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DETAILED ANALYSIS OF THE CATCH-AT-LENGTH AND AGE COMPOSITION DATA TO CHECK RESULTS FOR RECENT YEAR RECRUITMENT ESTIMATES FOR EASTERN ATLANTIC BLUEFIN TUNA

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SUMMARY

A model-free exercise was carried out to determine the plausibility of the high 2004-2007 recruitment estimates that resulted from the VPA base run for Eastern Atlantic bluefin tuna. Information on year class strength from the base run was compared to information on year class strength present in the catch at length data for the Japanese Northeast Atlantic longline fishery and the trap fishery. The analysis revealed inconsistencies: while the VPA results suggest the 2004-2007 cohorts are of near equal strength to the 2003 cohort, the catch at length data suggest that the 2003 cohort was certainly stronger. In addition, the catch at length information was somewhat more compatible with alternative VPA runs that indicate lower recruitment and lower biomass in recent years than the VPA base run does. This analysis suggests applying some assessment approach which will result in a reduction in the size of the 2004-2007 cohorts relative to the 2003 cohort. However, the analysis did not allow a quantification of the extent of change in VPA specifications that would best reflect the available data as a whole.

KEYWORDS

bluefin tuna, recruitment, catch-at-length, cohort strength

1. Introduction

Results from the Virtual Population Analysis (VPA) and Stock Synthesis 3 (SS3) show different patterns of recruitment in recent years for Eastern Atlantic bluefin tuna (EABT), with biomass being estimated to be much higher for the VPA than for SS3. While SS3 results suggest that only the 2003 year class was strong, the VPA suggests year-classes of similar size to 2003 for the next four years (2004-2007). In the VPA, estimates of recent recruitment are very sensitive to the addition of the terminal years of data. In particular, the addition of the 2015 data results in very high 2004-2007 year classes that were not particularly evident in earlier retrospectives, which raises concerns about the plausibility that these high recruitment estimates reflect reality. While SS3 should, in theory, be better informed as the model makes use of both length information and direct age information to estimate age composition (available for only part of the years and ages covered by the assessment), SS3 results may be compromised by seeking a longer period summary of conflicting datasets. To attempt to resolve these differences and assess the plausibility of the high 2004-2007 recruitment estimates, we compare VPA results to information present in the catch-at-length (CAL) data in a model-free way, following the methodology described below.

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2. Methods

2.1. Comparing CAL information to the VPA base run results

We compare proportions-at-age estimated from the VPA base run with those provided by the CAL for two fisheries of interest: 1. the Japanese Northeast Atlantic longline fishery and the trap fishery (i.e., Spanish-Morocco trap up to 2011 and Morocco-Portugal trap from 2012 onward). The comparison is made over the years 2006 to 2015 to focus on the 2003 to 2007 cohorts that are of particular interest.

Annual proportions-at-age ($P_{y,a}^{VPA}$) are calculated from VPA estimates of numbers-at-age ($N_{y,a}^{VPA}$) as follows:

$$P_{y,a}^{VPA} = N_{y,a}^{VPA} / \sum_{a=1}^{10} N_{y,a}^{VPA} \tag{1}$$

where y is year and a is age (using a plus group of 10+ in accordance with the base case scenario for the EABT stock assessment).

Proportions-at-age from the CAL data ($P_{y,f,a}^{CAL}$) from each of the two fisheries are calculated by converting length composition (C) to selectivity-corrected length composition (C^*) and then converting the output to age-based results using year-specific estimates of probabilities of age given length ($A_{y,a,l}$) generated using the combined forward-inverse age-length keys (ALKs) developed for EABT (SCRS/2017/179).

