Appendix 6

SPECIFICATIONS FOR MSE TRIALS FOR BLUEFIN TUNA IN THE NORTH ATLANTIC
Version 19-4: February 15 2019

Commented [AK1]: This is the adopted in the end of the Feb 2019 BFTWG meeting, we will start editing this version as version 19-4a in the next July meeting. The end of the July meeting, it will be version 19-5

Contents

1. BASIC CONCEPTS AND STOCK STRUCTURE

This first item intends to cover only the broadest overview issues. More detailed technical specifications are included under subsequent items.

I) **Spatial strata**

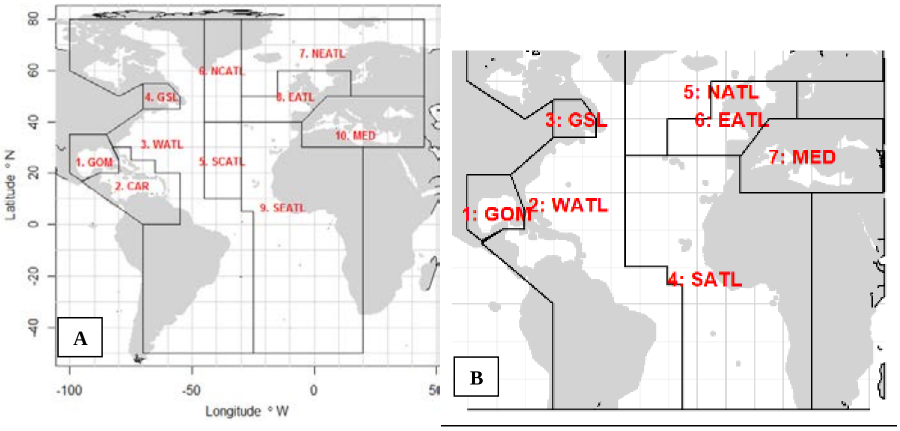


Figure 1.1A+B. Spatial definitions tabled by the 2015 ICCAT data preparatory meeting (A) (Anon. 2015) with simplification to a single Mediterranean area. And a seven-area model (B) that merges NCATL and NEATL into NATL and SCATL and SEATL into SATL and combines the CAR into the WATL.

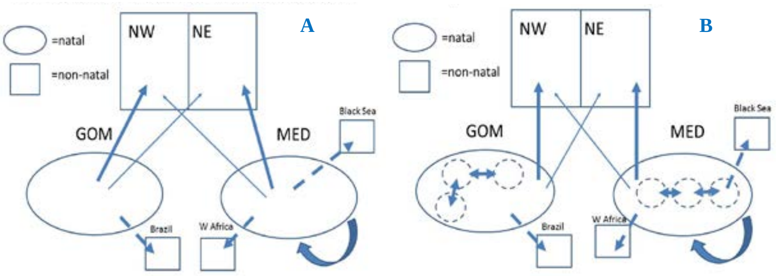
Baseline

The 7-area model of Figure 1.1B (the reported electronic tagging data and the stock of origin data do not have sufficient resolution to divide the Mediterranean area into Eastern and Western sub areas).

Alternative low priority future options

The MAST model (Taylor et al. 2011) which has strata the same as Figure 1.1A, but simplified such that the Central Atlantic is merged with the Western Atlantic.

II) **Stock mixing**



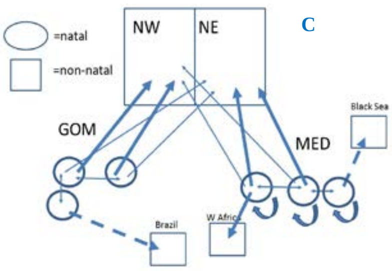


Figure 1.2. Mixing hypotheses suggested by Anon, (2014) and Arrizabalaga et al. (2019).
(A) A two stock model with no sub-populations.
(B) A two stock model with sub-population structure.
(C) A complex 2+ stock model.

Baseline

A two-stock model similar to Figure 1.2A but adhering to the spatial structure of Figure 1.1B. The mixing proportions are determined by the stock of origin data (genetics and otolith chemistry.

2. PAST DATA AVAILABLE

Table 2.5 provides an overview of the data that may be used to condition operating models for Atlantic bluefin tuna. The Table indicates those data that have been gathered, those that are currently available and those that have already been used in conditioning operating models.

I) **Raw data**

A preliminary demonstration operating model has been fitted to the fishery, tagging and survey data that are currently available (Table 2.5, field ‘Used in OM’). Currently the operating model is fitted to ICCAT Task II landings data scaled upwards to annual Task I landings.

Commented [D2]: Not really sure this sentence is really needed anymore

The ICCAT catch-at-size dataset was used to estimate gear selectivity for each of the baseline fleet types.

The pop-off satellite archival tag data from several sources (NOAA, DFO, WWF, AZTI, UNIMAR, IEO, UCA, FEDERCOOPESCA, COMBIOMA, GBYP, Stanford University) have been compiled by NOAA (M. Lauretta) and used in the preliminary model to estimate movements among areas. Daily tag tracks were provided by the seven geographic area strata. These are converted to strata-quarter records by the following rule: for each tag it’s strata position in a quarter is assigned as the strata the tag spent the most days in during that quarter (Fig 2.1A).

Only tags that have either corresponding weight or length data can be assigned an age class and can be used by the model. Similarly only those tags that have entered either of the natal areas (the Gulf of Mexico or the Mediterranean) can be assigned a stock of origin. All other tags are removed and not used in the MSE. The exception are tags released by AZTI in the Bay of Biscay, these are assumed to be of Eastern origin and are therefore given a stock of origin of Eastern stock. Of the data provided in November 2018 only around 1/5 of all quarterly transitions could be used by the model due to either a lack of age-class assignment or stock of origin assignment. In total 487 quarterly electronic tag transitions were recorded for tags of known stock of origin that entered or were released in either of the two natal spawning areas (GOM and Mediterranean) and had known age classes (Fig 2.1B).

Commented [D3]: Update with the newest transition count from new figures Tom will be providing.

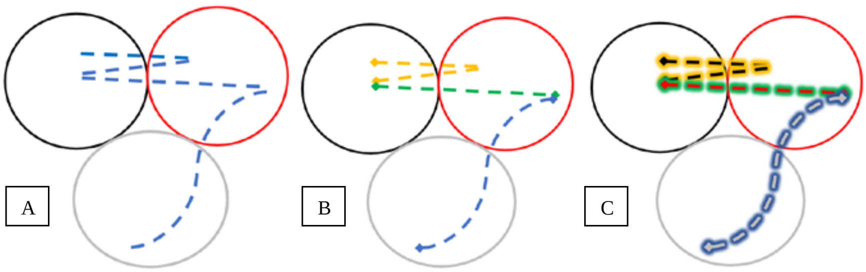
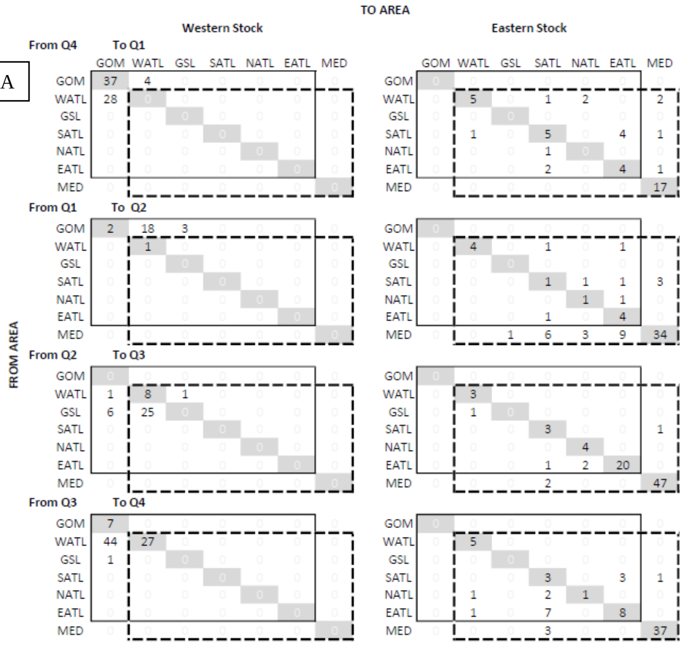
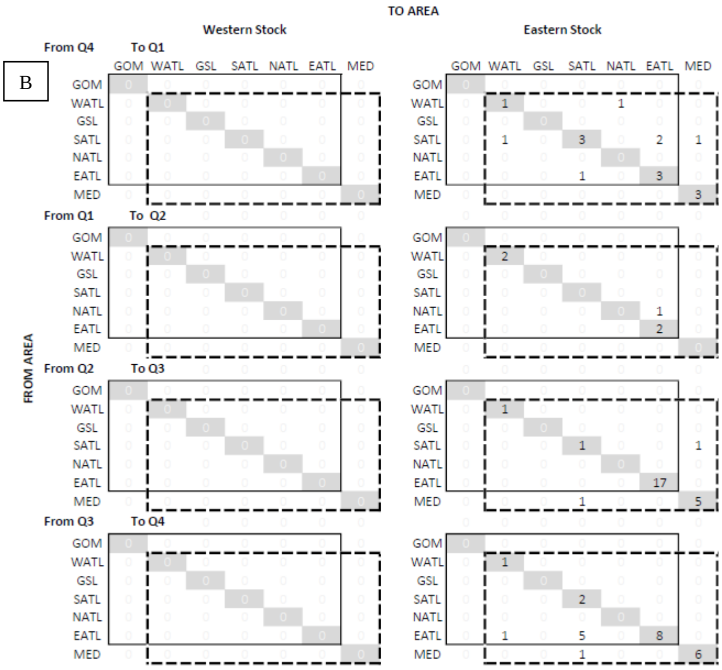


Figure 2.1A. PSAT tag data was used to inform transitions. This figure explains how each tag was allocated to a different strata (represented as black, red, and gray circles) and different seasons. The blue dashed line in (A) represents one PSAT tag track. In (B) this track is spliced into seasons (here the track is split into different seasons through different colours 1=yellow, 2=green, 3=blue). Then (C) the track for each season was allocated to a strata. This was done by counting the days (days are represented as dashes in these figures) the tag spent in each strata; the strata where the tag spent the most days in a season was determined to be the location for the tag in that season.

