Updated short-term projections of the South African anchovy resource using constant catch scenarios

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This document considers the short- and medium-term impact of a range of future constant catch scenarios on the anchovy resource based on a recently updated model to assist the SWG-PEL in making a scientifically justified final anchovy TAC recommendation.

Introduction

In January 2020 the Small Pelagic Scientific Working Group (SWG-PEL) declared Exceptional Circumstances for the South African anchovy resource as a result of (among other things) lower than previously expected recruitment resulting in recent survey estimates being outside the range assumed when OMP-18 (de Moor 2018) was simulation tested. The Total Allowable Catch (TAC) that would have been recommended under OMP-18 was thus set aside. An initial anchovy TAC was recommended based on the projected short- and medium-term impact of alternative constant catch levels on the anchovy resource (de Moor 2020a). The anchovy assessment has recently been updated to accommodate updates to the assumptions about anchovy maturity and hydro-acoustic survey bias (de Moor 2020b). This document presents results from short- and medium-term projections based on this updated model to assist the SWG-PEL in making a scientifically justified final anchovy TAC recommendation.

Methods

The model used for projections, based on the recent updated assessment (de Moor 2020b), is detailed in Appendix A. As before (de Moor 2020a), alternative scenarios are run assuming future recruitments to the resource in November each year vary about different proportions of the average historical recruitment of the full time series. A wider range of alternative proportions are now considered, assuming $N^A_{y,0}$ ranges from 10% to 150% of historical recruitment, with $N^{A,i}_{y,0} = N^A_{y,0} e^{\varepsilon^{A,i}_y}$, with $\varepsilon^{A,i}_y \sim N(0, 0.63^2)$, where the standard deviation is given by the Beverton Holt σ^A_r of the updated assessment (de Moor 2020b). Figure 1 shows the likelihood profile of the model predicted November survey biomass in 2019, used to incorporate some variability in the November 2019 starting point (de Moor 2020a).

A more detailed range of alternative catch levels are also now considered to better facilitate interpolation between the consequences of the alternative catch levels. Given the wider range of future recruitment and catch scenarios projected here, there were a substantial number of cases where the fixed catch could not be taken from the available biomass. Appendix A details how catch that cannot be taken from the available biomass is then taken from alternative ages and/or quarters (similar to de Moor 2020d). A maximum of 95% of available biomass is assumed to be fished at any point and thus the resource is never simulated to be completely fished out, but rather the realised catches from some scenarios (from the 10-50% of historical recruitment scenarios) are less than the assumed fixed catch. These projections assume recruitment is independent of the spawner biomass, and is therefore not negatively affected in these scenarios.

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Results and Discussion

Table 1 details the scenarios for which the fixed catch could not be taken given the available biomass. This occurs in <1% of cases when assuming future recruitment is about 50% of the historical average and does not occur for higher future recruitment scenarios. However, this occurs for a substantial percentage (1-74%) of years when future recruitment is about 10 or 30% of historical recruitment. In these years, the average amount by which the realised catch differs from the fixed catch is up to 75 000t or 180 000t for the 30% and 10% scenarios, respectively. It is therefore important to note that the statistics presented for these two recruitment scenarios in Tables 2-6, do not show the true impact of such a catch on the resource, but rather the impact of lower catch levels assuming the fixed catch is not taken and recruitment continues to vary about the given level independent of the remaining spawning biomass.

Table 2 gives the 5%ile, 20%ile and 50%ile of spawner biomass in 2020 relative to that in 2019 and Table 3 gives this ratio of these percentiles under the alternative catch scenarios compared to a no catch scenario. For example, considering the 20%ile of the statistics, under the 70% future recruitment scenario, the spawner biomass in 2020 is projected to decrease from 76% to 66% of that in 2019 as catch increases from 150 000t to 350 000t (Table 2b). Even under a no catch scenario, the spawner biomass in 2020 is projected to be below that in 2019 (at 84%). The spawner biomass in 2020 compared to that in 2019 therefore decreases from 91% to 78% of that which could be achieved if there were no catch in 2020 as catch increases from 150 000t to 350 000t (Table 3b).

Tables 4 to 6 give the projected 'depletion' of the resource, i.e. the short and medium term projected spawner biomass compared to the spawner biomass projected by the Dynamic B_0 model. For example, considering the 20%ile of the statistics, under a 70% future recruitment scenario the spawner biomass in 2020 is projected to range from 51% to 44% of the dynamic SSB_0 in 2019, as catch increases from 150 000t to 350 000t (Table 4b). The 'depletion' in 2020 is projected to range from 73% to 62% as catch increases from 150 000t to 350 000t (Table 5b). After 10 years of projection with recruitment about 70% of the historical average, the 'depletion' in 2029 is projected to range from 87% to 68% as catch increases from 150 000t to 350 000t (Table 6b).

Acknowledgements

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Table 1a. The proportion of years for which the catch could not be taken under different proportions (10% to 150% by row) of historical average recruitment and different future constant catch scenarios (columns). Grey cells indicate scenarios for which the catch could not always be taken.

	Proportion of historical average recruitment							
Catch (in thousand tons)	10%	30%	50%	70%	90%	110%	130%	150%
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
150	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00
200	0.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00
210	0.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00
220	0.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00
230	0.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00
240	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00
250	0.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00
260	0.56	0.01	0.00	0.00	0.00	0.00	0.00	0.00
270	0.58	0.01	0.00	0.00	0.00	0.00	0.00	0.00
280	0.61	0.01	0.00	0.00	0.00	0.00	0.00	0.00
290	0.63	0.02	0.00	0.00	0.00	0.00	0.00	0.00
300	0.65	0.03	0.00	0.00	0.00	0.00	0.00	0.00
310	0.67	0.03	0.00	0.00	0.00	0.00	0.00	0.00
320	0.68	0.04	0.00	0.00	0.00	0.00	0.00	0.00
330	0.70	0.05	0.00	0.00	0.00	0.00	0.00	0.00
340	0.72	0.05	0.00	0.00	0.00	0.00	0.00	0.00
350	0.74	0.06	0.00	0.00	0.00	0.00	0.00	0.00

Table 1b. The proportion of quarters for which the catch could not be taken under different proportions (10% to 150% by row) of historical average recruitment and different future constant catch scenarios (columns). Grey cells indicate scenarios for which the catch could not always be taken.