Selectivity-corrected length composition by year (y), fishery (f) and length (l) is obtained by dividing the CAL matrices for individual fisheries by the selectivity (S) vectors obtained from SS3 (**Figure 1**), as follows:

$$C_{f,y,l}^{*} = C_{f,y,l} / S_{f,y,l} \tag{2}$$

Selectivity-corrected length composition is then converted to an age-basis using matrices of probabilities of age given length, $A_{y,a,l}$:

$$C_{f,y,a}^{*} = \sum_{l=20}^{349} C_{f,y,l}^{*} A_{y,a,l} \tag{3}$$

Finally, catches are normalized to obtain proportions-at-age:

$$P_{f,y,a}^{CAL} = C_{f,y,a}^{*} \Big/ \sum_{a=1}^{10} C_{f,y,a}^{*} \tag{4}$$

We select a range of ages, a', over which to compare proportions-at-age from the VPA base run to those calculated from the CAL, and renormalize over the range of ages to compare results. The range of ages was chosen based on selectivities and the reliability of the ALK conversions. Based on selectivity, ages were truncated on the left at age 3 for the Japanese NE Atlantic longline index until 2009 and age 6 for this index from 2010 onward; similarly truncation was at age 3 for the trap index until 2011 and 4 from 2012 onward – see **Figure 1** for the selectivity curves by fishery and time period. In addition, because of concerns that fish belonging to the plus group 10+ could have been mis-assigned to age 9 in the ALK, the analysis was truncated with age 8 for the oldest age. The difference matrix, $\Delta P_{f,y,a'}$, is expected to show a pattern for specific cohorts if, indeed, the CAL data are incompatible with the VPA results:

$$\Delta P_{f,y,a'} = P^{CAL}_{f,y,a'} - P^{VPA}_{y,a'} \tag{5}$$

2.2 Comparing CAL information to alternatively tuned VPA runs

Four alternatively tuned VPA scenarios are presented here (**Appendix 1** shows all the configurations that were examined) and the resulting proportions-at-age were compared with the proportions-at-age in the CAL data of the two fisheries of interest following the methodology outlined in 2.1. These alternative runs were not chosen as potential replacements for the current base case VPA, but rather because they are examples which exhibit either or both lesser 2004-2007 recruitments and a subsequent lower recent trend in biomass than the base case run (**Figures 2 and 3**). Detailed descriptions of the alternative runs are listed below.

i. **FrSplt_NoLarv**
   The French aerial survey was split and the larval index removed.
ii. **NoFrLarJPNLLBB**
   The following 4 indices were removed: French aerial survey, larval index, recent part of the Japanese longline NE Atlantic index (JPLL NEATL 2) and recent part of the bait boat index (SPBB2)
iii. **350Pcent**
   Variances associated with the French aerial survey (0.509), larval survey (0.737) and Japanese longline CPUE (0.4151) were increased by 350 percent compared to the base case (2.291, 3.317 and 1.86, respectively) and then used as weighing factors for their respective indices in the VPA.
iv. **Fratio**
   The F-ratios from the first two time periods (1968-1980; 1981-1995), which were estimated separately in the base case (1.401 and 0.684, respectively), were merged and fixed at a value below one (0.75) since appreciable numbers of smaller fish were caught during this period and there seems no reason to believe that the catch of fish of ages 10+ would have been larger than the catch of age 9 fish. The F-ratio for the third period (1996-2007), estimated at 2.632 in the base case, was re-estimated in the new run (2.385). During this period, the French and Spanish purse seine fleets started to develop and move to the spawning grounds, targeting larger animals. The F-ratio for the last period (2007-2015), which was left to be estimated by the VPA in the base case (1.688), was rather fixed at 1 here.

A sum of squares metric (SS) was calculated for the base run and alternative runs to quantify the differences observed between the information present in the CAL data of the two fisheries of interest and the estimated numbers at age resulting from each VPA run (see **Table A1** of **Appendix 1** for results for all the runs examined). In addition absolute error differences for ages 6 to 8 from year classes 2003-2007 in the catches of the JPN LL NEA fishery and trap fishery can also be examined for the Frario run (**Appendix 1, Figure A1).** Similar figures were examined for all other runs, but we chose to only report the SS statistic below that focuses on the key issue at hand. SS provides a relative measure from which to compare the results from each run and establish which resulted in a catch at age matrix that was most similar to the information present in the CAL data for the two fisheries. The ranges of ages and years chosen for each fishery and time period are detailed in section 2.1.

$$SS_{f,\text{VPAalt}} = \sum_{y}\sum_{a}(P^{CAL}_{f,y,a'} - P^{\text{VPAalt}}_{f,y,a'})^2 \tag{6}$$