A


TO AREA
Western Stock
Eastern Stock
From Q4
To Q1
From Q1
To Q2
From Q2
To Q3
From Q3
To Q4
GOM WATL GSL SATL NATL EATL MED
FROM AREA

B


TO AREA
Western Stock
Eastern Stock
From Q4
To Q1
From Q1
To Q2
From Q2
To Q3
From Q3
To Q4
GOM WATL GSL SATL NATL EATL MED
FROM AREA

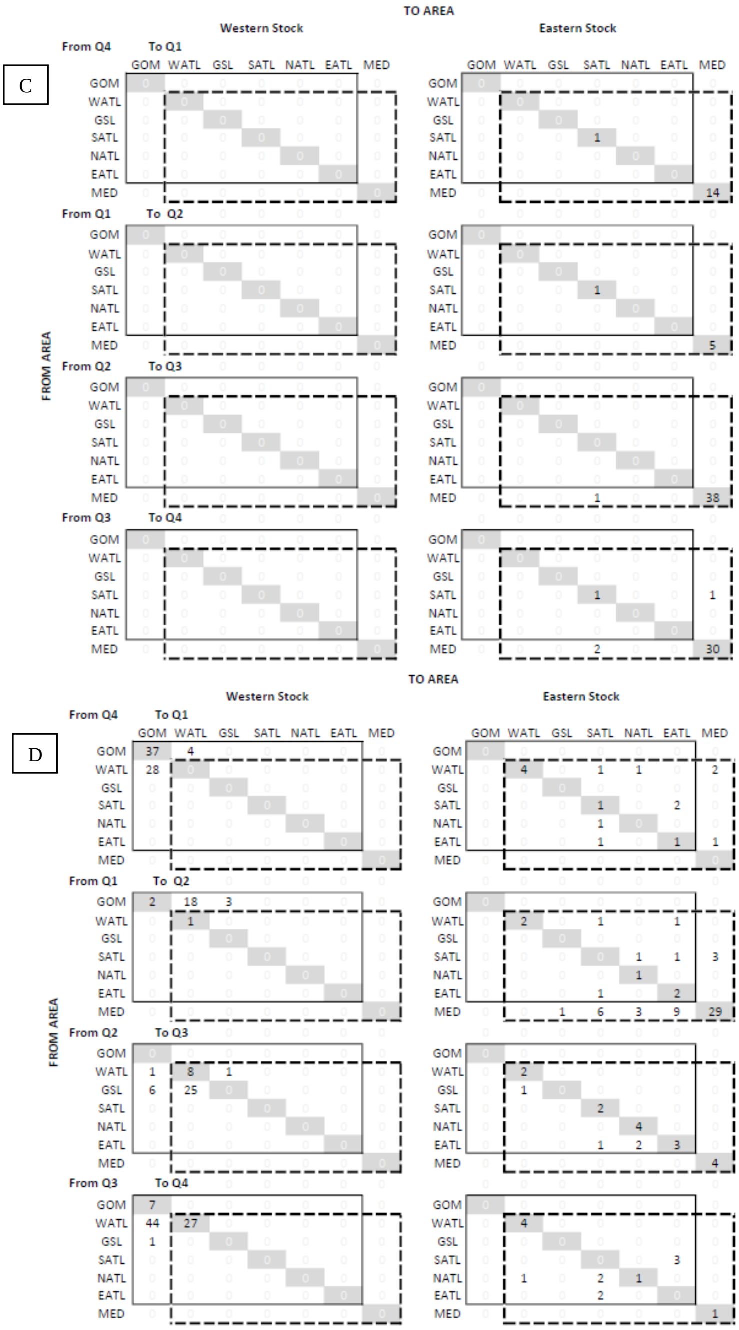


Figure 2.1B. Electronic tag transitions between geographic strata by quarter (A:all data, west=213 and east=274; B=age class 1, west=0 and east=71; C=age-class 2, west=0 and

east=94; D=age-class 3; west=213 and east=109). These are tags present in a particular strata in a quarter (row) that move to a strata in the next quarter (column). The solid line represents strata available to the western stock, the dashed line, strata available to the eastern stock. The shaded diagonal cells highlight tags that did not move strata from one quarter to the next. Age class 1 = 1-4 year olds; age class 2 = 5-8 year olds; age class 3 = 9+ year olds. Add the total number of tags that were used to record these transitions (by Stock, By season)

Commented [D4]: These tables need to be updated as 160 transitions have now been added. Also update n in the caption

Catch data provide scale to stock assessments. In a similar way, spatial stock of origin data are necessary to estimate the relative magnitude of the various stocks in a multi-stock model (to correctly assign catches to stock). Currently the model uses stock of origin data derived from the otolith microchemistry and genetic research of AZTI, UMCES, GBYP, and DFO (Table 2.5 and Table 2.6B).

Commented [D5]: So otolith microchemistry is the only data informing SOO? I believe this sentence needs to be updated to explain that Microchem and Genetic data are used to make up SOO.

There is uncertainty in regard to the stock of origin of bluefin tuna catches in the South Atlantic which reported prior to 1970. Currently these are dealt with in the same way as all other catches: they are assigned to the areas of Figure 1.1B by uprating Task II catches (that are reported spatially) to the annual Task I catch data. It follows that these South Atlantic catches are combined with north Atlantic catches in the areas WATL and SE.Atl (Figure 1.1B) and assumed to have the same stock of origin. Currently all the stock of origin data come from analyses undertaken in the north Atlantic only (e.g. otolith microchemistry).

Commented [D6]: Figure 1.1B??

Commented [D7]: This last sentence needs to be checked to make sure it is still accurate.

II) Analysed data

In the absence of a trip-level and fleet-specific regional abundance indices, a master index was calculated from Task II CPUE data and standardized assessment indices. The motivation for this was to produce indices of standardized effort by year, quarter and area (fleet specific catch divided by the master index) for operating model conditioning. The index was calculated using the following linear model (for more detail on this approach see Carruthers 2017, SCRS/2017/019):

$$\log\left(CPUE_{y,r,m,f}\right) = \alpha_{y,r} + \beta_{m,r} + \delta_{f,r} + \varepsilon \qquad (2.1)$$

where y, r, m and f refer to years, areas, quarters and fleets, respectively.

The Task II CPUE data provide information about the approximate spatial / season distribution of the stock within years (Table 2.1). The standardized assessment indices provide the primary information about trend within area over years (Table 2.2).

Commented [D8]: Should we also add Table 2.3

Table 2.1. The Task II CPUE data used to derive the master index.

Flag	Gear	Details
Japan	Longline	1,380,000 fish
USA	Longline	13,156 fish
Canada	Rod and reel	9,131 tonnes
Morocco	Trap	15,996 tonnes
Spain	Baitboat	35,625 tonnes

Table 2.2. The standardized CPUE indices of the assessments that are used to derive trend information for the master index and also fit the operating models. Many of these indices are available after 2016 but the model runs to 2016 due to the unavailability of CATDIS uprated catch data for more recent years.

Flag	Gear	Details
Spain	Baitboat	1952-2006, Q3, E Atl
Spain / France	Baitboat	2007-2014, Q3, E Atl
Morocco / Spain	Trap	1981-2011, Q2, SE Atl
Morocco / Portugal	Trap	2012-2016, Q2, SE Atl
Japan	Longline	1975-2009, Q2, SE Atl
Japan	Longline	1990-2009, Q4, NE Atl
Japan	Longline	2010-2016, Q4, NE Atl
US (66cm - 114cm)	Rod and reel	1993-2016, Q3, W Atl
US (115cm - 144cm)	Rod and reel	1993-2016, Q3, W Atl
US (177cm+)	Rod and reel	1993-2016, Q3, W Atl
US (<145cm)	Rod and reel	1980-1992 (gap in 1984), Q3, W Atl
US (195cm+)	Rod and reel	1983-1992, Q3, W Atl
US	Longline	1987-1991, Q2, GOM
US	Longline	1992-2016, Q2, GOM
Japan	Longline	1974-1980, Q2, GOM
Japan	Longline	1976-2009, Q4, W Atl
Japan	Longline	2010-2016, Q4, W Atl
Canada GSL	Rod and reel	1984-2016, Q3, GSL
Canada SWNS	Rod and reel	1988-2016, Q3, W Atl

Table 2.3. Fishery-independent indices used in the fitting of operating models.

Type	Details
French aerial survey	2000-2003, 2009-2017 (gap in 2013), Q3, Med
Spanish Larval survey	2001-2015 (gaps in 2006-2011), Q2, Med
Canadian acoustic survey	1994-2016, Q3, GSL
USA Larval survey	1977-2016 (gaps in 1979-1980, and 1985), Q2, GOM
Aerial survey – GBYP*	2010-2017 (gaps in 2012, 2014, and 2016), Q2, Med

** only the Balearic component is used (because there are problems with consistency regarding small treatment in other regions surveyed, but this does not affect the Balearic component for which small fish are virtually absent)*

The master index can be used to predict relative abundance (and hence standardized effort) for any fleet with catches over the full range of years, quarters and areas (Figure 2.2).

Commented [D9]: Are any of these split indices? I don't think so as they appear to be separated out (e.g. JPN LL NE Atl 1990-2009 then 2010-2016

However the splitting out of indices is not done in Table 2.3 below

Commented [DN10]: French Aerial survey terminal year should be 2016
Same 2016 for GBYP (possibly 2015)

The operating models are also fitted to the standardized indices used in the VPA stock assessments (Table 2.2) and range of fishery-independent indices (Table 2.3). These fishery-independent indices include a western larval index in the Gulf of Mexico (Lamkin et al., 2014) and an Eastern larval index in the Western Mediterranean (Ingram et al., SCRS/2015/035).

In order to predict observed catch at size from model predicted catch at age, operating models made use of an inverse age-at-length key (probability of length strata given age). These keys are developed from the base-case stock assessment growth curves for Eastern and Western stocks and an assumed coefficient of variation of 10% (variability in length at age).

III) **Assumptions**

The following are the default assumptions made in the model. Some of them may be relaxed in the robustness trials.