	Proportion of historical average recruitment							
Catch (in thousand tons)	10%	30%	50%	70%	90%	110%	130%	150%
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
150	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00
200	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
210	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00
220	0.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00
230	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00
240	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00
250	0.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00
260	0.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00
270	0.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00
280	0.49	0.01	0.00	0.00	0.00	0.00	0.00	0.00
290	0.51	0.01	0.00	0.00	0.00	0.00	0.00	0.00
300	0.53	0.01	0.00	0.00	0.00	0.00	0.00	0.00
310	0.55	0.01	0.00	0.00	0.00	0.00	0.00	0.00
320	0.57	0.02	0.00	0.00	0.00	0.00	0.00	0.00
330	0.59	0.02	0.00	0.00	0.00	0.00	0.00	0.00
340	0.61	0.03	0.00	0.00	0.00	0.00	0.00	0.00
350	0.63	0.03	0.00	0.00	0.00	0.00	0.00	0.00

Table 1c. The total catch not taken (in thousand tons) under different proportions (10% to 150% by row) of historical average recruitment and different future constant catch scenarios (columns). Grey cells indicate scenarios for which the catch could not always be taken.

Catch (in thousand tons)	Proportion of historical average recruitment							
	10%	30%	50%	70%	90%	110%	130%	150%
0	0	0	0	0	0	0	0	0
150	32323	0	0	0	0	0	0	0
200	125463	125	0	0	0	0	0	0
210	151485	211	0	0	0	0	0	0
220	179698	331	0	0	0	0	0	0
230	209719	473	0	0	0	0	0	0
240	241482	674	0	0	0	0	0	0
250	274657	961	0	0	0	0	0	0
260	309257	1414	0	0	0	0	0	0
270	345045	2058	1	0	0	0	0	0
280	382017	2987	30	0	0	0	0	0
290	420089	4303	57	0	0	0	0	0
300	459087	6096	84	0	0	0	0	0
310	498892	8328	125	0	0	0	0	0
320	539434	11098	175	0	0	0	0	0
330	580698	14483	225	0	0	0	0	0
340	622576	18437	294	0	0	0	0	0
350	664961	22990	414	0	0	0	0	0

Table 1d. The average annual catch (in thousand tons) not taken in cases where the full catch could not be taken under different proportions (10% to 150% by row) of historical average recruitment and different future constant catch scenarios (columns). Grey cells indicate scenarios for which the catch could not always be taken.

Catch (in thousand tons)	Proportion of historical average recruitment							
	10%	30%	50%	70%	90%	110%	130%	150%
0	0	0	0	0	0	0	0	0
150	40	0	0	0	0	0	0	0
200	68	42	0	0	0	0	0	0
210	75	30	0	0	0	0	0	0
220	82	41	0	0	0	0	0	0
230	89	47	0	0	0	0	0	0
240	97	42	0	0	0	0	0	0
250	104	42	0	0	0	0	0	0
260	111	40	0	0	0	0	0	0
270	119	39	1	0	0	0	0	0
280	126	45	15	0	0	0	0	0
290	134	46	28	0	0	0	0	0
300	142	49	42	0	0	0	0	0
310	150	56	42	0	0	0	0	0
320	158	59	58	0	0	0	0	0
330	165	64	56	0	0	0	0	0
340	173	71	49	0	0	0	0	0
350	181	75	52	0	0	0	0	0

Table 2a. The 5%ile of the ratio of spawner biomass in 2020 to that in 2019 under alternative catch scenarios. Results are given for different proportions (10% to 150% by row) of historical average recruitment and different future constant catch scenarios (columns).

Catch (in thousand tons)	Proportion of historical average recruitment							
	10%	30%	50%	70%	90%	110%	130%	150%
0	0.45	0.52	0.60	0.68	0.76	0.84	0.92	1.00
150	0.37	0.44	0.52	0.60	0.68	0.76	0.84	0.92
200	0.34	0.42	0.50	0.58	0.65	0.73	0.81	0.88
210	0.33	0.41	0.49	0.57	0.65	0.72	0.80	0.88
220	0.33	0.40	0.48	0.57	0.64	0.72	0.80	0.87
230	0.32	0.40	0.48	0.56	0.64	0.71	0.79	0.87
240	0.32	0.39	0.47	0.56	0.63	0.71	0.79	0.86
250	0.31	0.39	0.46	0.55	0.63	0.70	0.78	0.86
260	0.31	0.39	0.46	0.54	0.62	0.70	0.77	0.85
270	0.30	0.38	0.45	0.54	0.62	0.69	0.77	0.85
280	0.30	0.37	0.45	0.53	0.61	0.69	0.76	0.84
290	0.29	0.37	0.44	0.52	0.61	0.68	0.76	0.84
300	0.28	0.36	0.44	0.52	0.60	0.68	0.75	0.83
310	0.28	0.35	0.43	0.51	0.59	0.67	0.75	0.83
320	0.27	0.35	0.43	0.50	0.59	0.67	0.74	0.82
330	0.27	0.35	0.42	0.50	0.58	0.66	0.74	0.81
340	0.26	0.34	0.41	0.49	0.58	0.66	0.73	0.81
350	0.26	0.33	0.41	0.48	0.57	0.65	0.73	0.80

Table 2b. The 20%ile of the ratio of spawner biomass in 2020 to that in 2019 under alternative catch scenarios. Results are given for different proportions (10% to 150% by row) of historical average recruitment and different future constant catch scenarios (columns).

Catch (in thousand tons)	Proportion of historical average recruitment							
	10%	30%	50%	70%	90%	110%	130%	150%
0	0.47	0.59	0.72	0.84	0.97	1.09	1.22	1.34
150	0.39	0.52	0.64	0.76	0.89	1.01	1.13	1.26
200	0.37	0.49	0.62	0.74	0.86	0.99	1.11	1.23
210	0.36	0.48	0.61	0.73	0.86	0.98	1.10	1.23
220	0.36	0.48	0.60	0.73	0.85	0.97	1.10	1.22
230	0.35	0.47	0.60	0.72	0.85	0.97	1.09	1.22
240	0.35	0.47	0.59	0.72	0.84	0.96	1.09	1.21
250	0.34	0.46	0.59	0.71	0.84	0.96	1.08	1.21
260	0.34	0.46	0.58	0.71	0.83	0.95	1.08	1.20
270	0.33	0.45	0.58	0.70	0.83	0.95	1.07	1.19
280	0.33	0.45	0.57	0.70	0.82	0.94	1.07	1.19
290	0.32	0.44	0.57	0.69	0.81	0.94	1.06	1.18
300	0.31	0.44	0.56	0.69	0.81	0.93	1.06	1.18
310	0.31	0.43	0.55	0.68	0.80	0.93	1.05	1.17
320	0.31	0.42	0.55	0.67	0.80	0.92	1.05	1.17
330	0.30	0.42	0.54	0.67	0.79	0.92	1.04	1.16
340	0.30	0.41	0.54	0.66	0.79	0.91	1.04	1.16
350	0.29	0.41	0.53	0.66	0.78	0.91	1.03	1.15

Table 2c. The 50%ile of the ratio of spawner biomass in 2020 to that in 2019 under alternative catch scenarios. Results are given for different proportions (10% to 150% by row) of historical average recruitment and different future constant catch scenarios (columns).

