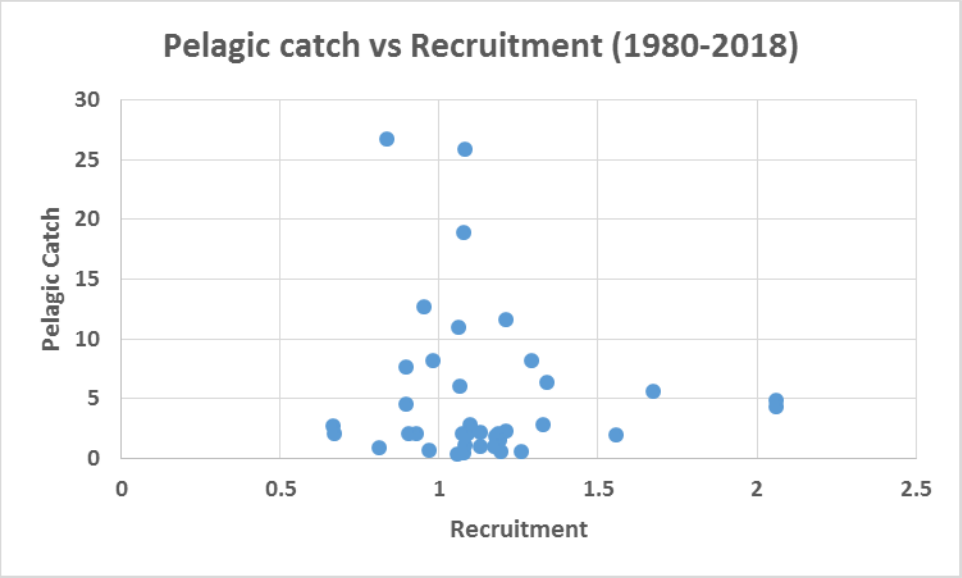
OMPs explored last year (2018) to provide management advice

This document reports the results of horse mackerel projections under alternative management options (termed OMPs here). Projections are reported for both Model 3b and Model 5. For each projection scenario, the resource is projected ahead for 10 years and the projections are repeated 1000 times with noise added to the future recruitment and incorporating uncertainty about future CPUE estimates.

The rules (OMPs) to compute future simulated catches under various management approaches are set out below.

1) Pelagic bycatches

The Figure below plots pelagic bycatches (in 1000 MT) against annual horse mackerel recruitment (in billions).



- Note that there is no clear relationship between pelagic bycatches and recruitment.
- Hence future (2019+) pelagic bycatches are set by drawing at random with replacement from the set of pelagic bycatches for the period 2000-2018, except that a value in excess of $PUCL_{y+1}$ below is reduced to $PUCL_{y+1}$, where:

  $PUCL_{y+1}$=12 000 - C_y^{pel} - C_{y-1}^{pel}. (Units: MT)

Note 12 000 (previously called PULC$_3$) is the total amount in MT that may be caught over a three-year period (see FISHERIES/2015/MAR/SWG-DEM/03).

2) **Incidental trawl/Demersal bycatches** – constant proportion of HM biomass

As recommended in FISHERIES/2016/OCT/SWG-DEM/79, the average reported incidental bycatches for the period 2000-2018 should be considered in the averaging used in order to produce a more representative $\bar{F}_{trawl}$ exploitation rate value. Table 1 below reports the demersal bycatches, Model 3b estimated horse mackerel biomass values, and the resultant exploitation proportion F=C/B. The median and upper 95th percentile of the F values over the years calculated (assuming a normal distribution) are reported. It was agreed (in 2018) that the upper 95th percentile (to allow for catchability fluctuations) of the 2000-2017 (now 2000-2018) F values (which turns out to be 0.0347) would be used as the $\bar{F}_{trawl}$ value in future equations to calculate the future demersal bycatches, i.e.:

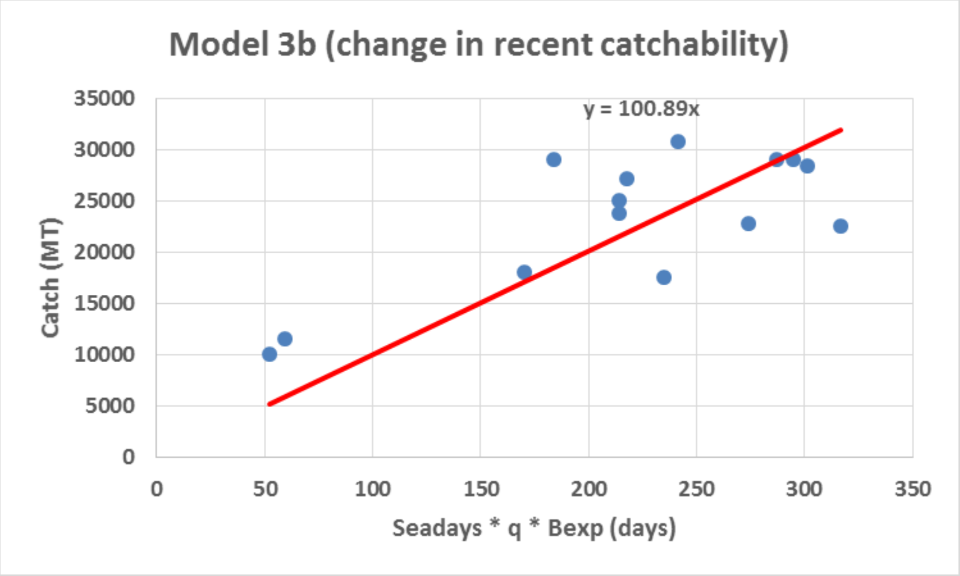
Future demersal bycatches = $\bar{F}_{trawl} * B_{exp}^{dem}$

3) **Midwater directed catches**

The plot below shows the observed (circles) midwater catches plotted against:

$$q * B_{exp}^{mid} * Seadays\_used.$$

for Model 3b (which assumes that catchability has been reduced in recent years).



A linear regression through the origin of the form shown below was fitted to these data:

$$C = k.(q * B_{exp}^{mid} * Seadays_{used})$$

The regression is shown as the red line on the above plot where $\boldsymbol{k = 100.89}$. The average standard deviation of the residuals about the regression line, σ , is 4430 MT.

The midwater catch in each future year is then determined as follows.

i) An Initial catch (C_1) set at 33 850 MT (as calculated by the Furman OMP for 2019 – see the Appendix 2).

ii) A Secondary (C_2) catch is calculated related to the limit on *Seadays*:

$$C_2 = k\left(q * B_{exp}^{mid} * Seaday_{limit}\right) + error$$

where for each year of each replicate projection the error is generated from $error \sim N(0, \sigma^2)$,

and where $q * B_{exp}^{mid}$ are the future midwater CPUE values, and $Seaday_{limit}$ value is fixed at 300, 388, 430 or 460 days.

The final midwater catch simulated is the **lesser** of C_1 and C_2.

Furthermore, a lower bound on midwater catch of 2000 MT is imposed.

OMPs explored (similar to 2018)

1) Midwater initial catch C_1 = 33 850 MT (as indicated by the Furman OMP for 2019 – see FISHERIES/2016/OCT/SWG-DEM/66). Appendix 2 shows the workings for this amount.
   Midwater catch lower bound 2000 MT
   $Seaday_{limit}$ = 300, 388, 430 or 460 days
2) C_1 = 33 850 MT; no Seaday restriction; midwater catch lower bound 2000 MT
3) C_1 = 20 000 MT; no Seaday restriction; midwater catch lower bound 2000 MT

Results

Table 2 provides a summary of results for the three different OMs. Figure 1a compares the model fits to the *Desert Diamond* (DD) CPUE values. Figure 1b shows the estimated midwater catchability for Model 3b. Figure 1c compares the model fits to the Dual Rights vessels' CPUE values. Figure 2a and compares the model fits to the Autumn and Spring survey biomass estimates respectively. Figures 3a and b plot the spawning biomass estimates and the spawning biomass estimates relative to pristine for the three models. Figure 4 plots the estimated stock-recruit residuals for each OM.