The age-length key is static and not adjusted according to fishing mortality rate and length selectivity of fishing.

CPUE indices are considered to be proportional to exploitable biomass (weighted by the selectivity indices).

Larval indices are assumed to be proportional to spawning stock biomass in the area in which they were collected in contrast to stock-wide spawning stock biomass (for scenarios where the two are not proportional).

Commented [D11]: I don't think that the indices listed in Table 2.2 were the ones used in the VPA, some of these indices were not used in the VPA.

Commented [AK12R11]: CPUE before the VPA starting year was not used in VPA, and combined CAN index was used instead of 2 CAN RR.

Commented [DN13R11]: I thought that Canadian Cmb and US RR large was not used in VPA?

Commented [D14]: Tom: describe the equations and assumptions of the historical catch reconstructions

Tom: write the equations and assumptions of the projections of the recent recruitments (i.e. lower triangles)

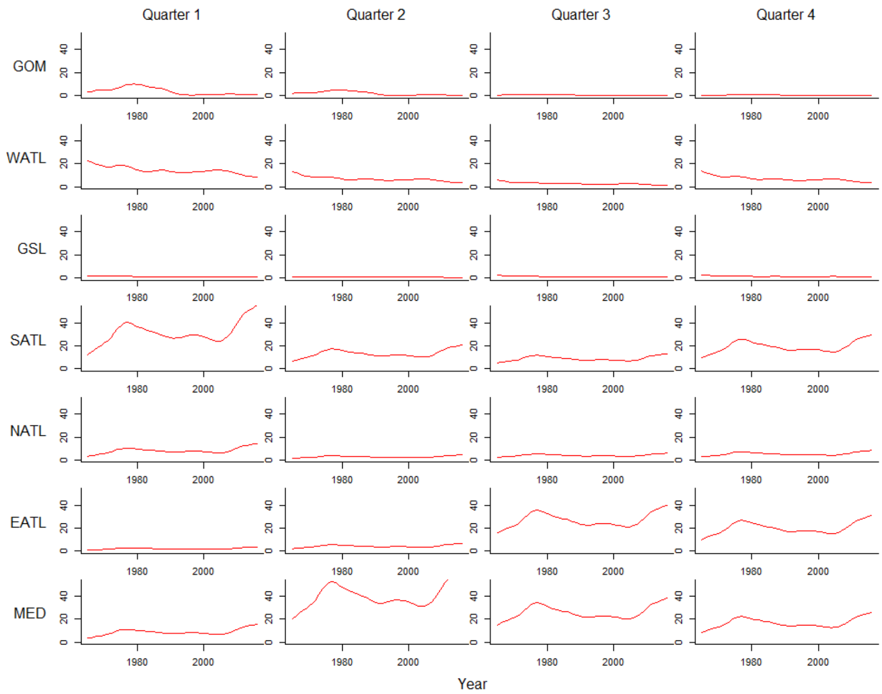


Figure 2.2. The seasonal /spatial master index derived by equation 2.1 (SCRS/2017/019)

Commented [D15]: Tom needs to update this figure. Ideally also vet the caption

Can more text be added to explain this figure? Is proportion of total population on the y-axis? If it is proportion, where did all the GOM fish go in the third quarter in 1980? I would have expected those fish to be present in GOM in quarter 1 to have moved to WATL or GSL in quarter 3 but few seem to be there?

Table 2.5. Overview of data that may be used to inform operating models for Atlantic bluefin tuna (available online here). Cells shaded green reflect sources for which data are available (‘Collab’, the Technical Team TT, or the ICCAT secretariat) and whether data that are available have also been used in conditioning preliminary operating models (‘used in OM?’).

Type of data (Informs)	Year range	TII	Spatial range	Can be by quarter?	By age-class?	Contact	Collab	Available to: TC	TT	ICCAT	ALL	Used in OM?
1. CPUE indices (relative abundance, movement, performance at stakeholder level)												
1.1. ICCAT task II CPUE	1950-2016	∞	All	Y	N	Carlos Palma (ICCAT)	Y	Y	Y	Y	Y	Y
1.2. Japanese LL standardized spatial	1976-2016	∞	E, NE, W, C	Y	N	Ai Kimoto	Y	Y	N	N	N	Y
1.3. USA LL standardized spatial	1992-2016	∞	W	Y	N		Y	Y	N	N	N	Y
	1992-2004	∞	GOM	Y	N		Y	Y	N	N	N	Y
	2005-2016	∞	GOM	Y	N	Matt Lauretta (NOAA)	Y	Y	N	N	N	Y
1.4. USA HL standardized spatial	1980-2015	∞	W	Y	N		Y	N	N	N	N	N
1.5. USA RR standardized spatial	1992-2016	∞	W	Y	N		Y	Y	Y	Y	Y	Y
1.6. USA-CAN LL standardized spatial	1992-2014	∞	W, C	Y	N	M. Lauretta (NOAA) /	Y	N	N	N	N	N
1.7. USA-CAN HL standardized spatial	1993-2014	∞	W, C	Y	N	A. Hanke (DFO)	Y	N	N	N	N	N
1.8. CAN LL standardized		∞	W, GSL	Y	N		Y	N	N	N	N	N
1.9. CAN HL standardized	1981-2014	∞	GSL	Y	N	Alex Hanke (DFO)	Y	N	N	N	N	N
	1988-2014	∞	W	Y	N		Y	N	N	N	N	N
1.10. CAN CMB RR	1984-2015	∞	W	Y	N	Alex Hanke (DFO)	Y	Y	Y	Y	Y	N
1.11 TWN LL standardized	1960-2004	2004	W, NE, E	Y	N	Julia Huang (NTOU)	N	N	N	N	N	N
1.12. MOR-SPN TRAP standardized	1982-2011	2011	WM	Y	N	N. Abid	Y	Y	Y	Y	Y	Y
1.13. MOR-POR TRAP standardized	2012-2016	∞	W, WM	Y	N	N. Abid	Y	Y	Y	Y	Y	Y
1.14. ESP TRAP standardized			W, WM	Y	N	Jose Miguel de la Serna	N	N	N	N	N	N
1.15. ITA (SAR) TRAP standardised	1993-2010	2010	CM	Y	N	Pierantonio Addis	Y	Y	Y	Y	Y	Y
1.16 ESP BB	1981 - 2006	2006	EATL	Y	N	Haritz Arrizabalaga	Y	Y	Y	Y	Y	Y
1.17 SP-FR BB	2007-2014	2014	EATL	Y	N	Haritz Arrizabalaga	Y	Y	Y	Y	Y	Y
2. Larval indices (SSB, movement)												
2.1. USA	1977-2016	∞	GOM	Y	N	Walter Ingram (NOAA)	Y	Y	Y	Y	Y	Y
2.2. ESP	01-'05 '12-'15	2018	W Med	Y	N	Franciso Alemany (IEO)	Y	Y	Y	Y	Y	Y
3. Catches (stock size, harvest rate)												
3.1. ICCAT task I	1950-2015	∞	non-spatial	N	N	Carlos Palma (ICCAT)	Y	Y	Y	Y	Y	N
3.2. ICCAT task II			All	Y	N		Y	Y	Y	Y	Y	N
3.3. ICCAT CATDIS					N		Y	Y	Y	Y	Y	Y
3.4 GBYP	1512-1950		E, M	Y	N	Carlos Palma (ICCAT)	Y	Y	Y	Y	Y	Y
4. Catch composition (selectivity, depletion)												
4.1. ICCAT catch-at-size	1950-2016	∞	All	Y	N	Carlos Palma (ICCAT)	Y	Y	Y	Y	Y	Y
4.2. Stereo video caging	2014	ended	WM, EM	Y	N	Mauricio Ortiz (ICCAT)	N	N	N	N	N	N
4.3. Canadian fisheries						Alex Hanke (DFO)	N	N	N	N	N	N
4.4 GBYP Historical catches	1910-1950	=	E, M	Y	N	Carlos Palma (ICCAT)	Y	Y	Y	Y	Y	Y
5. Conventional tags (feasible movement, growth, GTG heterogeneity)												
5.1. ICCAT	1954-2014	2015	All	Y	Y	Carlos Palma (ICCAT)	Y	Y	Y	Y	Y	Stock defs
6. Electronic tags (movement)												
6.1. LPRC (n=316)	2005-2009	ended	W	Y	Y	Molly Lutcavage	Y	Y	N	N	N	Y
6.2. DFO (n=89)	2009-2018	∞	GSL,W,GOM	Y	Y	Alex Hanke (DFO)	Y	Y	N	N	N	Y
6.3. Stanford (n=391)	1996-2015	∞	All	Y	Y	Barbara Block	Y	Y	N	N	N	Y
6.4. GBYP (n=216)	2011-2017	2015	E, M	Y	Y	Antonio Di Natale	Y	Y	N	N	N	Y
6.5. WWF (n=86)	2008-2015	2015	All	Y	Y	Pablo Cermeno	Y	Y	N	N	N	Y
6.6. NOAA (n=31)	2010-2013	2013	GOM,W,GSL	Y	Y	Craig Brown	Y	Y	N	N	N	Y
6.7. DFO-Acadia (n=37)	2010-2011	ended	GSL	Y	Y	Mike Stokesbury	Y	Y	N	N	N	Y
6.8. UCA (n=46)	2009-2011	ended	W, SE, NE, E,	Y	Y	Antonio Medina	Y	Y	N	N	N	Y
6.9. DFO - Duke (n = 15)	2007-2008	ended	W	Y	Y	Alex Hanke (DFO)	Y	Y				Y
6.10. IEO (n=13)	2001	ended	SE, E, NE, M	Y	Y	F. Abascal	Y	Y				Y
6.11. IFREMER (n=47)			SE, E, M	Y	Y	Tristan Rouyer	Y	Y				Y
7. Otolith microchemistry (stock of origin)												
7.1. UMCES, TAMU	2012-2013			Y	Y	David Secor	Y	Y	N	N	N	Y
7.2. NOAA					Y		Y	Y	N	N	N	Y
7.3. AZTI (n=189)	2009-2011	ended	E	Y	Y	Igaratza Fraile	Y	Y	N	N	N	Y
7.4. DFO / UMCES	2011-2013	∞	W, GSL	Y	Y	Alex Hanke (DFO)	Y	Y	N	N	N	Y
7.5 GBYP (n=1371)	2009-2014		All	Y	Y	GBYP	Y	Y	Y	Y		Y

Commented [D16]: 1.CPUE indices
- Can GSL and SWNS need to be added as separate lines; with “used in OM”=Y
- ITA (SAR) trap are really being used in the OM? (Tristan)

2. larval indices, move to independent survey (#11). Maybe this is more intuitive? (Tristan)

5. conventional tags how were they used in the OMs? Ideally there would be some text in the TSD to explain this.