Catch (in thousand tons)	Proportion of historical average recruitment							
	10%	30%	50%	70%	90%	110%	130%	150%
0	0.52	0.74	0.95	1.17	1.39	1.61	1.83	2.05
150	0.43	0.65	0.86	1.08	1.30	1.51	1.73	1.95
200	0.41	0.62	0.83	1.05	1.26	1.48	1.70	1.92
210	0.40	0.61	0.83	1.04	1.25	1.47	1.69	1.91
220	0.40	0.61	0.82	1.04	1.25	1.47	1.69	1.90
230	0.39	0.60	0.81	1.03	1.24	1.46	1.68	1.90
240	0.39	0.60	0.81	1.02	1.24	1.45	1.67	1.89
250	0.38	0.59	0.80	1.02	1.23	1.45	1.66	1.88
260	0.38	0.59	0.80	1.01	1.23	1.44	1.66	1.88
270	0.37	0.58	0.79	1.01	1.22	1.43	1.65	1.87
280	0.37	0.57	0.79	1.00	1.21	1.43	1.64	1.86
290	0.36	0.57	0.78	0.99	1.21	1.42	1.64	1.85
300	0.36	0.56	0.78	0.99	1.20	1.42	1.63	1.85
310	0.35	0.56	0.77	0.98	1.20	1.41	1.62	1.84
320	0.35	0.55	0.76	0.98	1.19	1.41	1.62	1.83
330	0.34	0.55	0.76	0.97	1.18	1.40	1.61	1.83
340	0.34	0.54	0.75	0.96	1.18	1.39	1.61	1.82
350	0.33	0.54	0.75	0.96	1.17	1.39	1.60	1.81

Table 3a. The 5%ile of the ratio of spawner biomass in 2020 to that in 2019 under alternative catch scenarios as a proportion of that ratio under the no catch scenario. Results are given for different proportions (10% to 150% by row) of historical average recruitment and different future constant catch scenarios (columns).

Catch (in thousand tons)	Proportion of historical average recruitment							
	10%	30%	50%	70%	90%	110%	130%	150%
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
150	0.82	0.84	0.87	0.88	0.89	0.90	0.91	0.92
200	0.76	0.79	0.82	0.84	0.86	0.87	0.88	0.89
210	0.75	0.78	0.81	0.84	0.85	0.86	0.87	0.88
220	0.73	0.77	0.80	0.83	0.84	0.86	0.87	0.88
230	0.72	0.76	0.79	0.82	0.84	0.85	0.86	0.87
240	0.71	0.75	0.78	0.81	0.83	0.84	0.86	0.87
250	0.70	0.74	0.77	0.80	0.82	0.84	0.85	0.86
260	0.69	0.73	0.76	0.80	0.82	0.83	0.84	0.85
270	0.68	0.72	0.75	0.79	0.81	0.83	0.84	0.85
280	0.66	0.71	0.74	0.77	0.80	0.82	0.83	0.84
290	0.65	0.70	0.73	0.77	0.80	0.81	0.83	0.84
300	0.64	0.69	0.72	0.76	0.79	0.81	0.82	0.83
310	0.62	0.68	0.72	0.75	0.78	0.80	0.82	0.83
320	0.61	0.67	0.71	0.74	0.77	0.79	0.81	0.82
330	0.60	0.66	0.70	0.73	0.77	0.79	0.80	0.82
340	0.59	0.65	0.68	0.72	0.76	0.78	0.80	0.81
350	0.57	0.63	0.67	0.71	0.75	0.78	0.79	0.81

Table 3b. The 20%ile of the ratio of spawner biomass in 2020 to that in 2019 under alternative catch scenarios as a proportion of that ratio under the no catch scenario. Results are given for different proportions (10% to 150% by row) of historical average recruitment and different future constant catch scenarios (columns).

	Proportion of historical average recruitment							
Catch (in thousand tons)	10%	30%	50%	70%	90%	110%	130%	150%
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
150	0.84	0.87	0.89	0.91	0.92	0.93	0.93	0.94
200	0.78	0.82	0.86	0.88	0.89	0.90	0.91	0.92
210	0.77	0.82	0.85	0.87	0.89	0.90	0.91	0.92
220	0.76	0.81	0.84	0.86	0.88	0.89	0.90	0.91
230	0.75	0.80	0.83	0.86	0.88	0.89	0.90	0.91
240	0.74	0.79	0.83	0.85	0.87	0.88	0.89	0.90
250	0.73	0.78	0.82	0.84	0.87	0.88	0.89	0.90
260	0.72	0.77	0.81	0.84	0.86	0.87	0.89	0.90
270	0.71	0.76	0.81	0.83	0.85	0.87	0.88	0.89
280	0.69	0.75	0.80	0.83	0.85	0.87	0.88	0.89
290	0.68	0.75	0.79	0.82	0.84	0.86	0.87	0.88
300	0.67	0.74	0.78	0.81	0.84	0.86	0.87	0.88
310	0.66	0.73	0.77	0.81	0.83	0.85	0.86	0.88
320	0.65	0.72	0.76	0.80	0.82	0.85	0.86	0.87
330	0.64	0.71	0.76	0.79	0.82	0.84	0.86	0.87
340	0.63	0.70	0.75	0.79	0.82	0.84	0.85	0.86
350	0.62	0.68	0.74	0.78	0.81	0.83	0.85	0.86

Table 3c. The 20%ile of the ratio of spawner biomass in 2020 to that in 2019 under alternative catch scenarios as a proportion of that ratio under the no catch scenario. Results are given for different proportions (10% to 150% by row) of historical average recruitment and different future constant catch scenarios (columns).