Figures 5a and b show projection results for Model 3b and Model 5 respectively. Results are shown for all six OMPs. Plots of median and lower 5 %ile Bsp/K, median CPUE and median midwater catches are shown. These results are preliminary and further results for other OMs will be provided in a forthcoming document.

Discussion

Important points to note from these initial results would seem to be the following.

- There is now little support for the hypothesis of an extra mortality event having been responsible for the drop in CPUE in 2014 (Model 5); the likelihood for this model is considerably less than those for the models with a period of reduced catchability (see Table 2a).

- There is certainly support for some reduction in catchability (the likelihood for Model 3a with no such drop is much less than for the related Models 3b and 3c with such a reduction); there is marginally more support for this reduction having extended over three years (2014-2016 – Model 3b) than over two (2014-2015 – Model 3c). Preferences for Models 3b and 3c (the catchability reduction hypothesis) over models 3a and 5 is also generally clear from the fits to the abundance indices shown in Figures 1 and 2.

- Models 3b and 3c indicate a very recent slight reduction in spawning biomass (following an increasing trend over the last decade – Figures 3a and b). Figure 3c shows that this is a consequence of poor recruitments estimated by these models for 2015 and 2016 (see Figure 4). Table 2b indicates that the evidence for these poor recruitments comes mainly from survey catch-at-length (CAL) information, but that this evidence is fairly weak.

Before considering projections and management advice further, it is suggested that the DWG first develop views on some of the points above, which have important consequences for this advice, specifically:

1) Is current information sufficient to conclude that the hypothesis of a catchability reduction for a few years commencing in 2014 being the cause of low CPUE values over that period is correct, and further that catchability can be assumed to have returned to (about) the same level as before this reduction occurred?

2) That in turn would suggest that spawning biomass has increased by some 50% over the past decade. Is that evidence sufficiently strong to support a consequent recommendation for a TAC increase?

3) It also suggests that effort restrictions for the midwater trawl fishery may no longer be necessary. Again, is the available evidence as yet sufficiently strong to support that conclusion?

4) There is evidence for recent poor recruitment, but that evidence is weak. To what extent should these estimates of poor recruitment (rather than, say, assuming median recruitment for those two years) be incorporated into resource projections and management advice?

The specification of further computations to inform final management advice would seem to best first await these questions being addressed by the DWG.

References

Fairweather, T.P. 2019. Horse mackerel Midwater catch data – Elucidation. FISHERIES/2019/OCT/SWG-DEM/14.

Table 1: Demersal bycatches, model estimated horse mackerel biomass values and resultant exploitation proportions F=C/B (caused by the incidental demersal trawl catches) for Model 3b. Biomass units are MT.

	Demersal bycatch	Model 3b horse mackerel biomass	Model 3b F
2000	9259	233973	0.0396
2001	9229	245492	0.0376
2002	8814	257468	0.0342
2003	4863	251824	0.0193
2004	3562	232301	0.0153
2005	4933	245256	0.0201
2006	5280	250287	0.0211
2007	4133	250859	0.0165
2008	4812	330216	0.0146
2009	4449	387741	0.0115
2010	4129	381685	0.0108
2011	5596	343611	0.0163
2012	5228	322269	0.0162
2013	4941	349639	0.0141
2014	2695	348499	0.0077
2015	3087	327088	0.0094
2016	4747	309524	0.0153
2017	5230	268251	0.0195
2018	5703	244675	0.0233
		median	0.0165
		upper 95%ile	**0.0347**

Table 2a: Summary of results for four different OMs. All variants fix q_{aut} = 0.75 and *h* = 0.75. “SR” and “CAL” refer to stock-recruitment and catch-at-length contributions respectively. Biomass units are thousand MT.

	Model 3a *q* constant for all years	Model 3b $q = q_2$ for 2014 q_{2017+} = q $_{2013}$	Model 3c $q = q_2$ for 2014 q_{2016+} = q $_{2013}$	Model 5 Extra proportion M^{extra} die at start of 2014
-ln L :Total	-228.376	-263.161	-262.560	-126.362
-ln L :Spr survey	0.366	1.202	1.141	0.582
-ln L :Aut survey	-1.382	-6.759	-6.724	5.908
-ln L :CPUE	-3.846	-10.161	-9.262	-1.455
-lnL Dual Rights	-4.319	-7.193	-7.450	-1.653
-ln L :CAL Spr survey	-44.861	-48.960	-48.946	-27.577
-ln L :CAL Aut survey	-84.859	-91.785	-91.710	-62.459
-ln L :CAL commercial	-81.233	-81.539	-81.753	-21.747
-ln L :SR residuals	-8.256	-17.966	-17.856	-18.030
K^{sp} (KT)	709	760	758	709
B^{sp}_{2018} (KT)	**420**	**465**	**456**	**251**
$MSYL^{sp}$ (KT)	174	186	185	184
MSY (KT)	53	55	55	96
B^{sp}_{2018}/K^{sp}	**0.592**	**0.612**	**0.601**	**0.354**
$B^{sp}_{2018}/MSYL^{sp}$	2.414	2.500	2.465	1.364
$MSYL^{sp}/K^{sp}$	0.245	0.245	0.244	0.260
q: Spr survey	0.537	0.821	0.750	0.780
q: CPUE (x10^{-6})	1.872	2.060	2.068	3.353
q_2 (applies to 2014)	1.000*q_{CPUE}	0.267*q_{CPUE}	0.274*q_{CPUE}	-
M^{extra} (once-off extra proportion die in 2014)	-	-	-	0.350
	M3a.tpl	M3b.tpl	M3c.tpl	M5dr19.tpl

Table 2b: Summary of results for Model 3c and Model 3c*. All variants fix q_{aut} = 0.75 and h = 0.75. "SR" and "CAL" refer to stock-recruitment and catch-at-length contributions respectively. Biomass units are thousand MT. Model 3c* forces the 2015 and 2016 stock-recruit residuals to equal zero. In the final column, a negative value indicates that the corresponding data prefer non-zero stock-recruit residuals for 2015 and 2016.

	Model 3c $q = q_2$ for 2014 $q_{2016+} = q_{2013}$	Model 3c* $q = q_2$ for 2014 $q_{2016+} = q_{2013}$	Model 3c-Model 3c*
-ln L :Total	-262.560	-261.883	-0.677
-ln L :Spr survey	1.141	1.227	-0.086
-ln L :Aut survey	-6.724	-6.038	-0.686
-ln L :CPUE	-9.262	-9.974	0.712
-lnL Dual Rights	-7.450	-7.267	-0.183
-ln L :CAL Spr survey	-48.946	-47.805	-1.141
-ln L :CAL Aut survey	-91.710	-91.219	-0.491
-ln L :CAL commercial	-81.753	-82.408	0.655
-ln L :SR residuals	-17.856	-18.399	0.543

Figure 1a: Comparisons amongst the model fits to the *Desert Diamond* (DD) CPUE values.