I think the PSAT tag totals by provided also needs to be updated, also the date ranges.

9. are the GBYP sample size and date range correct?

11. are USA acoustic and aerial used in OM conditioning?

Date ranges and totals for 7 (otolith microchem data) need to be updated

Commented [D17]: Tristan has several notes for this

Table 2.5 continued.

Type of data (Informs)	Year range	Til	Spatial range	Can be by quarter?	By age-class?	Contact	Collab	Available to: TC	TT	ICCAT	ALL	Used in OM?
8. Otolith shape analysis (stock of origin)												
8.1. GBYP (n=172)	2011-2013	2015	E, W, C, WM	Y	N	GBYP	Y	N	N	N	N	N
9. SNP (population structure, genetic structure)												
9.1. Med HCMR					N	Gianpaolo Zmpicinini	N	N	N	N	N	N
9.2. GBYP (n=789)	2011-2015	∞	All		N	GBYP	Y	Y	N	N	N	Y
9.3 NOAA/VIMS/CSIRO	2015	∞	GOM/M	N	N	John Walter	N	N	N	N	N	N
9.4 GBYP Historical UB	200 BC - 1927	1927	E, M	Y	N	Alessia Cariani	Y	N	N	N	N	N
10. Other genetics on population structure (population structure, genetic structure)												
10.1. mtDNA					N	Barbara Block	N	N	N	N	N	N
10.2. Micro Sat/ mtDNA (n=320 / 147)	2003	ended	GOM, WM	Y	N	Carlsson	N	N	N	N	N	N
11. Fish. Ind. surveys (relative abundance, movement)												
11.1. ICCAT Aerial	2010-2015	∞	M	Y	N	Antonio Di Natale	Y	Y	Y	Y	Y	Y
11.2. French Aerial	2000-2016	∞	M	Y	N	Tristan Rouyer	Y	Y	Y	Y	Y	Y
11.3. USA Aerial	2015-	∞	W	Y	N	Molly Lutcavage	Y	Y	Y	Y	Y	Y
11.4. USA Acoustic	2015-	∞	W	Y	N	Molly Lutcavage	Y	Y	Y	Y	Y	Y
11.5. SOG Hydro acoustic curtain (OTN)	proposed		W, WM	Y	N	Mike Stokesbury	N	N	N	N	N	N
12. Growth, aging (age-length keys, length-age keys)												
12.1. Age-length keys (NOAA)				Y	N	John Walter	Y	N	N	N	N	N
12.2. Age-length keys (IEO)	2010-2012	ended	E, WM	Y	N	Enrique Rodriguez-Marin	Y	N	N	N	N	N
12.3. Age-length keys (DFO)	2010-2013	ended	GSL, W	Y	N	Alex Hanke (DFO)	Y	N	N	N	N	N
12.4. Derived from tagging	1963-2012	ended	Es, W s	Y	N	Lisa Allioud	Y	Y	N	N	N	Y
12.5 Age-length keys (GBYP)	2011-2015		E, M	Y	N	Antonio Di Natale	Y	N	Y	Y		N
12.6 Ageing calibration (GBYP)	2014		E, M	Y	N	Antonio Di Natale	Y	N	Y	Y		N
13. Maturity (Spawning biomass)												
13.1. Western (NOAA)	1975-1981	ended	GOM	Y	N	Guillermo Diaz (NOAA)	Y	N	N	N	N	N
13.2 Mediterranean			M	Y	N	GBYP	Y	N	N	N	N	N
14. Other ecological data (spatial distribution, covariates for CPUE standardization, steepness, natural mortality rate, spawning locations etc.)												
14.1. Larval ecology (IEO)		ended	WM	Y	N	Diego Alvarez Berastegui		N	N	N	N	N
14.2. Habitat model				Y	N	Jean-Noel Druon		N	N	N	N	N

Table 2.6a. Summary of the assignment scores by area showing the probability of a fish being an eastern fish.

Type	Percentile	GOM	WATL	GSL	SATL	NATL	EATL	MED
Otolith microchemistry	5th	0%	1%	4%	14%	6%	48%	32%
	Median	**7%**	**27%**	**23%**	**87%**	**75%**	**87%**	**84%**
	95th	48%	97%	89%	99%	97%	98%	97%
Genetics	5th	0%	0%	0%	4%	9%	29%	40%
	Median	**0%**	**45%**	**56%**	**82%**	**96%**	**98%**	**99%**
	95th	94%	100%	100%	100%	100%	100%	100%

Table 2.6b. The sample size of stock of origin data by type (otolith micro-chemistry and genetics) and the 7 strata areas.

	GOM	WATL	GSL	SATL	NATL	EATL	MED	Total	%
Otolith Chemistry	319	2537	864	382	409	335	245	5091	79.7%
Genetics	214	123	34	294	172	82	380	1299	20.3%

Commented [D18]: This Table caption needs to be more fleshed out. Scores of what? Are these the proportion of the samples that are eastern fish of origin?

Or are these simply the number of fish that were assigned to either stock?

Commented [D19]: NEED to UPDATE
Is this fully updated and the sample size that is being used in the MSE

Table 2.6c. Seasonal-spatial coverage of the raw otolith chemistry data. Orange shaded cells represent quarter-area strata for which there are no stock of origin data available for the mixture model approach (i.e. no otolith chemistry and no genetic data were available for these strata-quarters).

Quarter	GOM	WATL	GSL	SATL	NATL	EATL	MED	Total	%
1: Jan-Mar	52	347	0	37	0	0	0	436	8.6%
2: Apr-Jun	267	303	0	259	0	22	154	1005	19.7%
3: Jul-Sept	0	1565	604	54	8	291	91	2613	51.3%
4: Oct-Dec	0	322	260	32	401	22	0	1037	20.4%
Total	319	2537	864	382	409	335	245		
%	6.3%	49.8%	17.0%	7.5%	8.0%	6.6%	4.8%		

Commented [D20]: NEED TO UPDATE
Is this fully up to date. Also GOM has had the CAR data points removed and added to WATL

Table 2.6d. Seasonal-spatial coverage of the raw genetics data. Orange shaded cells represent quarter-area strata for which there are no stock of origin data available for the mixture model approach (i.e. no otolith chemistry and no genetic data were available for these strata-quarters).

Quarter	GOM	WATL	GSL	SATL	NATL	EATL	MED	Total	%
1: Jan-Mar	214	0	0	58	0	0	0	272	20.9%
2: Apr-Jun	0	0	0	139	0	0	223	362	27.9%
3: Jul-Sept	0	84	26	34	26	82	41	293	22.6%
4: Oct-Dec	0	39	8	63	146	0	116	372	28.6%
Total	214	123	34	294	172	82	380		
%	16.5%	9.5%	2.6%	22.6%	13.2%	6.3%	29.3%		

Commented [D21]: See Table 2.6c comment above. Same thing applies here

3. BASIC DYNAMICS

I) Overview

The current operating model (modifiable multi-stock model, ‘M3’) is based on conventional age-structured accounting (e.g. Quinn and Deriso 1999, Chapter 8) which is common to stock assessment models such as Stock Synthesis 3 (Methot and Wetzel 2013), CASAL (Bull et al. 2012), Multifan-CL (Fournier et al. 1998) and iSCAM (Martell 2015).

Commented [D22]:
Tom: please write some more about the gravity model

The standard age-structured equations are complicated somewhat by the quarter temporal structure in which ageing and recruitment occur in a particular quarter. In this version of the model, spawning occurs for all stocks in a quarter *ms*, after quarter 1 (spawning in the Mediterranean and Gulf of Mexico is thought to occur after a period of movement early in the year).

II) Equations

Numbers of individuals N, for stock s, in a model year y, in the first quarter m=1, age class a, and area r are calculated from individuals that have moved $\vec{N}$, in the previous year, final quarter n_m, of the same age class subject to combined natural and fishing mortality rate Z:

$$N_{s,y,m=1,a,r} = \vec{N}_{s,y-1,n_m,a,r} \cdot \; e^{-Z_{s,y-1,n_m,a,r}} \qquad (3.1)$$

where total mortality rate is calculated from annual natural mortality rate *M*, divided by the fraction of the year represented by the quarter t_m, and fishing mortality rate *F*, summed over all fleets *f*:

$$Z_{s,y,m,a,r} = t_m \; M_{s,a} \sum_f F_{y,m,a,r,f} \qquad (3.2)$$

Fishing mortality rate at age is derived from fishing mortality rate by length class *FL* and the conditional probability of fish being in length class *l*, given age *a* (an inverse age-length key, LAK).:

$$F_{y,m,a,r,f} = \sum_l FL_{y,m,l,r,f} \cdot LAK_{s,a,l} \qquad (3.3)$$

The fishing mortality rate at length is calculated from an index of fishing mortality rate *I* (calculated from dividing the value of the catch for that fleet by the value of the ‘master index’ in that strata), an estimated catchability coefficient *q*, a season and area specific deviation *FD*, and a length selectivity ogive *s*, by fleet:

$$FL_{y,m,l,r,f} = q_f \cdot I_{y,f} \cdot FD_{m,r} \cdot s_{f,l} \qquad (3.4)$$

Selectivity is calculated by a double normal ogive and an estimate of mean length *L* for a length class *l*:

$$s_{f,l} = \begin{cases} \left(-\frac{L_l - smax_f}{\sigma_{f,A}{}^2}\right)^2 & L_l \le smax_f \\ \left(-\frac{L_l - smax_f}{\sigma_{f,D}{}^2}\right)^2 & L_l > smax_f \end{cases} \qquad (3.5)$$

where *smax* is the fleet-specific length at maximum vulnerability, and σ_A and σ_D are parameters controlling the width of the ascending and descending limbs of the selectivity respectively. Large values of σ_D approximate a ‘flat topped’ logistic selectivity.