3. Results

Table 1 illustrates the discrepancies between the catch at age information present in the CAL data and the VPA base run results. There does not appear to be a systematic/clear-cut pattern of residuals in $\Delta P_{f,y,a'}$, but these results do nevertheless appear to indicate that the strength of the 2003 cohort is being underestimated in the VPA base run. This is clearly apparent in the Japanese longline data (**Table 1B**) where the numbers associated with the 2003 cohort (outlined in black) are nearly all highly positive while those numbers associated with the 2004-2007 cohorts are, for the most part negative. The one exception is the strongly positive number assigned to age 3 in 2007 (.27) but this could be a result of the fact that there remains a small positive bias in the ALK for assigning ages to younger fish (due to issues in the otolith age readings where false bands may have occasionally lead to over-counting of bands in young fish). As such, it is likely that some of the fish that were assigned to age 3 in 2007 actually belong to the 2003 cohort. It is unclear why age 8 appears systematically stronger in the CAL data compared to the VPA base case for 2010 to 2015, even though the 2004-2007 cohorts appear systematically weaker in early age stages (**Table 1A**). This result could be due, in part, to the fact that the ALK is more reliably able to assigning ages to younger fish compared to older fish. In the TP fishery (**Table 1A**), the 2003 cohorts appears stronger in the CAL data compared to the VPA base run from 2009 to 2011. Subsequent cohorts do not appear to have such a strong signal from 2010 to 2015. In summary then, use of this approach for the JPN LL data provides qualitative indications that the base case VPA is over-estimating the strength of the 2004-2007 cohorts; the trap data does not provide as clear results, possibly because selectivity there is more variable over time.

All four alternative runs resulted in a lower SS than the base case VPA run (**Table 2**) but the differences in SS between the alternative runs and the base case scenario are relatively small, and hence unfortunately provide little basis for assigning preference.

4. Discussion

Results are not clear-cut (due to issues remaining in the ALK and potential mismatch between the selectivity vectors estimated and true selectivities of the fisheries which may not be constant over time as assumed) but **Table 1** suggests that the 2003 cohort was certainly stronger than the 2004-2007 cohorts (which conflicts with what the VPA base run indicates). The VPA base run recruitment estimates for the more recent years (2004-2007) are likely to be too high, but the extent to which they have been overestimated is unclear. With the alternative runs there is some improvement in SS but these improvements are not considerable.

Hence this analysis suggests applying some approach (e.g. an alternative F-ratio formulation, or down-weighing in the VPA fit of at least some of the indices showing recent upward trends) which will reduce the size of the 2004-2007 cohorts relative to the 2003 cohort, compared to their near equality in the base case VPA run. However this analysis in isolation is unable to quantify the extent of change in VPA specifications that would best reflect the available data (both abundance index and size structure) as a whole.

Table 1. Difference matrices, $\Delta P_{f,y,a'}$, illustrating the differences in proportions-at-age between the CAL information and the VPA base run for A. the trap fishery and B. the JPN LL NEA fishery. The 2003 cohort is outlined in black, with a lower outline indicating the span of the 2004-2007 cohorts. Colder colors/negative numbers indicate that the age group in question appears weaker in the CAL data than in the VPA base case in that specific year, while warmer colors/positive numbers indicate that the age group in question appears stronger in the CAL data than in the VPA base case in that specific year.

A

YEAR/AGE	3	4	5	6	7	8
2006	-0.41	-0.20	0.04	0.22	0.18	0.16
2007	-0.34	-0.24	0.13	0.27	0.10	0.08
2008	-0.33	-0.24	-0.10	0.03	0.18	0.47
2009	-0.35	-0.21	-0.05	0.24	0.28	0.08
2010	-0.21	-0.28	-0.14	0.01	0.33	0.29
2011	-0.15	-0.15	-0.18	-0.01	0.00	0.50
2012	-	-0.16	-0.08	0.07	0.05	0.12
2013	-	0.39	0.08	-0.13	-0.20	-0.13
2014	-	-0.06	0.28	-0.09	-0.11	-0.02
2015	-	-0.06	0.34	-0.11	-0.08	-0.09