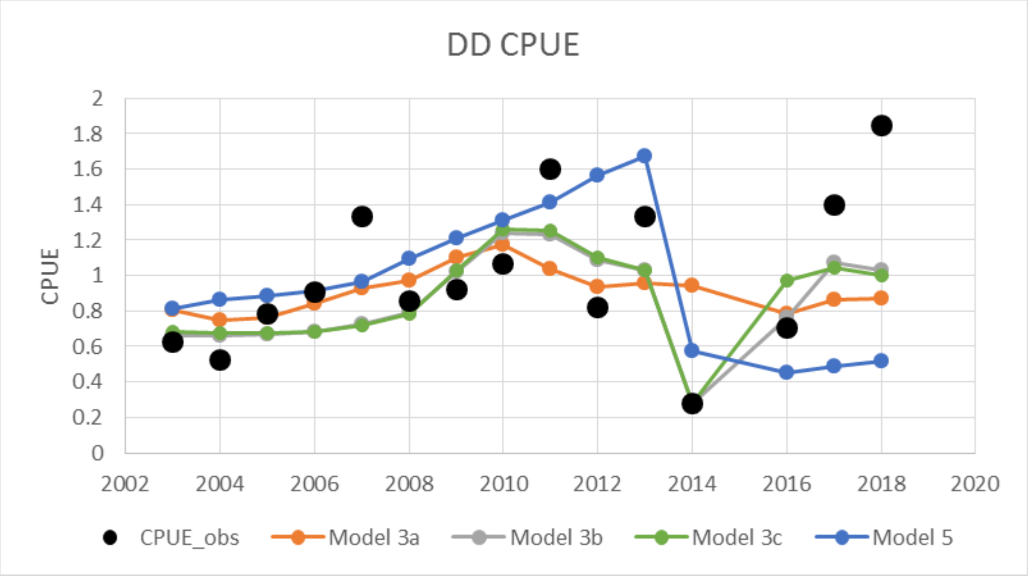


Figure 1b: Estimated midwater catchabilities for Model 3b and Model 3c.

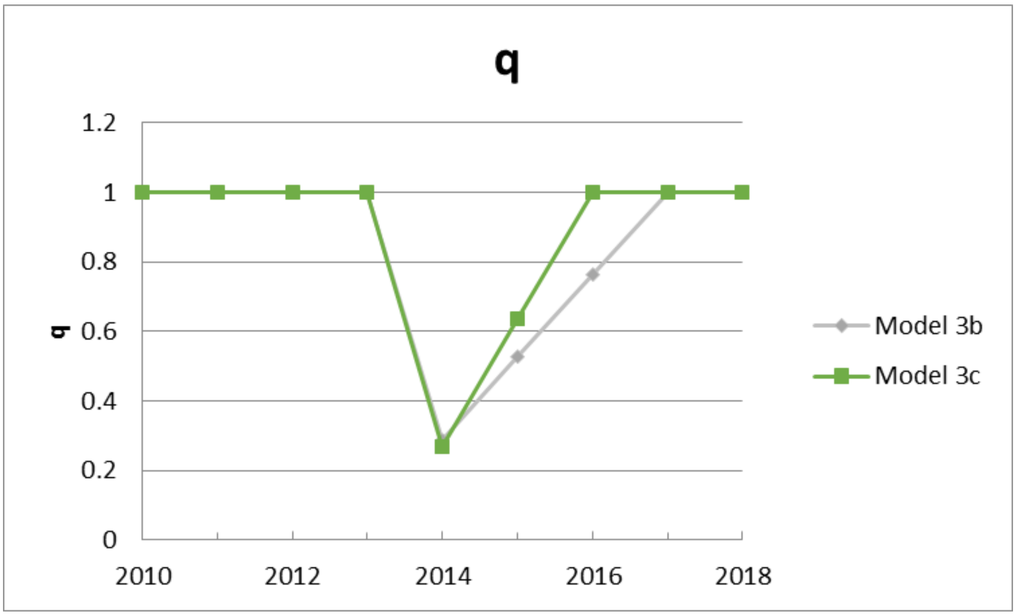


Figure 1c: Comparisons amongst the model fits to the Dual Rights vessels' CPUE values.

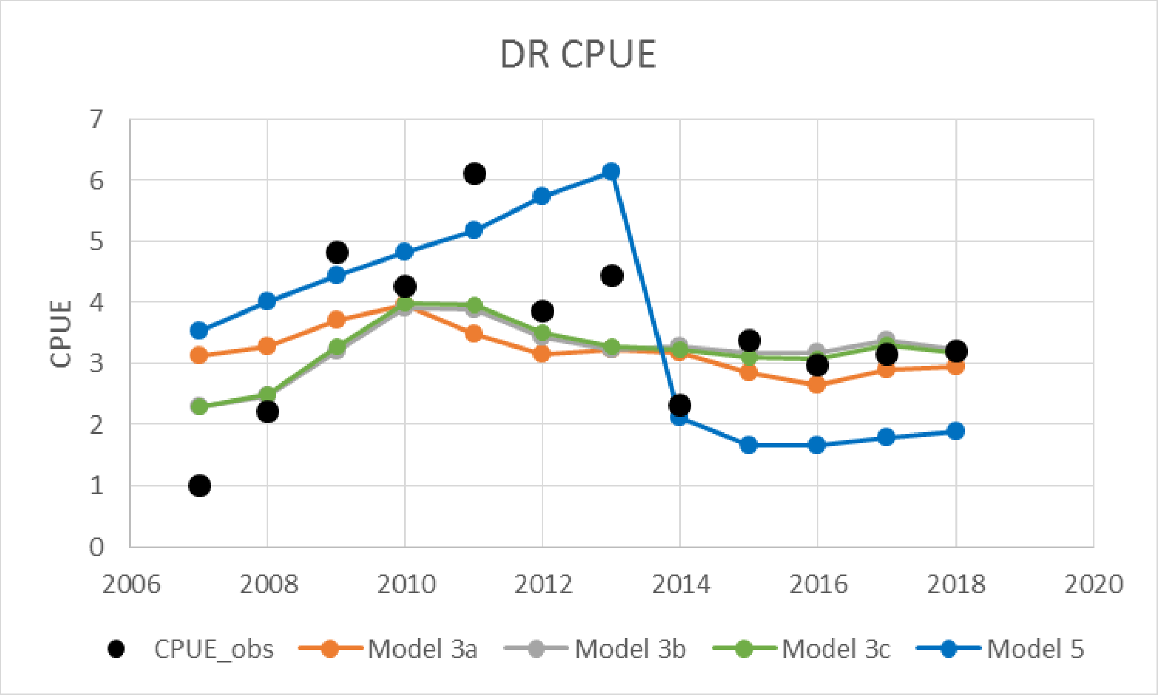


Figure 2a: Model fits to the Autumn survey biomass estimates.

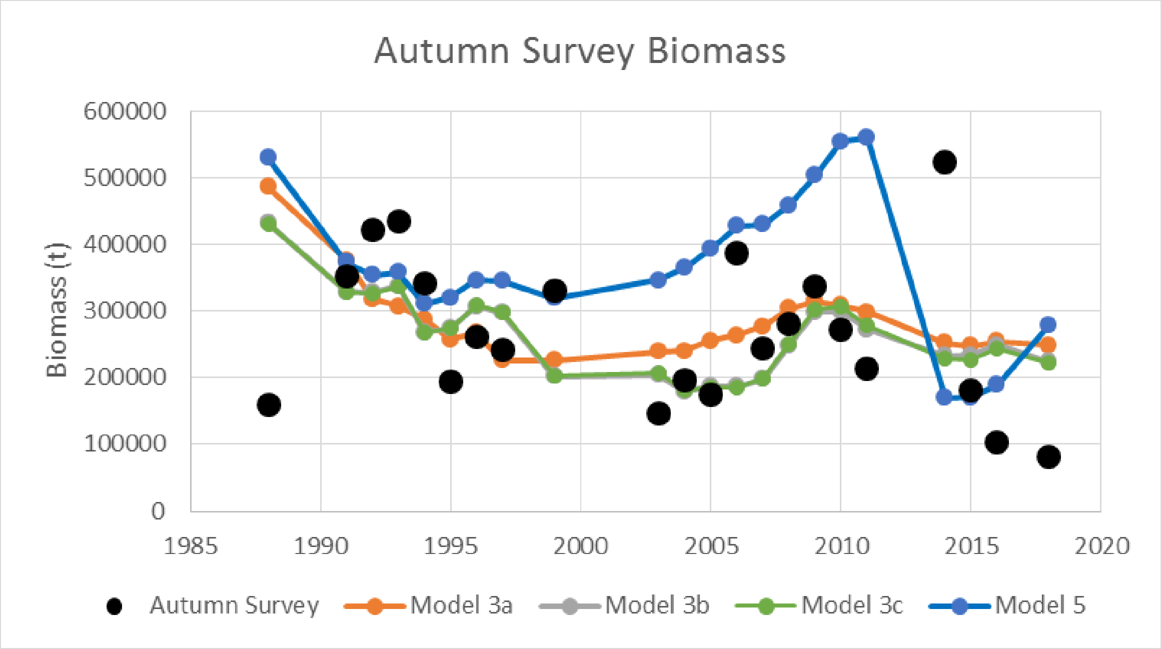


Figure 2b: Model fits to the Spring survey biomass estimates.