	Proportion of historical average recruitment							
Catch (in thousand tons)	10%	30%	50%	70%	90%	110%	130%	150%
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
150	0.84	0.88	0.90	0.92	0.93	0.94	0.95	0.95
200	0.79	0.84	0.87	0.89	0.91	0.92	0.93	0.94
210	0.78	0.84	0.87	0.89	0.90	0.92	0.93	0.93
220	0.77	0.83	0.86	0.88	0.90	0.91	0.92	0.93
230	0.76	0.82	0.85	0.88	0.89	0.91	0.92	0.93
240	0.75	0.81	0.85	0.87	0.89	0.90	0.91	0.92
250	0.74	0.81	0.84	0.87	0.89	0.90	0.91	0.92
260	0.73	0.80	0.84	0.86	0.88	0.89	0.91	0.92
270	0.72	0.79	0.83	0.86	0.88	0.89	0.90	0.91
280	0.71	0.78	0.83	0.85	0.87	0.89	0.90	0.91
290	0.70	0.77	0.82	0.85	0.87	0.88	0.89	0.91
300	0.69	0.77	0.81	0.84	0.86	0.88	0.89	0.90
310	0.68	0.76	0.81	0.84	0.86	0.88	0.89	0.90
320	0.67	0.75	0.80	0.83	0.86	0.87	0.89	0.90
330	0.66	0.74	0.80	0.83	0.85	0.87	0.88	0.89
340	0.65	0.74	0.79	0.82	0.85	0.87	0.88	0.89
350	0.64	0.73	0.78	0.82	0.84	0.86	0.88	0.89

Table 4a. The 5%ile of the ratio of spawner biomass in **2020** under alternative future catch scenarios to that in 2019 under the no catch scenario projected from the Dynamic B_0 model. Results are given for different proportions (10% to 150% by row) of historical average recruitment and different future constant catch scenarios (columns).

Catch (in thousand tons)	Proportion of historical average recruitment							
	10%	30%	50%	70%	90%	110%	130%	150%
0	0.30	0.35	0.40	0.46	0.51	0.56	0.61	0.67
150	0.25	0.30	0.35	0.40	0.45	0.51	0.56	0.61
200	0.23	0.28	0.33	0.39	0.44	0.49	0.54	0.59
210	0.22	0.27	0.33	0.38	0.43	0.48	0.54	0.59
220	0.22	0.27	0.32	0.38	0.43	0.48	0.53	0.58
230	0.22	0.27	0.32	0.38	0.43	0.48	0.53	0.58
240	0.21	0.26	0.31	0.37	0.42	0.47	0.53	0.58
250	0.21	0.26	0.31	0.37	0.42	0.47	0.52	0.57
260	0.21	0.26	0.31	0.36	0.42	0.47	0.52	0.57
270	0.20	0.25	0.30	0.36	0.41	0.46	0.52	0.57
280	0.20	0.25	0.30	0.35	0.41	0.46	0.51	0.56
290	0.19	0.25	0.30	0.35	0.41	0.46	0.51	0.56
300	0.19	0.24	0.29	0.35	0.40	0.45	0.50	0.56
310	0.19	0.24	0.29	0.34	0.40	0.45	0.50	0.55
320	0.18	0.23	0.28	0.34	0.39	0.45	0.50	0.55
330	0.18	0.23	0.28	0.33	0.39	0.44	0.49	0.55
340	0.17	0.23	0.28	0.33	0.39	0.44	0.49	0.54
350	0.17	0.22	0.27	0.32	0.38	0.44	0.49	0.54

Table 4b. The 20%ile of the ratio of spawner biomass in **2020** under alternative future catch scenarios to that in 2019 under the no catch scenario projected from the Dynamic B_0 model. Results are given for different proportions (10% to 150% by row) of historical average recruitment and different future constant catch scenarios (columns).

Catch (in thousand tons)	Proportion of historical average recruitment							
	10%	30%	50%	70%	90%	110%	130%	150%
0	0.31	0.40	0.48	0.56	0.65	0.73	0.81	0.90
150	0.26	0.35	0.43	0.51	0.59	0.68	0.76	0.84
200	0.25	0.33	0.41	0.49	0.58	0.66	0.74	0.82
210	0.24	0.32	0.41	0.49	0.57	0.66	0.74	0.82
220	0.24	0.32	0.40	0.49	0.57	0.65	0.73	0.82
230	0.24	0.32	0.40	0.48	0.57	0.65	0.73	0.81
240	0.23	0.31	0.40	0.48	0.56	0.65	0.73	0.81
250	0.23	0.31	0.39	0.48	0.56	0.64	0.72	0.81
260	0.23	0.31	0.39	0.47	0.56	0.64	0.72	0.80
270	0.22	0.30	0.39	0.47	0.55	0.64	0.72	0.80
280	0.22	0.30	0.38	0.47	0.55	0.63	0.71	0.80
290	0.21	0.30	0.38	0.46	0.54	0.63	0.71	0.79
300	0.21	0.29	0.37	0.46	0.54	0.63	0.71	0.79
310	0.21	0.29	0.37	0.46	0.54	0.62	0.70	0.79
320	0.20	0.28	0.37	0.45	0.53	0.62	0.70	0.78
330	0.20	0.28	0.36	0.45	0.53	0.61	0.70	0.78
340	0.20	0.28	0.36	0.44	0.53	0.61	0.69	0.78
350	0.19	0.27	0.36	0.44	0.52	0.61	0.69	0.77

Table 4c. The 50%ile of the ratio of spawner biomass in **2020** under alternative future catch scenarios to that in 2019 under the no catch scenario projected from the Dynamic B_0 model. Results are given for different proportions (10% to 150% by row) of historical average recruitment and different future constant catch scenarios (columns).