B

YEAR/AGE	3	4	5	6	7	8
2006	-0.15	0.29	-0.07	-0.04	-0.03	-0.01
2007	0.27	0.01	-0.08	-0.11	-0.05	-0.03
2008	-0.19	-0.20	0.20	0.13	0.02	0.04
2009	-0.24	-0.16	-0.12	0.19	0.33	0.01
2010	-	-	-	-0.13	0.19	-0.06
2011	-	-	-	-0.02	-0.23	0.25
2012	-	-	-	-0.22	0.15	0.07
2013	-	-	-	-0.16	-0.10	0.26
2014	-	-	-	-0.18	-0.17	0.35
2015	-	-	-	-0.34	-0.10	0.44

Table 2. SS metric calculated for the 4 alternative runs and the base case scenario for the trap fishery and the JPN LL NEA fishery. The abbreviations for the alternative runs are explained in the text.

	TP		JPN LL NEA	
Alternative run	**SS**	**%change from base**	**SS**	**%change from base**
Fratio	2.46	0.12	1.34	0.06
NoFrLarJPNLLBB	2.50	0.11	1.35	0.06
350Pcent	2.55	0.09	1.36	0.05
Frsplt_nolarv	2.65	0.06	1.38	0.03
Base	2.81	0.00	1.43	0.00

Figure 1. Selectivity curves for **A.** the trap fishery and **B.** the Japanese longline fishery in the NE Atlantic. Note that only the earlier periods shown are utilized for the comparisons reported in the main text.