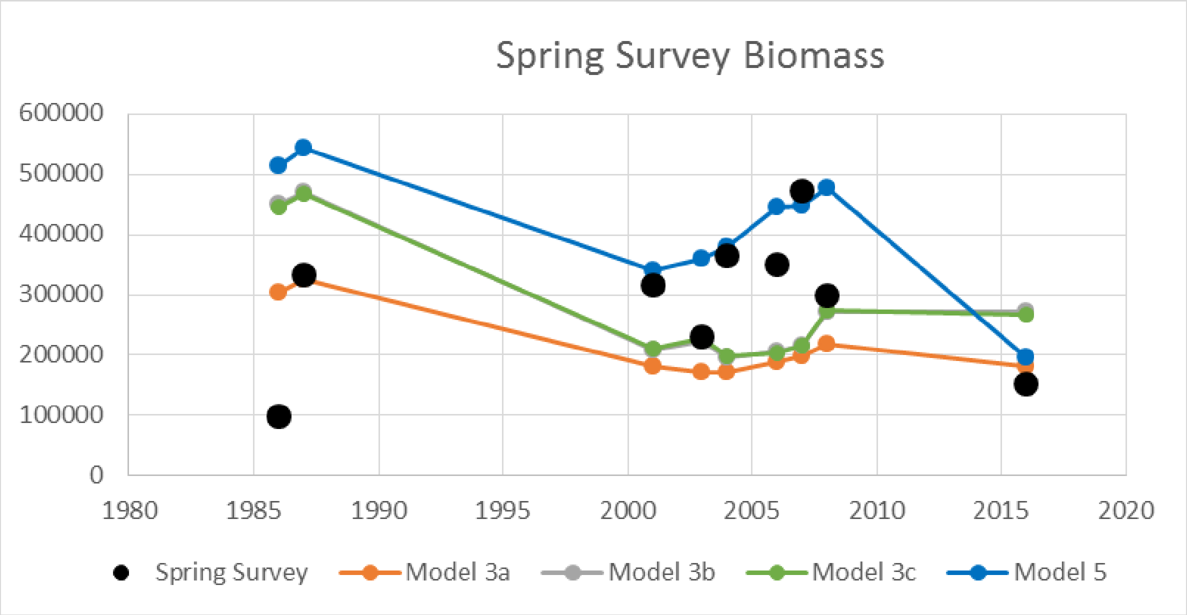


Figure 3a: Spawning biomass estimates for the three models.

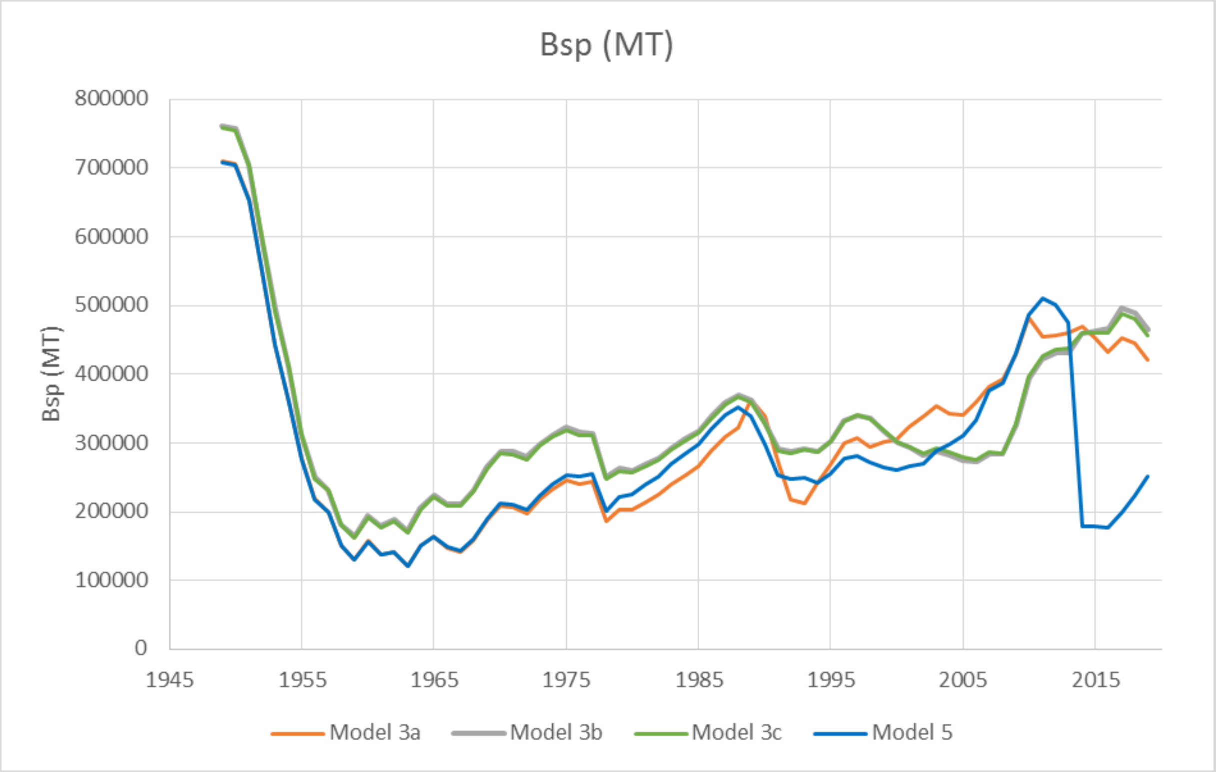


Figure 3b: Spawning biomass relative to K estimates for the three models.