Catch (in thousand tons)	Proportion of historical average recruitment							
	10%	30%	50%	70%	90%	110%	130%	150%
0	0.35	0.49	0.64	0.78	0.93	1.08	1.22	1.37
150	0.29	0.43	0.58	0.72	0.87	1.01	1.16	1.30
200	0.27	0.41	0.56	0.70	0.84	0.99	1.14	1.28
210	0.27	0.41	0.55	0.70	0.84	0.99	1.13	1.28
220	0.27	0.41	0.55	0.69	0.84	0.98	1.13	1.27
230	0.26	0.40	0.54	0.69	0.83	0.98	1.12	1.27
240	0.26	0.40	0.54	0.68	0.83	0.97	1.12	1.26
250	0.26	0.40	0.54	0.68	0.82	0.97	1.11	1.26
260	0.25	0.39	0.53	0.68	0.82	0.96	1.11	1.26
270	0.25	0.39	0.53	0.67	0.82	0.96	1.10	1.25
280	0.25	0.38	0.53	0.67	0.81	0.96	1.10	1.25
290	0.24	0.38	0.52	0.66	0.81	0.95	1.09	1.24
300	0.24	0.38	0.52	0.66	0.80	0.95	1.09	1.24
310	0.24	0.37	0.52	0.66	0.80	0.94	1.09	1.23
320	0.23	0.37	0.51	0.65	0.80	0.94	1.08	1.23
330	0.23	0.37	0.51	0.65	0.79	0.94	1.08	1.22
340	0.23	0.36	0.50	0.65	0.79	0.93	1.08	1.22
350	0.22	0.36	0.50	0.64	0.78	0.93	1.07	1.21

Table 5a. The 5%ile of the ratio of spawner biomass in **2020** under alternative future catch scenarios to that in 2020 under the no catch scenario projected from the Dynamic B_0 model. Results are given for different proportions (10% to 150% by row) of historical average recruitment and different future constant catch scenarios (columns).

Catch (in thousand tons)	Proportion of historical average recruitment							
	10%	30%	50%	70%	90%	110%	130%	150%
0	0.70	0.73	0.76	0.78	0.80	0.81	0.83	0.84
150	0.57	0.61	0.65	0.68	0.71	0.73	0.75	0.76
200	0.52	0.57	0.62	0.65	0.68	0.70	0.72	0.74
210	0.51	0.56	0.61	0.65	0.67	0.70	0.72	0.73
220	0.50	0.56	0.60	0.64	0.66	0.69	0.71	0.73
230	0.50	0.55	0.59	0.63	0.66	0.68	0.71	0.72
240	0.49	0.54	0.59	0.62	0.65	0.68	0.70	0.72
250	0.48	0.53	0.58	0.62	0.65	0.67	0.70	0.72
260	0.47	0.53	0.57	0.61	0.64	0.67	0.69	0.71
270	0.46	0.52	0.57	0.60	0.64	0.66	0.68	0.71
280	0.45	0.51	0.56	0.60	0.63	0.66	0.68	0.70
290	0.44	0.50	0.55	0.59	0.63	0.65	0.67	0.69
300	0.43	0.50	0.55	0.59	0.62	0.65	0.67	0.69
310	0.42	0.49	0.54	0.58	0.61	0.64	0.66	0.68
320	0.41	0.48	0.53	0.57	0.61	0.64	0.66	0.68
330	0.40	0.47	0.52	0.57	0.60	0.63	0.65	0.67
340	0.39	0.46	0.52	0.56	0.59	0.63	0.65	0.67
350	0.38	0.46	0.51	0.55	0.59	0.62	0.64	0.66

Table 5b. The 20%ile of the ratio of spawner biomass in **2020** under alternative future catch scenarios to that in 2020 under the no catch scenario projected from the Dynamic B_0 model. Results are given for different proportions (10% to 150% by row) of historical average recruitment and different future constant catch scenarios (columns).

Catch (in thousand tons)	Proportion of historical average recruitment							
	10%	30%	50%	70%	90%	110%	130%	150%
0	0.71	0.75	0.79	0.81	0.83	0.85	0.86	0.87
150	0.59	0.65	0.70	0.73	0.76	0.79	0.80	0.82
200	0.55	0.62	0.67	0.71	0.74	0.76	0.78	0.80
210	0.54	0.61	0.66	0.70	0.73	0.76	0.78	0.80
220	0.53	0.60	0.65	0.70	0.73	0.75	0.78	0.79
230	0.53	0.60	0.65	0.69	0.72	0.75	0.77	0.79
240	0.52	0.59	0.64	0.69	0.72	0.75	0.77	0.79
250	0.51	0.58	0.64	0.68	0.72	0.74	0.76	0.78
260	0.50	0.58	0.63	0.67	0.71	0.74	0.76	0.78
270	0.49	0.57	0.62	0.67	0.70	0.73	0.76	0.78
280	0.49	0.56	0.62	0.66	0.70	0.73	0.75	0.77
290	0.48	0.56	0.61	0.66	0.69	0.72	0.75	0.77
300	0.47	0.55	0.61	0.65	0.69	0.72	0.74	0.77
310	0.46	0.54	0.60	0.65	0.68	0.72	0.74	0.76
320	0.46	0.54	0.60	0.64	0.68	0.71	0.74	0.76
330	0.45	0.53	0.59	0.64	0.67	0.71	0.73	0.75
340	0.44	0.52	0.58	0.63	0.67	0.70	0.73	0.75
350	0.43	0.52	0.58	0.62	0.66	0.70	0.72	0.75

Table 5c. The 50%ile of the ratio of spawner biomass in **2020** under alternative future catch scenarios to that in 2020 under the no catch scenario projected from the Dynamic B_0 model. Results are given for different proportions (10% to 150% by row) of historical average recruitment and different future constant catch scenarios (columns).

Catch (in thousand tons)	Proportion of historical average recruitment							
	10%	30%	50%	70%	90%	110%	130%	150%
0	0.73	0.79	0.83	0.86	0.88	0.89	0.90	0.91
150	0.61	0.70	0.75	0.79	0.82	0.84	0.86	0.87
200	0.58	0.67	0.73	0.77	0.80	0.83	0.84	0.86
210	0.57	0.66	0.73	0.77	0.80	0.82	0.84	0.86
220	0.56	0.66	0.72	0.76	0.79	0.82	0.84	0.85
230	0.56	0.65	0.72	0.76	0.79	0.82	0.84	0.85
240	0.55	0.65	0.71	0.76	0.79	0.81	0.83	0.85
250	0.54	0.64	0.71	0.75	0.78	0.81	0.83	0.85
260	0.53	0.63	0.70	0.75	0.78	0.81	0.83	0.84
270	0.53	0.63	0.70	0.74	0.78	0.80	0.82	0.84
280	0.52	0.62	0.69	0.74	0.77	0.80	0.82	0.84
290	0.51	0.62	0.69	0.73	0.77	0.80	0.82	0.83
300	0.50	0.61	0.68	0.73	0.77	0.79	0.81	0.83
310	0.50	0.60	0.68	0.73	0.76	0.79	0.81	0.83
320	0.49	0.60	0.67	0.72	0.76	0.79	0.81	0.83
330	0.48	0.59	0.67	0.72	0.75	0.78	0.81	0.82
340	0.47	0.59	0.66	0.71	0.75	0.78	0.80	0.82
350	0.47	0.58	0.66	0.71	0.75	0.78	0.80	0.82

Table 6a. The 5%ile of the ratio of spawner biomass in **2029** under alternative future catch scenarios to that in 2029 under the no catch scenario projected from the Dynamic B_0 model. Results are given for different proportions (10% to 150% by row) of historical average recruitment and different future constant catch scenarios (columns).