In the spawning quarter *ms*, ages advance by one and recruitment occurs. The model includes a plus group which is the final age class n_a:

$$N_{s,y,ms,a,r} = \begin{cases} \vec{N}_{s,y,ms-1,a-1,r} \cdot \; e^{-Z_{s,y,ms-1,a-1,r}} & a < n_a \\ \vec{N}_{s,y,ms-1,a-1,r} \cdot \; e^{-Z_{s,y,ms-1,a-1,r}} + \vec{N}_{s,y,ms,a,r} \cdot \; e^{-Z_{s,y,ms,a,r}} & a = n_a \end{cases} \qquad (3.6)$$

Recruitment is calculated from either a Beverton-Holt stock recruitment relationship with fixed steepness or by a hockey-stick model (level 1 recruitment scenario for western stock, after 1975). In all cases the steepness (recruitment compensation) or the inflection point of the hockey stick, are fixed, single value inputs.

Commented [D23]: Need to check this to recruitment options

$$N_{s,y,ms,1,rs} = \exp\left(\varepsilon_{R,y} - \sigma_R^2/2\right) \cdot$$

$$
\begin{cases}
\dfrac{\frac{4}{5} \cdot h_s \cdot R_{0,s} \cdot SSB_{s,y}}{\frac{1}{5} \cdot SSBpR_s \cdot R_{0,s} \cdot (1-h_s)+(h_s-0.2) \cdot \cdot SSB_{s,y}} & (Beverton-Holt) \\
R_{0,s} \cdot SSB_{s,y}/SSB_{s,hinge} & SSB_{s,y} < SSB_{hinge}\,(HS) \\
R_{0,s} & SSB_{s,y} > SSB_{hinge}\,(HS)
\end{cases} \tag{3.7}
$$

where ε_R is a random normal deviate with variance σ_R^2 and $\sigma_R^2/2$ is the bias correction to ensure that on average, recruitment deviations have a mean of 1.

Spawning stock biomass is calculated from moved stock numbers in the previous year, and quarter prior to spawning quarter *ms*, weight of individuals at age *w*, and the fraction of individuals mature at age *mat*:

$$SSB_{s,y} = \sum_a \sum_{rs} \vec{N}_{s,y-1,ms-1,a,r} \cdot\ e^{-Z_{s,y,ms-1,a,r}} \cdot w_{s,a} \cdot mat_{s,a} \tag{3.8}$$

where weight is calculated from length at age *l*:

$$w_{s,a} = \alpha_s \cdot l_{s,a}^{\beta_s} \tag{3.9}$$

and the fraction mature at age is assumed to be a logistic function of age with parameters for the age at 50% maturity γ, and slope ϑ:

$$mat_{s,a} = 1/\left(1 + e^{(\gamma_s - a)/\vartheta_s}\right) \tag{3.10}$$

Stock numbers for quarters that are not the first quarter of the year and are not the spawning quarter are calculated:

$$N_{s,y,m,a,r} = \vec{N}_{s,y,m-1,a,r} \cdot\ e^{-Z_{s,y,m-1,a,r}} \tag{3.11}$$

In each quarter, after mortality and recruitment, fish are moved according to an age-specific Markov transition matrix *mov* that represents the probability of a fish moving from area *k* to area *r* at the end of the quarter *m*:

$$\vec{N}_{s,y,m,a,r} = \sum_k N_{s,y,m,a,k} \cdot mov_{s,m,\mathrm{a},k,r} \tag{3.12}$$

The movement matrix is calculated from a log-space matrix *lnmov* and a logit model to ensure each row (*k*) sums to 1:

$$mov_{s,m,\mathrm{a},k,r} = e^{lnmov_{s,m,\mathrm{a},k,r}} / \sum_r e^{lnmov_{s,m,\mathrm{a},k,r}} \tag{3.13}$$

Size/age stratification for movement models will initially be attempted for three age groups: 0-2, 3-8 and 9+ years (this will be kept the same for the Western Atlantic and the Eastern Atlantic/Mediterranean, but should be re-evaluated for the East as future data become available).

Movements from an area *k* to an area *r* that are considered to be implausible (e.g. from the Eastern Mediterranean to the Gulf of Mexico) are assigned a large negative number (essentially zero movement) in corresponding cells in these movement matrices. For each area *k*, from which individuals can move, one value is assigned zero and all other possible movements are assigned an estimated parameter ψ (since rows must sum to 1, there is one less degree of freedom):

$$lnmov_{s,m,a,k,r} = \begin{cases} 1e^{-10} & no\ movement\ from\ k\ to\ r \\ 0 & first\ assigned\ possible\ movement\ from\ k\ to\ r \\ \Psi_{s,m,k,r} & other\ possible\ movements\ from\ k\ to\ r \end{cases} \quad (3.14)$$

This movement model can be simplified to estimate only those movements for which data have been observed (e.g. at least one tag track or conventional tagging observation).

Compared with spatially aggregated models, initialization is more complex for spatial models, particularly those that need to accommodate seasonal movement by age and may include regional spawning and recruitment. The equilibrium unfished age structure / spatial distribution cannot be calculated analytically. For any set of model parameters it is necessary to determine these numerically by iteratively multiplying an initial guess of age structure and spatial distribution by the movement matrix. The solution used here is to iterate the transition equations above (Equations 3.1, 3.6, 3.7, 3.11, 3.12) given a fishing mortality rate averaged over the first five years of model predictions until the spatial distribution of stock numbers converges for each of the quarters.

Prior to this iterative process an initial guess at the spatial and age structure of stock numbers $\hat{N}$ is made based on the movement matrix and natural mortality rate at age M:

$$\hat{N}_{s,m,a,r} = \bar{R}_s \cdot \mathrm{e}^{-\sum_1^a M_{s,a}} \cdot \sum_k \frac{1}{n_r} \cdot mov_{s,m,\mathrm{a},k,r} \quad (3.15)$$

In years prior to the initial model year (e.g. before 1965), historical catches $\bar{C}$ for eastern and western areas (east/west of 45 degrees longitude) are used to initialize the model using stock reduction analysis (i.e. catches are removed without error from the asymptotic estimates of unfished numbers $\hat{N}$). Mean historical annual catches were divided up among areas and seasons assuming the same seasonal and spatial pattern of catches as the initial years of the modelled time series (e.g. 1961-1965).

Stock numbers for initialization years (e.g. 1864-1964) are calculated using the same equations (i.e. Eqn 3.11 and 3.12) as model years (e.g. 1965 – 2016). The exception is that rather than using effort data, selectivities and an inverse age-length key (Eqns 3.3 and 3.4), fishing mortality rate at age is derived from mean historical catches and the assumption is made that these are taken without error in the middle of the time step with natural mortality rate occurring both before and after fishing:

$$F_{i=1,m,a,r,f} = \begin{cases} -\log\left(1 - \frac{\bar{C}_{m,a,r,f}}{\hat{N}_{s,m,a,r} e^{-(t_m M_{s,a})/2}}\right) & i = 1 \\ -\log\left(1 - \frac{\bar{C}_{m,a,r,f}}{\vec{N}_{s,y-1,n_m,a,r}\, e^{-(t_m M_{s,a})/2}}\right) & i > 1, m = 1 \\ -\log\left(1 - \frac{\bar{C}_{m,a,r,f}}{\vec{N}_{s,y,m-1,a,r} e^{-(t_m M_{s,a})/2}}\right) & i > 1, m > 1 \end{cases} \quad (3.16)$$

where i=1 is the first year and calculates fishing mortality rates from asymptotic numbers $\hat{N}$ (Eqn. 3.15).

Total allowable catches (TAC) by East-West area are allocated according to a fleet-specific allocation A_f and the predicted seasonal-spatial-age composition of catches $\hat{V}_{s,y,m,a,r,f}$

$$C_{s,y,m,a,r,f} = \hat{V}_{s,y,m,a,r,f} \cdot A_f \cdot TAC_{y,r} \tag{3.17}$$

where

$$\hat{V}_{s,y,m,a,r,f} = \frac{\vec{N}_{s,y,m,a,r} \cdot F_{y,m,a,r,f}}{\sum_m \sum_a \sum_r \vec{N}_{s,y,m,a,r} \cdot F_{y,m,a,r,f}} \tag{3.18}$$

and $TAC_{y,r}$ is the western TAC when $r < 4$ and $TAC_{y,r}$ is the eastern TAC when $r > 3$.

Commented [D24]: I think I understand this but wouldn't it be easier to say:

West TAC r=<3
East TAC r=>4

When $C_{s,y,m,a,r,f} > U_{max} \cdot \vec{N}_{s,y,m,a,r}$ the catch is redistributed into season-age-area (*m*, *a*, *r*) strata in order of the magnitude of $\hat{V}$ up to a maximum harvest rate of U_{max} (the default value is 80%). This means that, for example, the catch taken will start to drop below the TAC specified for MPs that lead to continued stock declines.

<u>Baseline</u>

Beverton Holt with fixed steepness or hockey-stick with fixed hinge point (see Section 9A for a detailed account of the stock-specific recruitment assumptions.
Recruitment calculated from stock-wide SSB
Gravity movement model used to calculate Markov movement matrix by quarter and stock (e.g. Carruthers et al. 2011).

<u>Alternative options</u>

Recruitment calculated from spawning area SSB
Markov movement matrix by quarter and stock (following model updates the gravity model – a specific case of the more general Markov model – seemed an appropriate choice for the Baseline).

III) Fleet structure and exploitation history

Commented [D25]: Does this title really make sense if its really about selectivity?

Table 3.1. Selectivity definitions for modelled fleets (1-14) based on the selectivities of fleets historically operating in the Atlantic.

No.	Gear	Flag	Start	End	Notes
1	LL	All except Japan	1960	2015	
2	LL	Japan	1960	2015	
3	BB	All	1960	2008	
4	BB	All	2009	2015	
5	PS	All	2009	2015	Med
6	PS	All	1960	2008	Med, Quarter 2
7	PS	All	1960	2008	Med, Not Quarter 2
8	PS	All	1960	1986	Not Med
9	PS	All	1987	2015	Not Med
10	TP	All	1960	2008	
11	TP	All	2009	2015	
12	RR	Canada	1988	2015	
13	RR	USA	1988	2015	
14	Other		2015	2015	

Commented [D26]: Are the end dates now 2016?