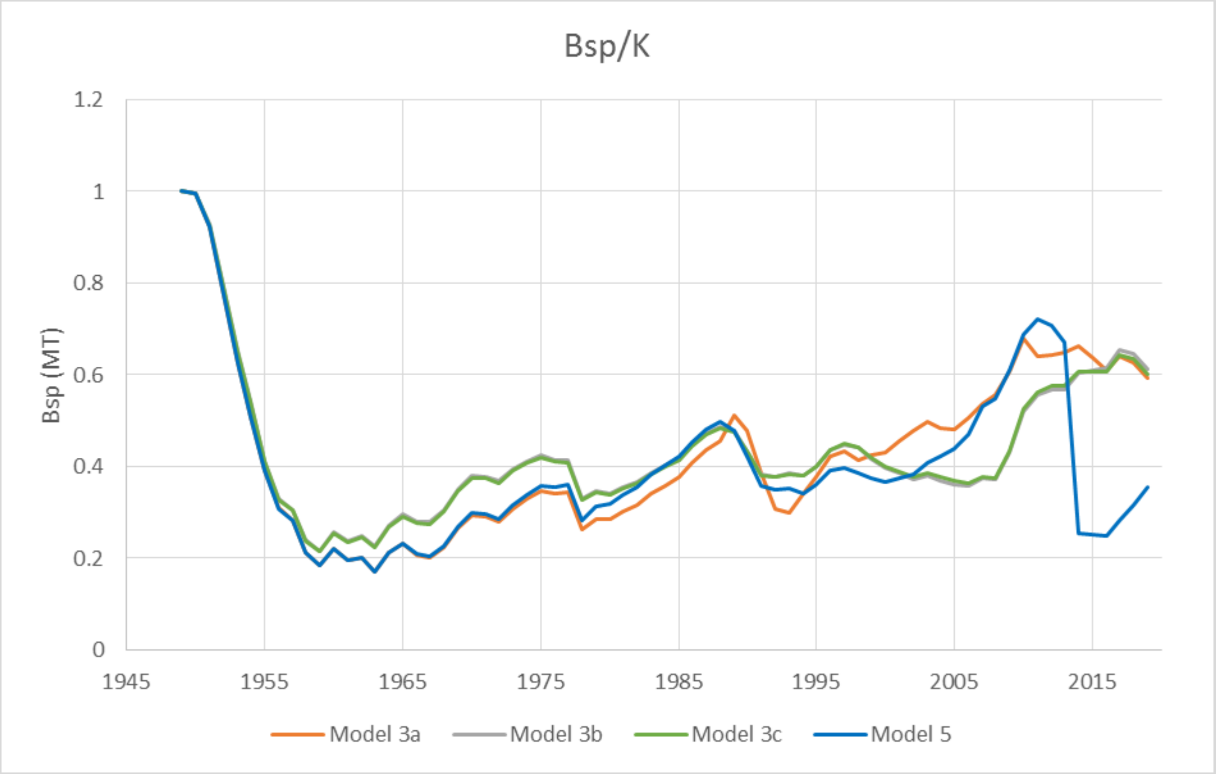


Figure 3c: Spawning biomass relative to K estimates for Model 3c and Model 3c*.

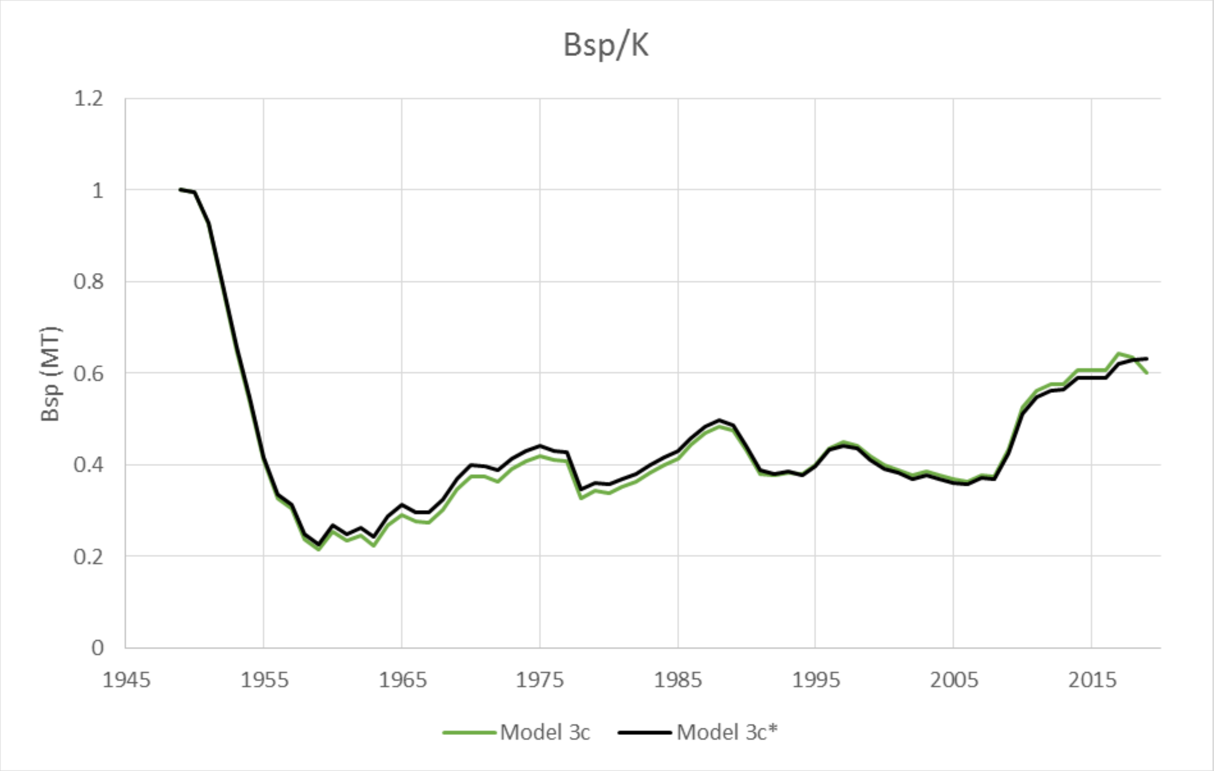


Figure 4: Estimated stock-recruit residuals.

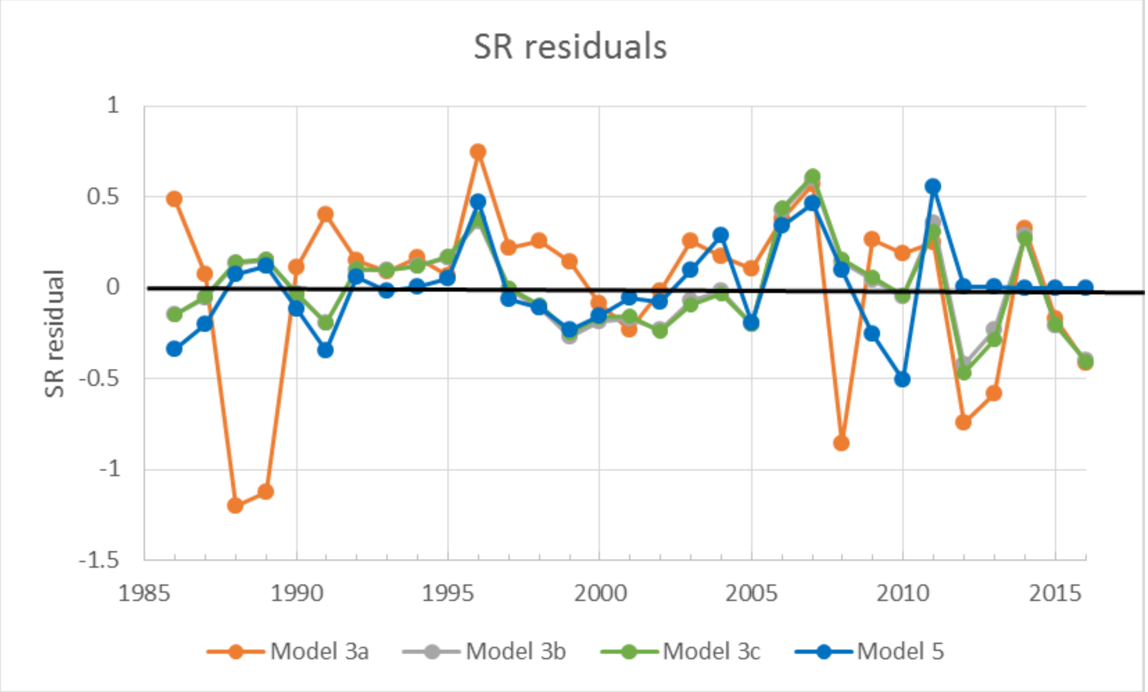


Figure 5a: Model 3b projections– results are shown for all six OMPs. Catches given here and in the Figures following are in MT.