	Proportion of historical average recruitment							
Catch (in thousand tons)	10%	30%	50%	70%	90%	110%	130%	150%
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
150	0.00	0.55	0.73	0.81	0.85	0.88	0.90	0.91
200	0.00	0.40	0.64	0.75	0.80	0.84	0.87	0.88
210	0.00	0.36	0.63	0.73	0.79	0.83	0.86	0.88
220	0.00	0.33	0.61	0.72	0.78	0.82	0.85	0.87
230	0.00	0.30	0.59	0.71	0.77	0.82	0.85	0.87
240	0.00	0.27	0.57	0.70	0.76	0.81	0.84	0.86
250	0.00	0.24	0.55	0.68	0.75	0.80	0.83	0.85
260	0.00	0.21	0.53	0.67	0.74	0.79	0.82	0.85
270	0.00	0.17	0.51	0.66	0.73	0.78	0.82	0.84
280	0.00	0.14	0.50	0.64	0.72	0.78	0.81	0.84
290	0.00	0.11	0.48	0.63	0.71	0.77	0.80	0.83
300	0.00	0.07	0.46	0.62	0.70	0.76	0.80	0.82
310	0.00	0.03	0.44	0.60	0.69	0.75	0.79	0.82
320	0.00	0.01	0.42	0.59	0.68	0.74	0.78	0.81
330	0.00	0.00	0.40	0.58	0.67	0.73	0.78	0.81
340	0.00	0.00	0.38	0.57	0.66	0.73	0.77	0.80
350	0.00	0.00	0.36	0.55	0.65	0.72	0.76	0.79

Table 6b. The 20%ile of the ratio of spawner biomass in **2029** under alternative future catch scenarios to that in 2029 under the no catch scenario projected from the Dynamic B_0 model. Results are given for different proportions (0.10 to 1.50 by column) of historical average recruitment and different future constant catch scenarios (rows).

	Proportion of historical average recruitment							
Catch (in thousand tons)	10%	30%	50%	70%	90%	110%	130%	150%
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
150	0.01	0.68	0.81	0.87	0.90	0.91	0.93	0.94
200	0.00	0.57	0.74	0.82	0.86	0.89	0.90	0.92
210	0.00	0.54	0.73	0.81	0.85	0.88	0.90	0.91
220	0.00	0.52	0.72	0.80	0.85	0.87	0.89	0.91
230	0.00	0.50	0.70	0.79	0.84	0.87	0.89	0.90
240	0.00	0.48	0.69	0.78	0.83	0.86	0.88	0.90
250	0.00	0.45	0.68	0.77	0.82	0.86	0.88	0.90
260	0.00	0.43	0.66	0.76	0.82	0.85	0.87	0.89
270	0.00	0.41	0.65	0.75	0.81	0.85	0.87	0.89
280	0.00	0.39	0.64	0.74	0.80	0.84	0.86	0.88
290	0.00	0.36	0.62	0.73	0.80	0.83	0.86	0.88
300	0.00	0.34	0.61	0.73	0.79	0.83	0.85	0.87
310	0.00	0.31	0.60	0.72	0.78	0.82	0.85	0.87
320	0.00	0.29	0.58	0.71	0.77	0.82	0.84	0.87
330	0.00	0.26	0.57	0.70	0.77	0.81	0.84	0.86
340	0.00	0.24	0.56	0.69	0.76	0.80	0.83	0.86
350	0.00	0.21	0.54	0.68	0.75	0.80	0.83	0.85

Table 6c. The 50%ile of the ratio of spawner biomass in **2029** under alternative future catch scenarios to that in 2029 under the no catch scenario projected from the Dynamic B_0 model. Results are given for different proportions (0.10 to 1.50 by column) of historical average recruitment and different future constant catch scenarios (rows).

Catch (in thousand tons)	Proportion of historical average recruitment							
	10%	30%	50%	70%	90%	110%	130%	150%
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
150	0.27	0.77	0.86	0.90	0.92	0.94	0.95	0.95
200	0.04	0.69	0.81	0.87	0.90	0.92	0.93	0.94
210	0.01	0.67	0.81	0.86	0.89	0.91	0.93	0.94
220	0.00	0.66	0.80	0.86	0.89	0.91	0.92	0.93
230	0.00	0.64	0.79	0.85	0.88	0.90	0.92	0.93
240	0.00	0.62	0.78	0.84	0.88	0.90	0.92	0.93
250	0.00	0.61	0.77	0.83	0.87	0.90	0.91	0.92
260	0.00	0.59	0.76	0.83	0.87	0.89	0.91	0.92
270	0.00	0.57	0.75	0.82	0.86	0.89	0.90	0.92
280	0.00	0.55	0.74	0.81	0.86	0.88	0.90	0.91
290	0.00	0.54	0.73	0.81	0.85	0.88	0.90	0.91
300	0.00	0.52	0.72	0.80	0.85	0.87	0.89	0.91
310	0.00	0.50	0.71	0.79	0.84	0.87	0.89	0.91
320	0.00	0.49	0.70	0.79	0.84	0.87	0.89	0.90
330	0.00	0.47	0.69	0.78	0.83	0.86	0.88	0.90
340	0.00	0.46	0.68	0.77	0.83	0.86	0.88	0.90
350	0.00	0.44	0.67	0.77	0.82	0.85	0.88	0.89

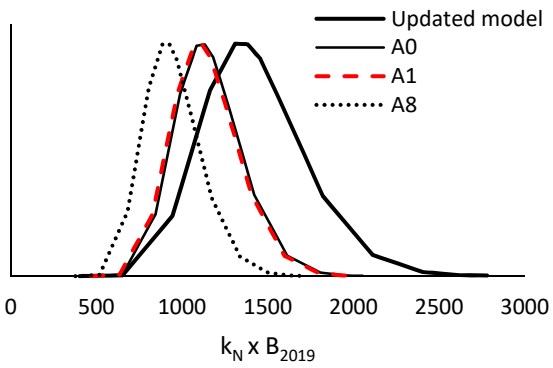

Figure 1. The AD Model Builder estimated likelihood profile over $k_N^A B_{2019}^A$ for the updated model of de Moor (2020b), compared to the models A_0, A_1 and A_8 of de Moor (2020c).