Commented [AK27]: NEED TO CHECK. No. 8 and 9 for PS not in Med.
There were historical big catches by Norway for large size, by US for small size, respectively

Baseline

A 14-fleet model based on the definitions of Table 3.1.

Alternative options

A proposal for alternatives may need to be developed and reviewed in the future.

4. MANAGEMENT OPTIONS

Notes:

a) The following section is included to provide some suggestions on possible structures to MP developers of management options to be included in the MPs. The suggestions offered are illustrative – clearly they will need to be discussed with stakeholders as the process develops.
b) As above, for convenience they have been set out in baseline and alternative option form. It is recommended that many of the choices for the final MP options be made later in the process, so that they can be informed by results from trials which show the pro/con trade-offs amongst such options.
c) The specifics of future candidate MPs will be left to their developers to determine based on the results of their application to the finalised trials. However those candidates need to take account of the broad desired characteristics/limitations set out below.
d) HCRs need not to explicitly include reference points

I) **Spatial strata for which TACs are set**

Baseline

Conventional West and East/Mediterranean regions (Figure 1.1B):

West: areas 1-3 (GOM, WATL(+CAR), GSL)
East: areas 4-7 (SATL, NATL, EATL, MED)

Alternative options

Commented [D28]: Perhaps have these alt scenarios in an appendix? Look at what this would look like

Various possibilities exist, based on alternative combinations of the spatial strata defined in Item 1. For example, separating out the central Atlantic (Figure 1.1A).

More complex 10 area option (Figure 1, left-hand panel):
West: areas 1-4 (GOM, CAR, WATL, GSL).
East+Med: areas 5-10 (SCATL, NCATL, NEATL, EATL, SEATL, MED).

More complex 10 area option:
West: areas 1-4 (GOM, CAR, WATL, GSL).
Central: areas 5-6 (SCATL, NCATL).
East+Med: areas 7-10 (NEATL, EATL, SEATL, MED).

However it is suggested that consideration of such more complex options be postponed to a "second round".

II) **management period length for the setting of TACs**

Commented [DN29]: Nick added explanation below, Tom to check

The management period is the number of years a TAC is set before the management procedure is used again to calculate a new TAC. The length of the management period must be set when implementing a MP, managers should be consulted on desirable management period lengths to make certain the period length is functional for other management actions needed beyond TAC (e.g. fleet allocation planning, consultations, etc.).

Baseline

Every two years both a West Area TAC and an East+Med Area TAC are set.

Commented [D30]: Need some feedback from the Commission on 2 or 3 years?

Alternative options

i) Every three years
ii) Every four years

III) **Upper limits on TACs**

Commented [DN31]: Nick added explanation below, Tom to check

The "upper limits of TAC" allows MP developers to put restrictions in place on maximum level TAC can achieve in the running of the MPs. Note that this option has potential advantages for reducing risk and avoiding over-capitalisation.

Baseline

No upper limit

Alternative options

West	e.g. 5 000, 6 000 mt
East +Med	e.g. 30 000, 40 000 mt

IV) **Minimum extent of TAC change**

The "minimum extent of TAC change" allows the MP developer to avoid having small changes in TAC between management periods. Managers might find this desirable to avoid having insignificant increases or decreases being incorporated in management recommendations. This constriction should only be used if it is requested by managers, otherwise it should be kept at no minimum as is the case in the baseline below.

Baseline

No minimum.

Alternative options

West	e.g. 200, 300 mt
East +Med	e.g. 1 000, 2 000 mt

V) **Maximum extent of TAC change**

The "maximum extent of TAC change" allows MP developers to force a maximum allowed increase or decrease in TAC between management periods. Overall this helps to achieve TAC stability.

Baseline

West	No restriction
East +Med	No restriction

Alternative options

West	15%
East +Med	15%

Note that developers of candidate MPs should consider including options which:

a) Override such restrictions on the maximum extent of reduction if abundance indices drop below specified thresholds.

Commented [D32]: Explain. Nick added explanation below, Tom to check

Commented [D33]: explain. Nick added explanation below, Tom to check

Commented [D34]: This baseline should now be "no restriction".

Need Tom to confirm

b) Allow for greater increases (in terms of tonnage) if a TAC has had to be reduced to a low level and indices confirm subsequent recovery.

VI) **Technical measures**

No "technical measures" are currently being implemented in the MSE. However, size restrictions might be considered on a fleet and/or spatial stratum basis. However, for a "first round" it is suggested that these not be included explicitly, but instead be considered to be effected implicitly through the selectivity prescriptions for future catches by the various fleets which are set out under item 6 below.

5. FUTURE RECRUITMENT AND DISTRIBUTION SCENARIOS

See also section 9 of this document for additional detail on specified trials.

Commented [D35]: Perhaps move some of the section 9 info to here. Consider moving section to make flpow better

I) **West**

Functional forms fitted to assessment outputs for the years 1970+

a) Beverton Holt with steepness *h* fixed to 0.6 until 1974, then Hockey stick with fixed hinge point (mean SSB from 1990-1995) starting from 1975
b) Beverton Holt with steepness *h* fixed to 0.6

Commented [D36]: Update with the new recruitment scenario removing the hockey stick

II) **East + Mediterranean**

Functional forms fitted to assessment outputs for the years 1950+

a) Beverton Holt with *h* = 0.98 with separate unfished recruitment estimated for two periods: 1950-1987 and 1988+
b) Hockey stick with fixed hinge point (SSB in 1973)

Commented [D37]: Not sure I understand what this means?

Commented [CT38]: New hockey-stick model for all years

Note that 1950-1987 is "low" recruitment, and 1988+ is "high" recruitment.

III) **Future regime shifts**

West

a) None
b) After 10 years of projection, hockey stick changes to Beverton-Holt

East+Med

a) 1988+ relationship continues unchanged
b) 1988+ relationship changes to 1950-1987 relationship with h=0.98 after 10 years

IV) **Statistical properties**

Residuals are taken to be lognormally distributed about the relationship assumed with the standard deviation of the log recruitments (σ_R) invariant over time.

Baseline

Uncorrelated residuals with σ_R = 0.5. (a common value obtained from the RAM legacy database).

Alternative options

σ_R and autocorrelation as estimated from the residuals for the conditioning concerned (post model fit, not within model fit, for greater statistical stability). For East+Med this will refer to the 1950+ fits.

V) **Possible future distributional changes**

Plausible options for future distributional changes (in relative terms) in response to changes in abundance and to possible environmental changes will be considered in a "second round".

6. FUTURE CATCHES

Baseline

a) Future catches will be taken to equal future TACs (up to a maximum harvest rate of 90%).
b) The allocation of these future catches amongst fleets will be set equal to the average over 2014-2016
c) The spatial distribution per stratum (see item 1 above) of these future catches will be set equal to the average over 2014-2016
d) The selectivity function for each fleet for the most recent period for which this is estimated in the conditioning of the trial concerned will be taken to apply for all future years
e) If the TAC is changed, the proportional allocation by fleet will remain unchanged, as will the proportional distribution by spatial stratum (unless the harvest rate exceeds 90% and then excess catches for a given fleet will be taken from other strata in descending order of their harvest rate).
f) TAC and catches are fixed into projection model (2017 and after) based on realized catches for 2017 and determined TAC from Rec 17-06, 17-07, and 18-xx.

Alternative options

Clearly many are possible, but are probably best delayed until a "second round". Were substantial changes to eventuate during a period when an MP was in operation, this would in any case likely necessitate re-tuning and re-testing or a modified MP.

Commented [D39]: Does this mean the new allocations put in Rec 17-04 aren't included in the future catches?

Also does this take into account the change in catches and allocations that happen when Western TAC changes when it goes over 2500 mt?

Perhaps also applies to C below

Commented [D40]: Check this wording

The impacts of possible IUU catches should perhaps be considered under robustness trials (see item 9 below).

7. GENERATION OF FUTURE DATA

Note that these are for use as input to MPs, so need to be chosen carefully from a set of those highly likely to be regularly (i.e. annually) available. This is because application of the MP relies on these data being available in this way, so difficulties can (and have in other cases) obviously arise should they fail to do so. Though any candidate MP proposed should include a rule to deal with the absence of just one future value from an input series, any more than that would require re-tuning and re-testing of a modified MP, which is preferably planned to be avoided given the associated extra costs.

Commented [D41]: This is really a Exc Circumstance. Also there isn't really anyway to test this in the MP testing.

Perhaps should be deleted here and moved to another section. E.g. generic rule for what to do when you have a 1 year gap in a data source for the MP

Consideration is also needed of the "delays" associated in such data becoming available for input to an MP. When a TAC is set for year y, the last year of finalised data at the time of setting the TAC is y-2 for surveys and CPUE indices and y-3 for catch data. For years y-2 and y-1 the catch can be assumed to be equal to the TAC.

Commented [CT42]: Clarification on lags

TAC implementation year = X
Commission decision year = X-1
SCRS advice year = X-1
CPUE/Independent data = X-2
Therefore CPUE/independent data would have to be finalized and provided to SCRS Sept meeting.

I) Baseline suggestions

West

a) Gulf of Mexico larval index of spawning stock abundance
b) US RR 66-114 cm index of exploitable abundance
c) JLL_W CPUE index of exploitable abundance
d) Canadian acoustic survey

East+Med

a) JLL_NEA CPUE index of exploitable abundance
b) Western Mediterranean larval index of spawning stock abundance
c) GBYP aerial survey of adults
d) Juvenile aerial survey Gulf of Lion

For both areas, these indices are generated based on the simulation-specific fit of the operating model to the indices, including lognormal error and autocorrelation in residuals.

Commented [CT43]: Some additional details about the observation error model.

In MSE projections, TACs are assumed to be taken exactly (removed from the population biomass with zero discarding) up to a maximum harvest rate of 90%. Some MPs may use annual catch observations in addition to the simulated indices. As the baseline, simulated annual catch data are assumed to have been observed with error and a log-normal CV of 4% (95% of

Commented [D44]: Clarify "catch". Is this removal, landings, reported catch?