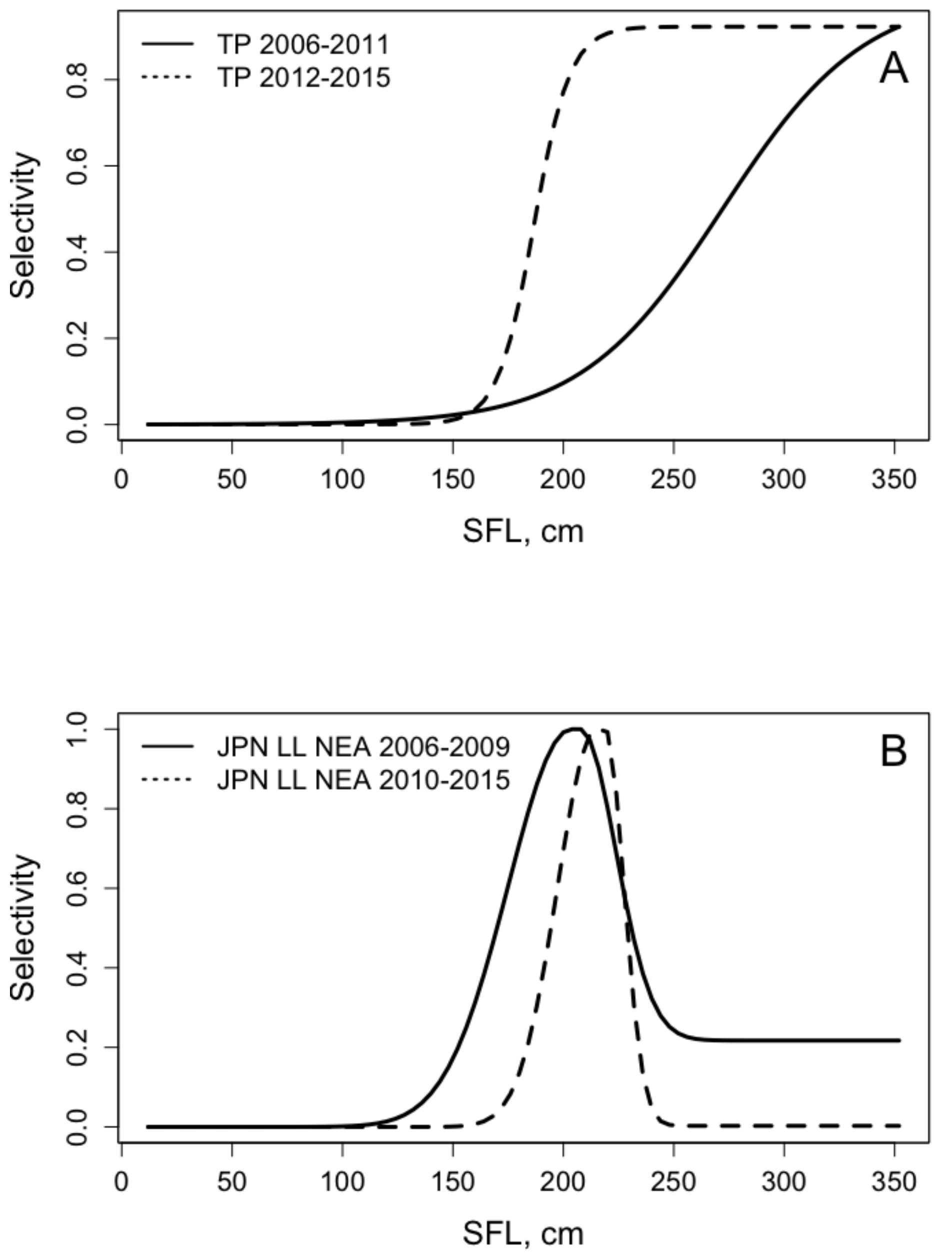

Figure 2. Spawning stock biomass (SSB) and recruitment estimates (R) resulting from the 4 alternative runs compared to the base case scenario. The 2003 cohort is indicated by the dotted line on the lower recruitment plot.