Appendix A: Projections using constant catch assumptions (updated from de Moor 2020a)

The projections are run from November $y_n = 2019$ to November $y_{end} = 2029$. The notation used corresponds to that of Appendix A and Table A1 of de Moor (2020e).

- The numbers-at-age are calculated according to equation (A.1) of de Moor (2020e)

$$N^A_{y,a} = \left(\left(\left(\left(N^A_{y-1,a-1}e^{-M^A_{a-1,y}/8} - C^A_{y,1,a-1}\right)e^{-M^A_{a-1,y}/4} - C^A_{y,2,a-1}\right)e^{-M^A_{a-1,y}/4} - C^A_{y,3,a-1}\right)e^{-M^A_{a-1,y}/4} - C^A_{y,4,a-1}\right)e^{-M^A_{a-1,y}/8}$$

$$y_n \le y \le y_{end}\,,\ 1 \le a \le 3$$

$$N^A_{y,4+} = \left(\left(\left(\left(N^A_{y-1,3}e^{-M^A_{3,y}/8} - C^A_{y,1,3}\right)e^{-M^A_{3,y}/4} - C^A_{y,2,3}\right)e^{-M^A_{3,y}/4} - C^A_{y,3,3}\right)e^{-M^A_{3,y}/4} - C^A_{y,4,3}\right)e^{-M^A_{3,y}/8}$$

$$+\left(\left(\left(\left(N^A_{y-1,4+}e^{-M^A_{4+,y}/8} - C^A_{y,1,4+}\right)e^{-M^A_{4+,y}/4} - C^A_{y,2,4+}\right)e^{-M^A_{4+,y}/4} - C^A_{y,3,4+}\right)e^{-M^A_{4+,y}/4} - C^A_{y,4,4+}\right)e^{-M^A_{4+,y}/8}$$

$$y_n \le y \le y_{end}$$

- Natural mortality is assumed to be time-invariant at $M^A_{0,y} = M^A_{1+,y} = 1.2$ year^{-1} for all years, as per the initial assessment of de Moor (2020e).
- November biomass and spawner biomass are calculated according to equations (A.7) and (A.8) of de Moor (2020e), with the numbers-at-length given according to equations (A.2) and (A.3) of de Moor (2020e):

$$B^A_y = \sum_{l=1.5^-}^{16^+} N^A_{y,l} w^A_l \qquad y_n \le y \le y_{end}$$

$$SSB^A_y = \sum_{l=1.5^-}^{16^+} f^A_l N^{A,1+}_{y,l} w^A_l \qquad y_n \le y \le y_{end}$$

$$N^A_{y,l} = \sum_{a=0}^{4+} A^{sur}_{a,l} N^A_{y,a} \qquad y_n \le y \le y_{end},\ 1.5^- cm \le l \le 16^+ cm$$

$$N^{A,1+}_{y,l} = \sum_{a=1}^{4+} A^{sur}_{a,l} N^A_{y,a} \qquad y_n \le y \le y_{end},\ 1.5^- cm \le l \le 16^+ cm$$

- Eight alternatives levels of future recruitment $N^A_{y,0}$ are assumed:
  - i) 10% of the historical average 1984-2018 recruitment of 57 billion.
  - ii) 30% of the historical average 1984-2018 recruitment of 170 billion.
  - iii) 50% of the historical average 1984-2018 recruitment of 283 billion.
  - iv) 70% of the historical average 1984-2018 recruitment of 396 billion.
  - v) 90% of the historical average 1984-2018 recruitment of 509 billion.
  - vi) 110% of the historical average 1984-2018 recruitment of 623 billion.
  - vii) 130% of the historical average 1984-2018 recruitment of 736 billion.
  - viii) 150% of the historical average 1984-2018 recruitment of 849 billion.
- Quarterly pulse catches are calculated as per equation (A.12) of de Moor (2020e):

$$C^A_{y,1,a} = N^A_{y-1,a}e^{-M^A_{a,y}/8}S_{y,1,a}F_{y,1}$$

$$C^A_{y,2,a} = \left(N^A_{y-1,a}e^{-M^A_{a,y}/8} - C^A_{y,1,a}\right)e^{-M^A_{a,y}/4}S_{y,2,a}F_{y,2}$$

$$C^A_{y,3,a} = \left(\left(N^A_{y-1,a}e^{-M^A_{a,y}/8} - C^A_{y,1,a}\right)e^{-M^A_{a,y}/4} - C^A_{y,2,a}\right)e^{-M^A_{a,y}/4}S_{y,3,a}F_{y,3}$$

$$C^A_{y,4,a} = \left(\left(\left(N^A_{y-1,a}e^{-M^A_{a,y}/8} - C^A_{y,1,a}\right)e^{-M^A_{a,y}/4} - C^A_{y,2,a}\right)e^{-M^A_{a,y}/4} - C^A_{y,3,a}\right)e^{-M^A_{a,y}/4}S_{y,4,a}F_{y,4} \qquad y_n \le y \le y_{end},\ 0 \le a \le 4^+$$

where

$$F_{y,1} = \frac{p^{catch}_1 C^{ton}_y}{\sum_{a=0}^{4^+} N^A_{y-1,a}e^{-M^A_{a,y}/8}w^c_{1,a}S_{y,1,a}}$$

$$F_{y,2} = \frac{p_2^{catch} C_y^{ton}}{\sum_{a=0}^{4^+}\left(N_{y-1,a}^A e^{-M_{a,y/8}^A} - C_{y,1,a}^A\right)e^{-M_{a,y/4}^A} w_{2,a}^c S_{y,2,a}}$$

$$F_{y,3} = \frac{p_3^{catch} C_y^{ton}}{\sum_{a=0}^{4^+}\left(\left(N_{y-1,a}^A e^{-M_{a,y/8}^A} - C_{y,1,a}^A\right)e^{-M_{a,y/4}^A} - C_{y,2,a}^A\right)e^{-M_{a,y/4}^A} w_{3,a}^c S_{y,3,a}}$$