Are we trying to say the observed catch has 4% error.

Commented [D45]: Perhaps this needs more thought. Is 4% an appropriate number?

observations are within +/- 8% of the true catch that was taken) which is the same value used in operating model conditioning.

While not all of the indices are being used for projections, this does not imply that they should be discontinued nor updated and reviewed by the SCRS BFT species group. It will also be important to have these updated indices for model re-conditioning when the MSE is re-run (which would be done at a set interval to be determined by the Commission).

II) Alternative options

Obviously many additions or alternatives to the suggestions made are possible. The reasons behind the initial suggestions above are respectively lengthy continuity (though admitting a concern about the decrease in spatial coverage of the JLL_NEA index over time) and fishery-independence. Accordingly, the East + Med might be extended to include trap or baitboat indices.

Including additional indices of abundance will increase the workload (see below), so might be better postponed to a "second round".

Catch-at-length series could also be considered for inclusion, but raise further technical complications regarding the specification of how they are generated, so are likely best deferred from consideration until a "second round".

A 'perfect information' observation error model (suitable for CMP testing) that include essentially no observation error in or autocorrelation in indices, or observation error in catches.

A 'bad' observation error model that is the same as the base-case but includes the estimated non-linearity in indices with biomass, and a 10% lognormal CV in annual catch data.

III) Relationships with abundance

For baseline trials, abundance indices will be taken to be linearly proportional to the appropriate component of the underlying model biomass in the stratum/strata concerned.

Possible alternatives to this are considered under Robustness trials (see item 9 below).

IV) Statistical properties

Baseline

a) Residuals are taken to be lognormally distributed;
   standard deviation of the log recruitments (σ) invariant over time.
b) The values of σ will be estimated
c) No Autocorrelation of residuals
d) The conditioning results will be inspected for model mis-specification regarding the fit to the series concerned; if so the bias identified will be modelled to continue into the future in a "plausible" way.

Alternative options

a) Fix σ values for all trials based on a central trial from the Reference set (see item 9 below).
b) If additional CPUE indices to the single one initially suggested are included, residuals need to be examined for correlation, with this being taken into account in generating future values.

Other aspects

Note that consideration should at some stage also be given to new data types that are only now becoming available (e.g. aerial surveys, genetic tagging). These will not at this stage have been collected over a sufficient length of time to be able to serve as MP inputs, but the overall testing process can be used to provide insight into their potential future utility.

8. PARAMETERS AND CONDITIONING

Recruits go into the spawning areas and their distribution is proportion to their stock biomass in each area. For the Baseline model, spawning is assumed to occur in areas 'GOM' + WATL for the West stock and 'MED' for the East + Mediterranean stock (Figure 1.1B).

Commented [D46]: Need to add more explanation on how recruits get created and placed. Basically clear up the first sentence

Model does not force all the SSB back to the spawning area. Therefore biomass is not forced to particular quarters during spawning time.

Atl scenario to have alternative spawning areas for either stock

I) **Fixed parameters**

Table 8.1. The parameters that are fixed (user specified)

Parameter	Number of parameters	Symbol
Steepness	n_s	h
Maximum length	n_s	*Linf*
Growth rate	n_s	K
Age at length zero	n_s	t_0
Natural mortality rate at age	$n_a \cdot n_s$	M
Selectivity of at least one fleet	*2-3*	Θ
Maturity at age	$n_a \cdot n_s$	*mat*

Table 8.2. Parameter values of baseline and alternative options

Parameter	**West**		**East**
Steepness (Bev. - Holt)	N/A (hockey-stick) 0.6		0.98 0.7
Type	***Richards growth*** *(Ailloud et al., 2017)*	***von Bert. Growth*** *(Cort, 1991)*	
A2	34		
L1 **(cm)**	33.0		
L2 **(cm)**	270.6	***Linf (cm)***	318.8
K	0.22	***K***	0.093
p_0	-0.12	***t0***	-0.97

Natural mortality rate at age (East and West)

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15+**
High	0.38	0.30	0.24	0.20	0.18	0.16	0.14	0.13	0.12	0.12	0.11	0.11	0.11	0.10	0.10
Low	0.36	0.27	0.21	0.17	0.14	0.12	0.11	0.10	0.09	0.09	0.08	0.08	0.08	0.08	0.07

Selectivity of at least one fleet	-	Japanese Longline fleet is asymptotic	-

Spawning fraction

Age	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13+**
Younger	0	0	0	0.25	0.5	1	1	1	1	1	1	1	1	1
Older (East)	0	0	0	0.15	0.3	0.45	0 .6	0 .75	0.9	1	1	1	1	1
Older (West)	0	0	0	0	0	0	0	0.01	0.04	0.19	0.56	0.88	0.98	1

II) **Estimated parameters**

The majority of parameters estimated by the model relate to movement probabilities and annual recruitment deviations (Table 8.3).

Commented [D47]: Check to make sure this the most up-to-date table

Can we add reference to when and how these were determined

Also need to be clear about the Steepness values
-What they are used in, what they represent

Commented [D48]: SS analysis

Commented [D49]: An alt to 0.98

Commented [D50]: For Tom to check and confirm

Also write down the assumed functional forms are

Table 8.3. The parameters estimated by the model. The example is for a possible bluefin tuna operating model of 7 strata areas (Figure 1.1B), 4 quarters, 14 fleets, 32 years and 18 ages and 3 movement age classes.

Parameter	**Number of parameters**	
Unfished recruitment (recruitment level 1)	$2n_{stocks}$	4
Length a modal selectivity	n_{fleets}	14
Ascending precision of selectivity	n_{fleets}	14
Descending precision of selectivity	$n_{fleets\text{-}1}$	13
Recruitment deviations	$[(n_{years} + n_{ages} + 1) \cdot n_{stocks} \cdot n_{ageclass}]/2$	153
Fleet catchability (*q*)	n_{fleets}	14
F deviation (*FD*)	$n_{quartersseasons} \cdot n_{areas}$	28
Movement	$n_{areas} \cdot n_{squarterseasons} \cdot n_{stocks}$	56
	Total	286

Commented [D51]: 296?

Table 8.4. Prior probability distributions for model parameters with mean μ and standard deviation σ, and lower and upper bounds *LB* and *UB*, respectively.

Parameter	**Prior**	**Likelihood component**
All operating models		
Total recruitment	log-uniform(*LB* = 11.5, *UB* = 16.5)	$-lnL_{rec}$
Unfished recruitment	logit-uniform(*LB* = -∞, *UB* = ∞)	$-lnL_{R0}$
Selectivity	lognormal(μ = 0, σ = 0.9) (*LB* = -5.0, *UB* = 5.0)	$-lnL_{sel}$
Fleet catchability (*q*) (mean F)	log-uniform(*LB* = -10.0, *UB* = 1.0)	$-lnL_{q}$
F deviation (*FD*, Eqn 3.4)	lognormal(μ = 0, σ = 0.4)	$-lnL_{FD}$
Movement deviations (from fully mixed)	lognormal(μ = 0, σ = 1.0) (*LB* = -6.0, *UB* = 6.0)	$-lnL_{mov}$
Recruitment deviations	lognormal(μ = 0, σ = 0.5)	$-lnL_{recdev}$
Unfished recruitment change (applicable only to the level 1 and 3 recruitment scenarios)	lognormal(μ = 0, σ = 0.6)	$-lnL_{R0dif}$
Some operating		
Assessment SSB	lognormal(SSB, σ = 0.01)	$-lnL_{SSB}$

A summary of likelihood functions can be found in Table 8.4.

For each fleet *f*, total predicted catches in weight $\hat{C}$, are calculated from the Baranov equation:

$$\hat{C}_{y,m,r,f} = \sum_s \sum_a w_{s,a} \cdot N_{s,y,m,a,r} \cdot (1 - e^{-Z_{s,y,m,a,r}}) \cdot \left(\frac{F_{y,m,a,r,f}}{Z_{s,y,m,a,r}}\right) \qquad (8.1)$$

Similarly predicted catches in numbers at age (*CAA*) are given by:

$$\widehat{CAA}_{s,y,m,a,r,f} = N_{s,y,m,a,r} \cdot (1 - e^{-Z_{s,y,m,a,r}}) \cdot \left(\frac{F_{y,m,a,r,f}}{Z_{s,y,m,a,r}}\right) \quad (8.2)$$

This can be converted to a prediction of total catches in numbers by length class *CAL* using a stock specific inverse age-length key, *LAK*:

$$\widehat{CAL}_{y,m,l,r,f} = \sum_s \sum_a \widehat{CAA}_{s,y,m,a,r,f} \cdot LAK_{s,a,l} \quad (8.3)$$

The model predicts spawning stock biomass indices $\widehat{Issb}$, that are standardized to have a mean of 1 for each stock over the total number of years n_y:

$$\widehat{Issb}_{s,y} = n_y \cdot SSB_{s,y} / \sum_y SSB_{s,y} \quad (8.4)$$

The model predicts exploitable biomass indices $\hat{I}$, by fleet that are standardized to have a mean of 1 for each fleet:

$$\hat{I}_{y,m,r,f} = n_y \cdot n_m \cdot n_r \cdot V_{y,m,r,f} / \sum_y \sum_m \sum_r V_{y,m,r,f} \quad (8.5)$$

where exploitable biomass *V* is calculated as:

$$V_{y,m,r,f} = \sum_l \left(s_{f,l} \cdot \sum_s \sum_a \left(N_{s,y,m,a,r,f} \cdot LAK_{s,a,l} \cdot w_{s,a}\right)\right) \quad (8.6)$$

The model predicts stock of origin composition of catches (fraction eastern) $\hat{R}$, from predicted catch numbers at age:

$$\hat{R}_{y,m,r,f} = \sum_a \widehat{CAA}_{s=1,y,m,a,r,f} / \sum_s \sum_a \widehat{CAA}_{s,y,m,a,r,f} \quad (8.7)$$