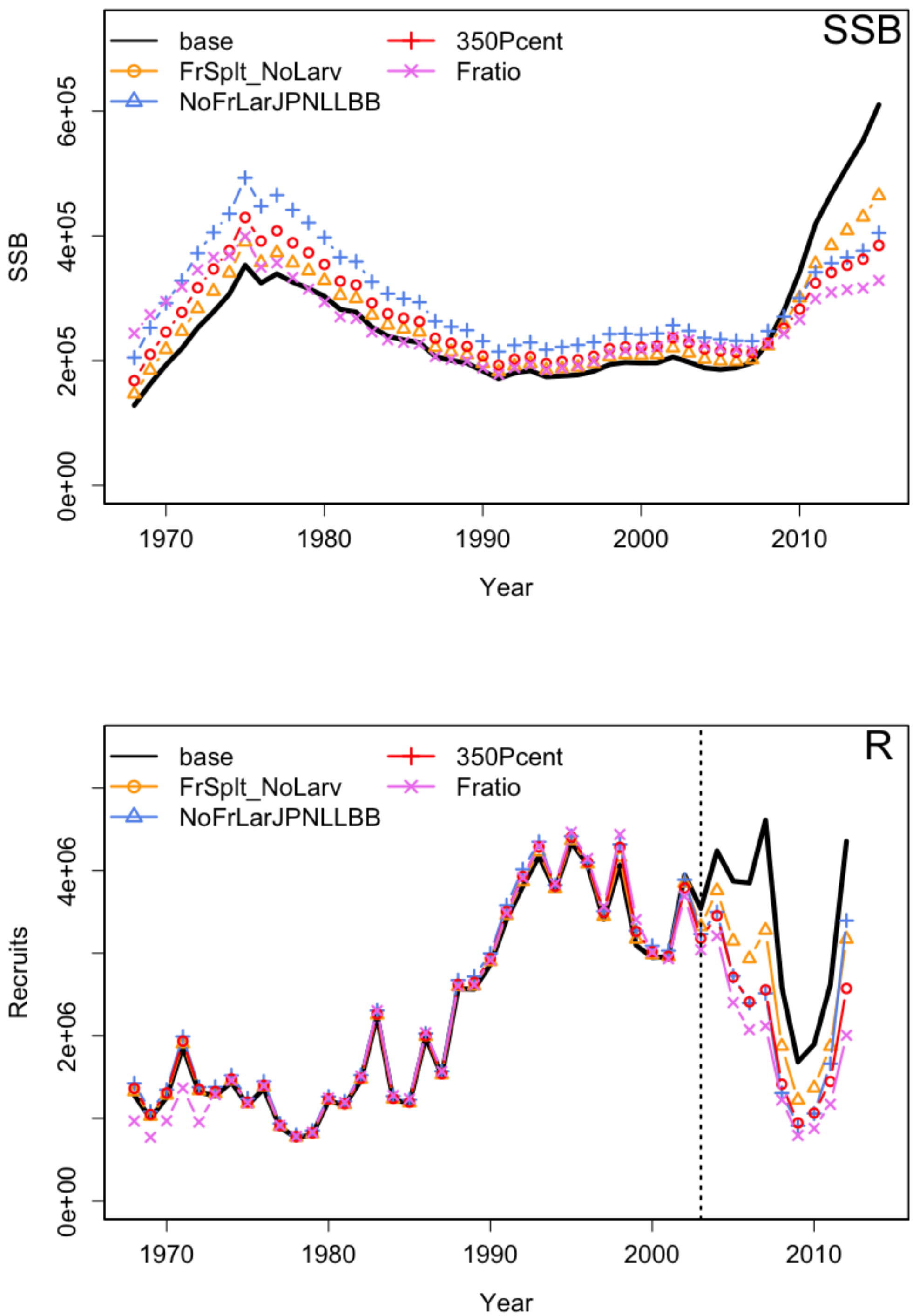

Figure 3. Numbers-at-age estimates from the base run and four alternative VPA runs. The abbreviations for the alternative runs are explained in the text. Green colors indicate higher numbers and red colors lower numbers. The 2003 cohort is outlined in black, with a lower outline indicating the span of the 2004-2007 cohorts.

Base

YEAR/AGE	1	2	3	4	5	6	7	8	9	10+
2004	4238019									
2005	3872593	2804886								
2006	3849940	2525098	1964660							
2007	4608930	2596812	1826763	1451791						
2008	2592791	3133805	1829508	1373108	1035510					
2009		1771101	2210637	1393570	1063670	802555				
2010			1289197	1719740	1117093	865977	643780			
2011				995727	1385659	905483	721819	541924		
2012					803106	1136032	762741	622063	469455	
2013						656394	961010	657422	539410	1085117
2014							551023	824995	566447	1417591
2015								476480	719958	1731776

FrSplt_NoLarv

YEAR/AGE	1	2	3	4	5	6	7	8	9	10+
2004	3758280									
2005	3147589	2476808								
2006	2933900	2029349	1721634							
2007	3278557	1970360	1459511	1260638						
2008	1874074	2224035	1365457	1084229	879061					
2009		1279602	1536706	1028549	827173	671889				
2010			925091	1189611	818244	668437	532439			
2011				709310	951632	655870	553488	445126		
2012					568607	773506	550031	475724	384458	
2013						460527	652084	472503	410913	1008691
2014							384116	556430	404071	1234390
2015								331376	484130	1422050

NoFrLarJPNLLBB

YEAR/AGE	1	2	3	4	5	6	7	8	9	10+
2004	3498486									
2005	2722936	2299172								
2006	2396069	1738975	1590054							
2007	2514278	1602569	1244403	1157142						
2008	1306999	1701363	1093026	915035	794367					
2009		891809	1149569	814255	688665	601156				
2010			637815	885078	642797	552745	472168			
2011				483336	702305	509326	454906	392734		
2012					383597	565250	425158	390023	338452	
2013						305997	474622	363945	335659	1063814
2014							252439	402154	308749	1217542
2015								216901	348663	1322068

Figure 3 continued. Numbers-at-age estimates from the base run and four alternative VPA runs. The abbreviations for the alternative runs are explained in the text. Green colors indicate higher numbers and red colors lower numbers. The 2003 cohort is outlined in black, with a lower outline indicating the span of the 2004-2007 cohorts.