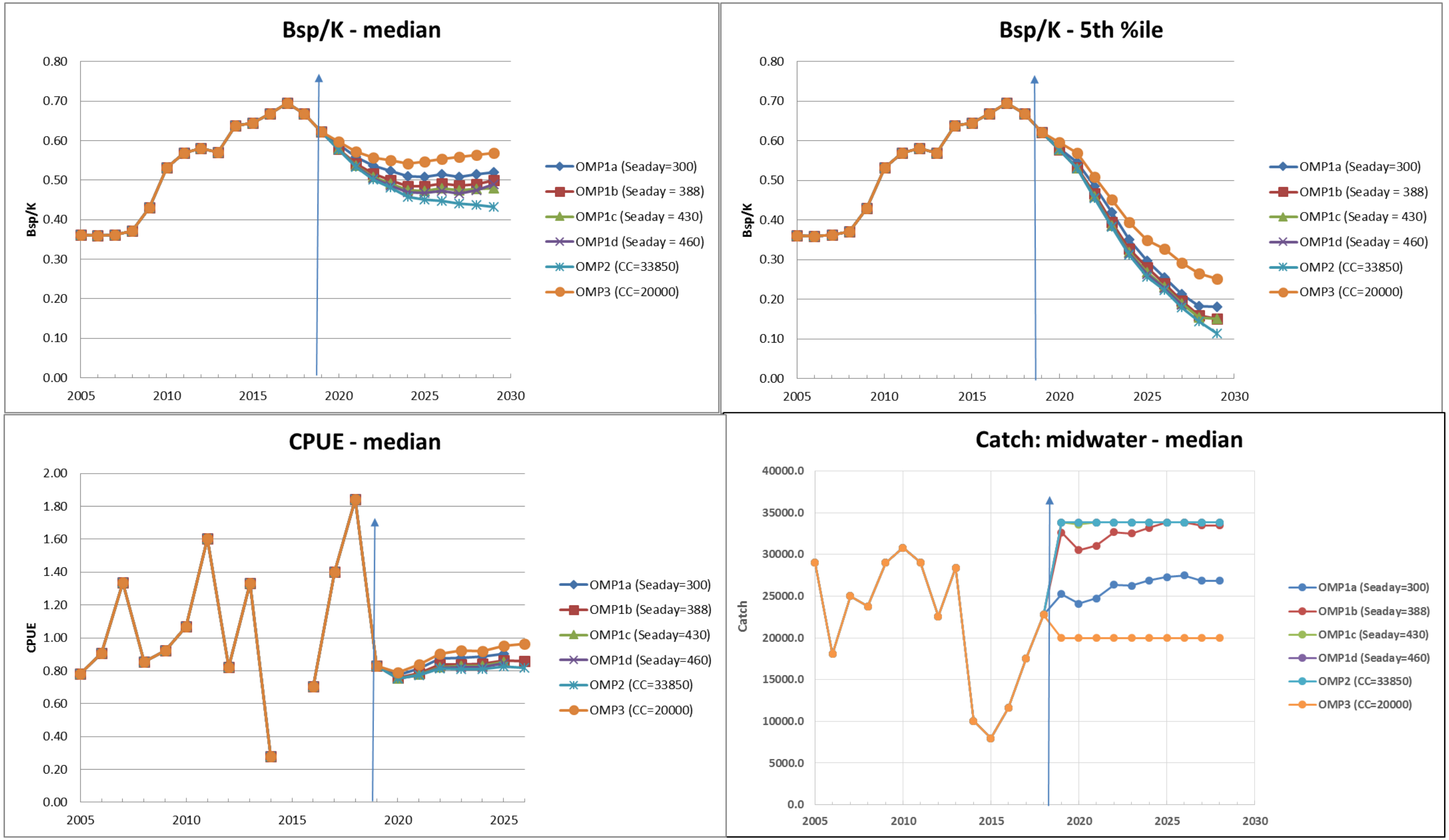
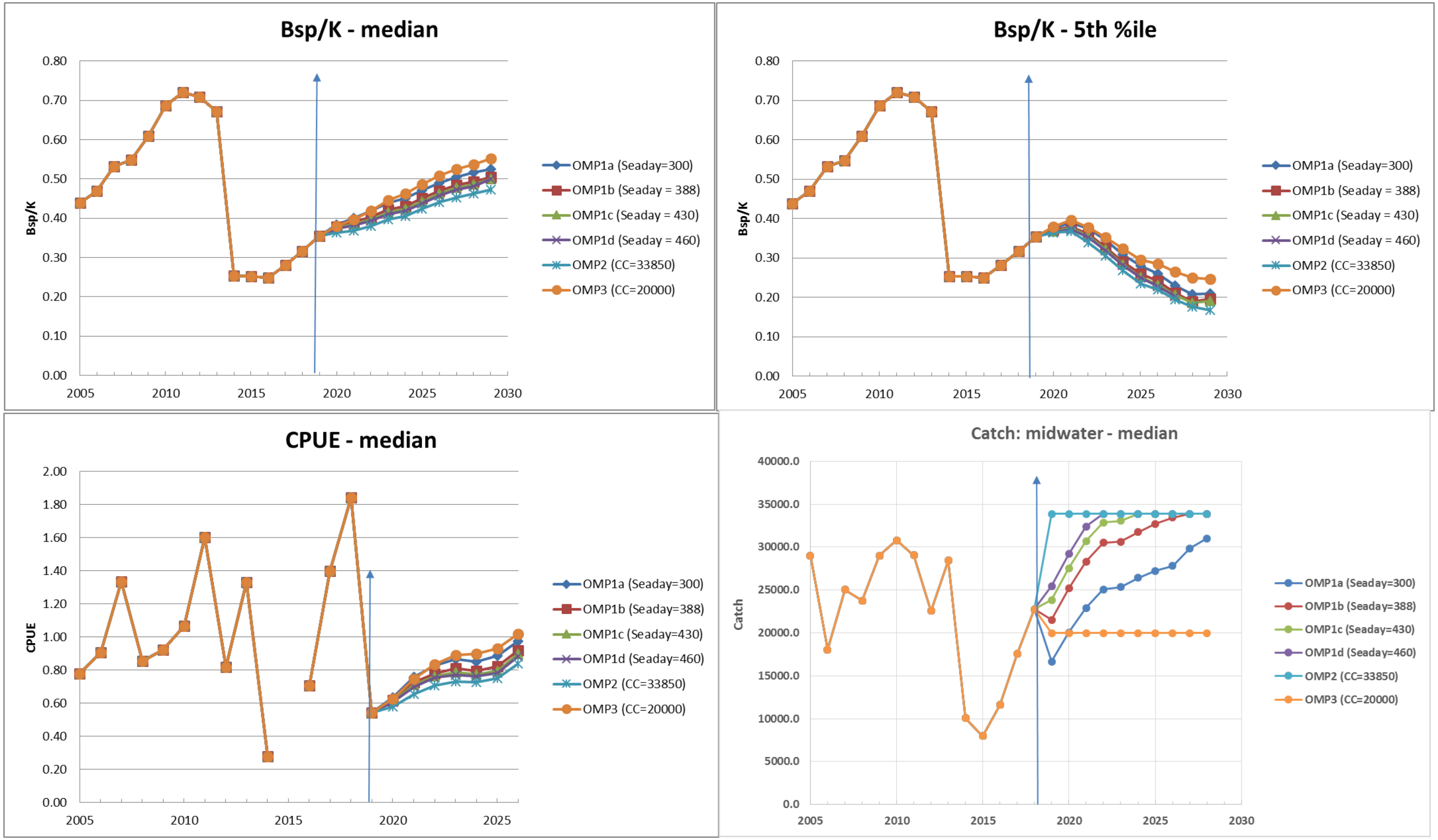


Figure 5b: Model 5 projections– results are shown for all six OMPs. Catches given here and in the Figures following are in MT.



Appendix 1: Input data used for the 2019 Horse mackerel assessments

Table A1: Horse Mackerel catch data for the three different fleets (values in MT) (data provided by DEFF).