$$F_{y,4} = \frac{p_4^{catch} C_y^{ton}}{\sum_{a=0}^{4^+}\left(\left(\left(N_{y-1,a}^A e^{-M_{a,y/8}^A} - C_{y,1,a}^A\right)e^{-M_{a,y/4}^A} - C_{y,2,a}^A\right)e^{-M_{a,y/4}^A} - C_{y,3,a}^A\right)e^{-M_{a,y/4}^A} w_{4,a}^c S_{y,4,a}} \quad y_n \le y \le y_{end}$$

and

$$w_{q,a}^c = \begin{cases} \left[1 - \frac{(2q-1)}{8}\right] w_a^A + \frac{(2q-1)}{8} w_{a+1}^A & a < 4^+ \\ w_a^A & a = 4^+ \end{cases} \qquad 0 \le a \le 4^+, 1 \le q \le 4$$

and $w_a^A = \sum_{l=1.5^1}^{16^+} A_{a,l}^{sur} w_l^A$. A penalty is imposed to ensure that $S_{y,q,a} F_{y,q} < 0.95$ for all a.

- The catch tonnage is split between quarters based on the average over the most recent 5 years: $p_1^{catch} = 0.004$, $p_1^{catch} = 0.304$, $p_1^{catch} = 0.514$ and $p_1^{catch} = 0.178$.
- In cases where the above constraints would otherwise result in the realised catch being less than the scenario being tested, the selectivity is increased, with the catch being progressively taken from the younger ages first, and then from subsequent quarters within the same year. For example, selectivity at age 0 in quarter $q = 1$ is increased, such that a maximum of 95% of the available biomass of 0 year olds is removed:

  i) $C_{y,q,0}^A = 0.95\left(N_{y-1,0}^A e^{-M_{0,y/8}^A}\right)$

  ii) If $\frac{p_q^{catch} C_y^{ton} - C_{y,q,0}^A w_{q,0}^c}{\sum_{a=1}^{4+}\left(N_{y-1,a}^A e^{-M_{a,y/8}^A}\right) S_{y,q,a}^A w_{q,a}^c} \times S_{y,q,1}^S \le 0.95$, then

  $C_{y,1,a}^A = N_{y-1,a}^A e^{-M_{a,y/8}^A} S_{y,1,a} \frac{p_1^{catch} C_y^{ton} - C_{y,1,0}^A w_{1,0}^c}{\sum_{a=1}^{4+}\left(N_{y-1,a}^A e^{-M_{a,y/8}^A}\right) S_{y,1,a}^A w_{1,a}^c}$ for $1 \le a \le 4^+$, else selectivity at age 1 is increased, such that a maximum of 95% of the available biomass of 1 year olds is removed:

  $C_{y,q,1}^A = 0.95\left(N_{y-1,1}^A e^{-M_{1,y/8}^A}\right)$

  and catches for ages 2 to 4^+ are calculated as follows:

  iii) If $\frac{p_q^{catch} C_y^{ton} - \sum_{a=0}^{1} C_{y,q,a}^A w_{q,a}^c}{\sum_{a=2}^{4+}\left(N_{y-1,a}^A e^{-M_{a,y/8}^A}\right) S_{y,q,a}^A w_{q,a}^c} \times S_{y,q,2}^S \le 0.95$, then

  $C_{y,1,a}^A = N_{y-1,a}^A e^{-M_{a,y/8}^A} S_{y,1,a} \frac{p_1^{catch} C_y^{ton} - \sum_{a=0}^{1} C_{y,q,a}^A w_{q,a}^c}{\sum_{a=2}^{4+}\left(N_{y-1,a}^A e^{-M_{a,y/8}^A}\right) S_{y,1,a}^A w_{1,a}^c}$ for $2 \le a \le 4^+$, else selectivity at age 2 is increased, such that a maximum of 95% of the available biomass of 2 year olds is removed:

  $C_{y,q,2}^A = 0.95\left(N_{y-1,2}^A e^{-M_{2,y/8}^A}\right)$

  and catches for ages 3 to 4^+ are calculated as follows:

  iv) If $\frac{p_q^{catch} C_y^{ton} - \sum_{a=0}^{2} C_{y,q,a}^A w_{q,a}^c}{\sum_{a=3}^{4+}\left(N_{y-1,a}^A e^{-M_{a,y/8}^A}\right) S_{y,q,a}^A w_{q,a}^c} \times S_{y,q,3}^S \le 0.95$, then

  $C_{y,1,a}^A = N_{y-1,a}^A e^{-M_{a,y/8}^A} S_{y,1,a} \frac{p_1^{catch} C_y^{ton} - \sum_{a=0}^{2} C_{y,q,a}^A w_{q,a}^c}{\sum_{a=3}^{4+}\left(N_{y-1,a}^A e^{-M_{a,y/8}^A}\right) S_{y,1,a}^A w_{1,a}^c}$ for $3 \le a \le 4^+$, else selectivity at age 3 is increased, such that a maximum of 95% of the available biomass of 3 year olds is removed:

  $C_{y,q,3}^A = 0.95\left(N_{y-1,3}^A e^{-M_{3,y/8}^A}\right)$

  and catches for ages 4^+ are calculated as follows:

v) If $\frac{p_q^{catch} C_y^{ton} - \sum_{a=0}^{3} C_{y,q,a}^{A} w_{q,a}^{c}}{\left(N_{y-1,4+}^{A} e^{-M_{4+,y/8}^{A}}\right) S_{y,q,4+}^{A} w_{q,4+}^{c}} \times S_{y,q,4+}^{S} \leq 0.95$, then

$C_{y,1,4+}^{A} = N_{y-1,4+}^{A} e^{-M_{4+,y/8}^{A}} S_{y,1,4+} \frac{p_1^{catch} C_y^{ton} - \sum_{a=0}^{3} C_{y,q,a}^{A} w_{q,a}^{c}}{\left(N_{y-1,4+}^{A} e^{-M_{4+,y/8}^{A}}\right) S_{y,q,4+}^{A} w_{q,4+}^{c}}$, else selectivity at age 4^{+} is increased, such that a maximum of 95% of the available biomass of 4^{+} year olds is removed:

$C_{y,q,4+}^{A} = 0.95 \left(N_{y-1,4+}^{A} e^{-M_{4+,y/8}^{A}}\right)$ [1].

[1] There are still cases where the full catch is not realised because this equation reaches the constraint, even after the modifications to the selectivity are made. This is indicated by grey shading in the results tables.