350Pcent

YEAR/AGE	1	2	3	4	5	6	7		9	10+
2004	3452755									
2005	2710093	2267879								
2006	2410544	1730187	1566871							
2007	2555909	1612467	1237891	1138907						
2008	1413282	1729844	1100354	909916	779445					
2009		964488	1170668	820018	684473	588695				
2010			691653	901674	647517	549248	461551			
2011				525687	715888	513267	451925	383503		
2012					418273	576595	428516	387432	330347	
2013						334960	484287	366864	333383	983480
2014							277118	410557	311309	1142843
2015								238357	356040	1256882

Fratio

YEAR/AGE	1	2	3	4	5	6	7	8	9	10+
2004	3207854									
2005	2401471	2100412								
2006	2072664	1519170	1442828							
2007	2119489	1381415	1081574	1041347						
2008	1222255	1431384	929221	786964	699617					
2009		833851	949617	685409	583820	522028				
2010			594879	727790	537313	465175	404746			
2011				449566	573529	421222	380283	334120		
2012					355950	457694	350081	325149	286982	
2013						282908	382966	298676	278694	939895
2014							232762	322472	251437	1054944
2015								199796	278694	1124237

Appendix 1: Summary of all models examined

Table A1. SS of all models examined using A. the Trap fishery and B. the JPN LL NEA fishery. The four runs of interest are shown in bold and the base run is highlighted in grey. Abbreviations for the alternative runs are explained below.

A. TP

RUN	SS
Fratio	2.46
NoFrLarJPNLLBB	2.50
NoFrLarJPNLLTPBB	2.53
350Pcent	2.55
NoFrLarNoJPNLL	2.58
NoFrLarNoJPNLLTP	2.61
NoFrLarNoBB	2.63
Frsplt_nolarv	2.65
FrAndLarvSplit*	2.66
Minus55Pcent3series	2.66
NoFrLar	2.68
Minus75Pcent3series	2.68
Minus150Pcent3series	2.68
Minus150Pcent2series	2.69
Minus350Pcent2series	2.69
Minus55Pcent2series	2.72
Minus25Pcent3series	2.73
Minus35Pcent3series	2.74
Minus75Pcent2series	2.74
Minus35Pcent2series	2.75
Minus25Pcent2series	2.80
Base	2.81

B. JPN LL NEA

RUN	SS
Fratio	1.34
NoFrLarJPNLLBB	1.35
350Pcent	1.36
NoFrLarJPNLLTPBB	1.36
NoFrLarJPNLL	1.37
NoFrLarJPNLLTP	1.37
NoFrLarBB	1.38
Minus55Pcent3series	1.38
Frsplt_nolarv	1.38
FrAndLarvSplit*	1.39
Minus75Pcent3series	1.39
Minus150Pcent3series	1.39
NoFrLar	1.39
Minus150Pcent2series	1.39
Minus350Pcent2series	1.39
Minus55Pcent2series	1.40
Minus35Pcent3series	1.40
Minus25Pcent3series	1.40
Minus75Pcent2series	1.41
Minus35Pcent2series	1.41
Minus25Pcent2series	1.42
Base	1.43

Indice abbreviations:
JPNLL = recent part of the Japanese longline NE Atlantic index (JPLL NEATL 2)
BB = recent part of the bait boat index (SPBB2)
TP = Combined Morocco – Spain and Morocco – Portugal index
Fr = French aerial survey
Lar = Larval index in the western Mediterranean

NoXX = the XX indices listed in the run names were removed from the VPA for that run.

MinusXXPcent3series = Variances associated with Fr, Lar and JPNLL were increased by XX% compared to the base case and used as weighing factors for downweighing their respective indices in the VPA.

MinusXXPcent2series = Variances associated with Fr and Lar were increased by XX% compared to the base case and used as weighing factors for their respective indices in the VPA.

*Fr and Lar series were split.

Figure A1. Percent error calculated from the difference matrices ($\Delta P_{f,y,a}$-- equation 5) comparing **A.** the trap fishery and **B.** the JPN LL NEA fishery to the current VPA base run over ages 6 to 8. The 2003 cohort is outlined in black, with a lower outline indicating the span of the 2004-2007 cohorts.

A

YEAR/AGE	6	7	8
2009	-14	51	-28
2010	-64	35	95
2011	-58	-55	170
2012	-10	-9	30
2013	2	-6	8
2014	-58	-47	61
2015	-36	-32	61

B

YEAR/AGE	6	7	8
2009	-19	89	-64
2010	-27	54	-31
2011	-5	-68	98
2012	-48	49	28
2013	-55	-23	89
2014	-76	-56	77
2015	-91	-38	121