Year	Pelagic catch	Demersal catch	Midwater catch
1949	3360	0.00001	0.00001
1950	49900	445	0.00001
1951	98900	1105	0.00001
1952	102600	1226	0.00001
1953	85200	1456	0.00001
1954	118100	2550	0.00001
1955	78800	1926	0.00001
1956	45800	1334	0.00001
1957	84600	959	0.00001
1958	56400	2073	0.00001
1959	17700	2075	0.00001
1960	62900	3712	0.00001
1961	38900	3627	0.00001
1962	66700	3079	0.00001
1963	23300	1401	0.00001
1964	24400	9522	0.00001
1965	55000	7017	0.00001
1966	26300	7596	0.00001
1967	8800	6189	0.00001
1968	1400	9116	0.00001
1969	26800	12252	0.00001
1970	7900	17872	0.00001
1971	2200	33329	0.00001
1972	1300	20560	0.00001
1973	1600	33900	0.00001
1974	2500	38391	0.00001
1975	1600	55459	0.00001
1976	400	50981	0.00001
1977	1900	116400	0.00001
1978	3600	37290	0.00001
1979	4300	53584.5	0.00001
1980	400	39187.5	0.00001
1981	6100	41215	0.00001
1982	1100	32176	0.00001
1983	2100	38332	0.00001
1984	2800	37969	0.00001
1985	700	27278	0.00001
1986	500	31378	0.00001
1987	2834	38571	0.00001
1988	6403	41482	0.00001
1989	25872	58205.5	0.00001
1990	7645	56721.3	0.00001
1992	2057	37207.53	0.00001
1993	11651	35998	0.00001
1994	8207	20029.5	0.00001
1995	1986	10790	0.00001
1996	18920	31846	0.00001
1997	12654	34670.5	0.00001
1998	26680	36278.8	15769.8
1999	2057	21579.73	2160.77
2000	4503	9228.977	15375.74
2001	915	8813.736	19220.38
2002	8148	4863.111	11098.47
2003	1012	3562.168	25290.98
2004	2048	4933.367	27154.31
2005	5627	5280.164	29005.21
2006	4824	4132.990	18068.35
2007	1903	4811.698	24251.18
2008	2280	4449.295	23774.56
2009	2087	4128.813	29021.42
2010	4385	5595.850	23479.62
2011	10990	5228.260	29048.46
2012	2199	4941,442	22616.49
2013	596	2695.003	28480.64
2014	2760	3087.010	10053.03
2015	2040	4747.106	7975.594
2016	1588	5230.374	11612.686
2017	1466	5703.439	17545.203
2018	967	4625.880	22774.618

Table A2: GLM standardised CPUE (for the *Desert Diamond*), the Dual rights CPUE and survey abundance data for South African horse mackerel for the period 1986-2018. Data were provided by Coetzee, Fairweather and Singh (DEFF, *pers. commn*).

Year	Desert Diamond CPUE	Dual rights CPUE	Autumn demersal survey		Spring demersal survey	
			Biomass (KT)	CV	Biomass (KT)	CV
1986					97.36	0.13
1987					332.97	0.14
1988			159.07	0.29		
1989						
1990						
1991			352.19	0.23		
1992			422.21	0.23		
1993			435.28	0.20		
1994			340.72	0.26		
1995			195.13	0.24		
1996			261.77	0.23		
1997			241.02	0.23		
1998						
1999			330.63	0.24		
2000						
2001					316.72	0.18
2002						
2003	0.622		146.72	0.24	231.36*	0.20*
2004	0.525		195.73*	0.32*	366.50*	0.19*
2005	0.781		175.04*	0.21*		
2006	0.907		386.57	0.20	350.28	0.19
2007	1.336	0.994	243.58*	0.40*	473.22*	0.19*
2008	0.856	2.202	279.86*	0.27*	300.00*	0.17*
2009	0.923	4.820	337.16*	0.24*		
2010	1.068	4.254	271.79	0.37		
2011	1.602	6.098	213.09*	0.22*		
2012	0.820	3.854				
2013	1.331	4.432	522.69*	0.28*		
2014	0.280	2.311	180.08*	0.17*		
2015		3.381	104.00*	0.43*		
2016	0.706	2.960			153.32*	0.25*
2017	1.401#	3.138				
2018	1.843	3.193	80.68*	0.49*		

*These values correspond to surveys that used the new trawl net, which was introduced in September 2003.

The 2017 DD CPUE has recently been corrected for an error made in its computation in 2018.

Table A3a: Spring demersal survey catch-at-length for South African horse mackerel (shown as proportions of numbers each year) as used in the assessment model. Provided by Fairweather (DEFF, *pers. commn*).

	Total length (cm)								
Year	0–10	10–15	15–20	20–25	25–30	30–35	35–40	40–45	45+
1986	0.0000	0.0000	0.0020	0.0900	0.2380	0.1640	0.1690	0.2310	0.1050
1987	0.0000	0.0000	0.1160	0.2230	0.1600	0.2060	0.1240	0.1290	0.0430
2001	0.0020	0.0150	0.3750	0.2550	0.1240	0.1360	0.0750	0.0150	0.0040
2003	0.0000	0.0500	0.0680	0.3760	0.3670	0.0910	0.0400	0.0080	0.0010
2004	0.0010	0.2380	0.2560	0.1610	0.2260	0.0740	0.0350	0.0080	0.0010
2006	0.0080	0.2670	0.2430	0.2880	0.1440	0.0410	0.0080	0.0010	0.0000
2007	0.0000	0.2230	0.6340	0.0950	0.0440	0.0030	0.0010	0.0000	0.0000
2008	0.0010	0.0270	0.4580	0.4290	0.0680	0.0100	0.0050	0.0020	0.0000
2016	0.0001	0.0263	0.2914	0.5157	0.1325	0.0223	0.0099	0.0008	0.0010

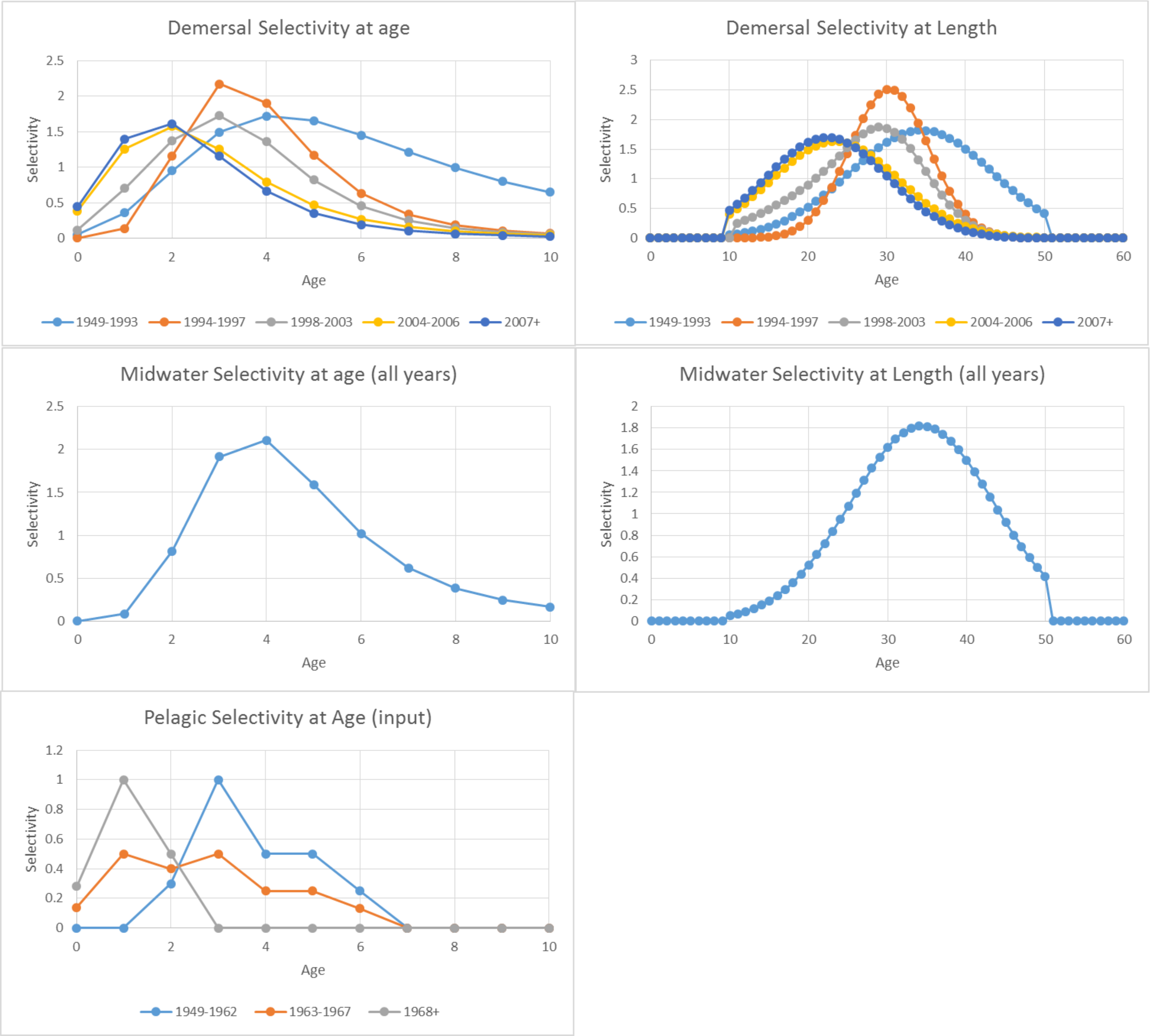
Table 3b: Autumn demersal survey catch-at-length for South African horse mackerel (shown as proportions of numbers each year) as used in the assessment model. Provided by Fairweather (DEFF, *pers. commn*).

	Total length (cm)								
Year	0–10	10–15	15–20	20–25	25–30	30–35	35–40	40–45	45+
1988	0.0000	0.0150	0.0510	0.0140	0.1560	0.1660	0.1800	0.2910	0.1270
1992	0.0000	0.0720	0.0460	0.1050	0.3740	0.2730	0.0560	0.0430	0.0300
1993	0.0000	0.0920	0.3530	0.0750	0.1980	0.1180	0.0760	0.0650	0.0230
1994	0.0000	0.0270	0.1570	0.2200	0.2980	0.2540	0.0290	0.0100	0.0040
1995	0.0000	0.0000	0.0230	0.1090	0.4600	0.2710	0.0920	0.0330	0.0110
1996	0.0000	0.0000	0.0010	0.0230	0.5420	0.3080	0.1110	0.0130	0.0020
1997	0.0000	0.0030	0.0240	0.0050	0.4680	0.4010	0.0790	0.0160	0.0050
1999	0.0000	0.0100	0.1690	0.0630	0.0820	0.5220	0.1140	0.0330	0.0060
2003	0.0000	0.0010	0.3930	0.3290	0.1200	0.0600	0.0820	0.0150	0.0010
2004	0.0220	0.1420	0.4320	0.0550	0.1860	0.1000	0.0530	0.0080	0.0010
2005	0.0000	0.3540	0.1980	0.1480	0.1860	0.0570	0.0500	0.0070	0.0000
2006	0.0010	0.0330	0.2390	0.3450	0.2820	0.0630	0.0300	0.0060	0.0000
2007	0.1080	0.4630	0.3190	0.0880	0.0160	0.0040	0.0020	0.0010	0.0000
2008	0.0010	0.0710	0.3820	0.3840	0.1500	0.0090	0.0010	0.0020	0.0000
2009	0.0000	0.0680	0.1550	0.5250	0.2200	0.0280	0.0020	0.0010	0.0000
2010	0.0000	0.0560	0.0680	0.5270	0.2940	0.0440	0.0030	0.0060	0.0010
2011	0.1410	0.7700	0.0320	0.0330	0.0220	0.0010	0.0000	0.0000	0.0000
2014	0.0011	0.2538	0.3791	0.3062	0.0410	0.0132	0.0043	0.0007	0.0005
2015	0.0003	0.0550	0.3614	0.4436	0.0902	0.0350	0.0078	0.0023	0.0044
2016	0.0000	0.0678	0.1958	0.3441	0.1749	0.1353	0.0490	0.0313	0.0017
2019	0.0055	0.1768	0.0689	0.2033	0.2306	0.2186	0.0776	0.0113	0.0073

Table A3c: Commercial midwater catch-at-length for South African horse mackerel (shown as proportions of numbers each year) as used in the assessment model. Provided by Singh (DEFF, *pers. commn*).

Year	Total length (cm)								
	0–10	10–15	15–20	20–25	25–30	30–35	35–40	40–45	45+
2003	0	0	0	0.0010	0.1350	0.2560	0.5050	0.1020	0.0010
2004	0	0	0	0.0120	0.2410	0.3820	0.3280	0.0360	0.0010
2005	0	0	0.0040	0.0790	0.2880	0.3880	0.1900	0.0350	0.0160
2006	0	0	0.0060	0.1130	0.3390	0.4030	0.1260	0.0100	0.0030
2007	0	0	0.0030	0.0900	0.2930	0.3590	0.1870	0.0540	0.0140
2008	0	0.0010	0.0430	0.2560	0.3280	0.2460	0.1110	0.0140	0.0010
2009	0	0	0.0010	0.0880	0.3860	0.3180	0.1700	0.0340	0.0020
2010	0	0	0.0180	0.2200	0.3780	0.2550	0.1000	0.0260	0.0030
2011	0	0	0.0052	0.0482	0.3945	0.1932	0.1272	0.1077	0.1240
2012	0	0	0.1175	0.1337	0.3229	0.2901	0.1027	0.0306	0.0024
2013	0	0.0001	0.4181	0.2915	0.0893	0.1555	0.0395	0.0047	0.0013
2014	0	0	0.0002	0.0414	0.1093	0.5491	0.2703	0.0273	0.0024
2016	0	0	0.0010	0.1707	0.5813	0.1906	0.0430	0.0111	0.0022
2017	0	0	0.0004	0.1868	0.5711	0.2040	0.0269	0.0089	0.0019
2018	0	0	0.0003	0.0818	0.4975	0.3481	0.0585	0.0096	0.0042

Figure A1: (Model 3) Selectivity functions.



Appendix 2: TAC for the midwater fleet for 2019 based on the Furman OMP

The Furman OMP (FISHERIES/2016/OCT/SWG-DEM/66) is used in conjunction with the most recent CPUE series (FISHERIES/2019/OCT/SWG-DEM/14) to provide a Horse Mackerel TAC recommendation for the midwater sector.

The Catch control rules for the midwater catches are as follows:

$$TAC_{y+1} = \Delta_y \, TAC_y$$

$$\Delta_y = \begin{cases} 1 - X_{decr} & \text{for} \quad I_y < I_{decr} \\ 1 - X_{decr} + \dfrac{X_{incr} + X_{decr}}{I_{incr} - I_{decr}} \left(I_y - I_{decr} \right) & \text{for} \quad I_{decr} \leq I_y < I_{incr} \\ 1 + X_{incr} & \text{for} \quad I_y \geq I_{incr} \end{cases}$$

I_y is related to a weighted average of the last three years of CPUE data, e.g.:

$$I_{2019} = \frac{1/3 \sum_{2016,2017,2018} CPUE_y}{1/7 \sum_{2003}^{2009} CPUE_y}$$

$$= \frac{1.316}{0.850}$$

$$= 1.548$$

Thus as $I_{2019} \geq I_{incr}$ i.e. (1.548 > 1.01)

$$\Delta_y = 1 + X_{incr} = 1 + 0.10 = 1.10$$

Therefore

$$TAC_{2019} = 1.10 \, TAC_y = 1.10 \; (30\ 773) = 33\ 850 \text{ MT}$$

I_{inc} and *I_{dec}* values as calculated by Furman from the revised midwater MP:

I_{decr}	**0.85**
I_{inc}	**1.01**
X_{inc}	**0.10**
X_{decr}	**0.15**