A log-normal likelihood function is assumed for total catches by fleet. The negative log-likelihood is calculated as:

$$-lnL_c = \sum_y \sum_m \sum_r \sum_f ln(\sigma_{catch}) + \frac{\left(\ln(\hat{C}_{y,m,r,f}) - \ln(C_{y,m,r,f})\right)^2}{2 \cdot \sigma_{catch}^2} \quad (8.8)$$

Similarly the negative log-likelihood components for indices of exploitable biomass and spawning stock biomass are calculated as:

$$-lnL_i = \sum_y \sum_m \sum_r \sum_f ln(\sigma_{index}) + \frac{\left(ln(\hat{I}_{y,m,r,f}) - ln(I_{y,m,r,f})\right)^2}{2 \cdot \sigma_{index}^2} \quad (8.9)$$

$$-lnL_{SSB} = \sum_s \sum_y ln(\sigma_{SSB}) + \frac{\left(ln(\widehat{Issb}_{s,y}) - ln(Issb_{s,y})\right)^2}{2 \cdot \sigma_{SSB}^2} \quad (8.10)$$

The negative log-likelihood component for length composition data is calculated by the log-normal density function with variance inversely related to the observed fraction of observations in each length class *p* (of Maunder 2011):

$$-lnL_{CAL} = -\sum_y \sum_m \sum_l \sum_r \sum_f ln\left(\sqrt{0.02/p_{y,m,l,r,f}}\right) + \frac{\left(\ln(\hat{p}_{y,m,l,r,f}) - \ln(p_{y,m,l,r,f})\right)^2}{\sqrt{0.02/p_{y,m,l,r,f}}} \quad (8.11)$$

where the model predicted fraction of catch numbers in each length class *p*, is calculated as:

$$\hat{p}_{y,m,l,r,f} = \widehat{CAL}_{y,m,l,r,f} / \sum_l \widehat{CAL}_{y,m,l,r,f} \quad (8.12)$$

The negative log-likelihood component for PSAT tagging data of known stock of origin (SOO), released in year *y*, quarter *m*, area *r* and recaptured in year *y2*, quarter *m2*, and area *k* is calculated from a multinomial likelihood function as:

$$-lnL_{PSAT} = -\sum_s \sum_y \sum_m \sum_{y2} \sum_{m2} \sum_r \sum_k PSAT_{s,y,m,y2,m2,k} \cdot ln\left(\hat{\theta}_{s,y,m,y2,m2,r,k}\right) \quad (8.13)$$

where recapture probabilities θ, are calculated by repeatedly multiplying a distribution vector *d*, by the movement probability matrix *mov*. For example, for a tag released on a fish of stock 1 in year 2, quarter 3, and area 4, the probability of detecting the tag in year 3, quarter 2 for the various areas is calculated as:

$$\hat{\theta}_{s=1,y=2,m=3,y2=3,m2=2,r=4,1:n_r} = \left(\left(d \cdot mov_{s,m=3}\right) \cdot mov_{s,m=4}\right) mov_{s,m=1} \quad (8.14)$$

Where: $$d_k = \begin{cases} 0 & k \neq r \\ 1 & k = r \end{cases} \quad (8.15)$$

The negative log-likelihood component for stock of origin data is calculated assuming a normal likelihood function (without constants) comparing model predicted $\hat{r}$ (SCRS/2018/133), using genetics and otolith microchemistry data) with *r* derived using the mixture model:

$$-lnL_{SOO} = \sum_i ln\left(\sigma_{r,i}\right) + \frac{(\hat{r}_{i-} r_i)^2}{2{\sigma_{i,s}}^2} \quad (8.16)$$

where the operating model estimated logit fraction eastern fish for the i^{th} strata, $\hat{r}_i$ is calculated from the operating model predicted ratio of eastern fish in the catch $\hat{R}_i$ (Eqn. 8.7):
$\hat{r}_i = ln\left(\hat{R}_i / \left(1 - \hat{R}_i\right)\right)$.

In order to fit the operating models to assessment model predictions (Factor 2 level B) a likelihood function is included for mean spawning $\overline{SSB}$,

$$-lnL_{SSB} = \sum_y \sum_k ln(\sigma_{SSB}) + \frac{\left(\ln(\overline{SSB}_{y,k})-\ln(\overline{\overline{SSB}}_{y,k})\right)^2}{2\cdot\sigma_{SSB}^2}$$
(8.17)

where $\overline{\overline{SSB}}$ is the annual SSB estimated from the VPA stock and operating model predicted spawning biomass $\overline{SSB}$ is calculated:

$$\overline{SSB}_{y,k} = \sum_y \sum_s \sum_m \sum_a \sum_r (\vec{N}_{s,y-1,ms-1,a,r} \cdot e^{-Z_{s,y,ms-1,a,r}} \cdot w_{s,a} \cdot mat_{s,a})^{area_{k,r}}$$
(8.18)

and *area* is a switch that is either 1 or zero depending on whether the area *r* is in the Eastern or Western assessment areas *k*. An additional likelihood is included in some operating models to simulate low stock depletions over recent years: lnL_{dep} which is identical to that above except that it fits spawning biomass relative to unfished levels.

$$\sum_y \sum_m \sum_r \sum_f ln(\sigma_{R0dif}) + \frac{\left(\ln(R_{0,1})-\ln(R_{0,2})\right)^2}{2\cdot\sigma_{catch}^2} \quad (8.19)$$

Commented [CT52]: New prior on the magnitude in difference in R0s for recruitment level 1 that includes early/late R0s for each stock.

The global penalised negative log-likelihood $-lnL_T$, to be minimized is the summation of the weighted negative log-likelihood components for the data and priors (Table 8.4):

$$-lnL_T = -[\omega_c \cdot lnL_c + \omega_i \cdot lnL_i + \omega_{SSB} \cdot lnL_{SSB} + \omega_{CAL} \cdot lnL_{CAL} + \omega_{PSAT} \cdot lnL_{PSAT} + \omega_{SOO} \cdot lnL_{SOO} + \omega_{SSB} \cdot lnL_{SSB} + \omega_{rec} \cdot lnL_{rec} + \omega_{sel} \cdot lnL_{sel} + \omega_q \cdot lnL_q + \omega_{qI} \cdot lnL_{qI} + \omega_{FD} \cdot lnL_{FD} + \omega_{mov} \cdot lnL_{mov} + \omega_{recdev} \cdot lnL_{recdev} + \omega_{R0dif} \cdot lnL_{R0dif}] \quad (8.20)$$

Table 8.5. Summary of the negative log-likelihood function contributions from various data

Type of data	Disaggregation	Function	Likelihood component
Total catches (weight)	year, quarter, area, fleet	Log-normal	lnL_c
Index of exploitable biomass (assessment CPUE index)	year, quarter, area, fleet	Log-normal	$lnLi$
Index of spawning stock biomass (e.g. a larval survey)	year, stock	Log-normal	lnL_{SSB}
Length composition	year, quarter, area	Log-normal	lnL_{CAL}
PSAT tag (known stock of origin)	stock, year, quarter, area, age class	Multinomial	lnL_{PSAT}
Stock of origin	year, quarter, area, age class	Normal	lnL_{SOO}

A likelihood weighting scheme (the ω values of equation 8.20, Table 8.6) was selected that balanced the contribution of the various data sources and achieve as closely as possible the specified observation errors (achieved via iterative reweighting).

Table. 8.6. Likelihood weightings for various components of equation 8.20.

Likelihood component	Symbol	Typical *lnL* value	Weighting (ω)	End product
Total catches (weight)	ω_c	17,000	$4e^{-3}$	68
Index of exploitable biomass (assessment CPUE index)	ωi	200	$4e^{-2}$	8
Index of spawning stock biomass (e.g. a larval survey)	ω_{SSB}	300	$7e^{-1}$	210
Length composition	ω_{CAL}	200,000	$2.5e^{-4}$	50
Stock of origin	ω_{SOO}	300	$8e^{-1}$	240
Electronic tag (known stock of origin)	ω_{PSAT}	5,000	$3e^{-1}$	1500
Recruitment deviations (prior)	ω_{rec}	50	$5e^{-1}$	25
Movement (prior)	ω_{mov}	2000	$1e^{-3}$	2
Selectivity (prior)	ω_{sel}	100	$1e^{-2}$	1
SSB prior (to match VPA assessments, level B abundance)	ω_{SSB}	100	*0 or 5*	0 or 500
F deviation from master index (prior)	ω_{FD}	20	$2.5e^{-1}$	5
Difference in early/late R0 estimates for recruitment levels 1 and 3.	ω_{Rodiff}	6	*10*	60

Commented [CT53]: Weightings changed given new two-phase R0 model, electronic tagging, SOO and index data.

III) Characterising uncertainty

Baseline

Include within-model uncertainty via MCMC sampling of posteriors for model parameters.

Alternative options

Include within-model uncertainty (parameter uncertainty) via Monte Carlo sampling from the inverse Hessian matrix of model parameters.

Concentrate on among-model uncertainty using the maximum posterior density estimates of model parameters and a prior model weight based on expert judgement. Uniform weights will be used to start, possibly updated later using a Delphi-type approach.

9. TRIAL SPECIFICATIONS

A. Reference set

Three major uncertainty axes: future recruitment; current abundance; and natural mortality/maturity (in combination) for conditioning and projections. These axes assume that the options of East and West are linked across rows of the table below. This has been done with the intention of capturing extremes.

	West	East
Recruitment		
1	B-H with h=0.6 (high R0) switches to h = 0.9 (low R0) starting from 1975	50-87 B-H h=0.98 switches to 88+ B-H *h*=0.98
2	B-H with h=0.6 fixed, high R0*	Hockey-stick (1973 hinge point)
3	Low R0 (level 2) switches to high R0 (level 1) after 10 years	88+ B-H with *h*=0.98 changes to 50-87 B-H with *h*=0.98 after 10 years
Abundance		
A	Best estimate	
B	East-West area spawning biomasses match 2017 VPA assessment	
Spawning fraction both stocks		Natural Mortality rate both stocks
I	Younger (E+W same)	High
II	Younger (E+W same)	Low
III	Older (E+W older but diff)	High
IV	Older (E+W older but diff)	Low

*High recruitment should reflect higher R0 than for hockey-stick

The West stock recruitment scenarios are intended to capture two alternative hypotheses for historical recruitment: the 'high then low recruitment' hypothesis captured by level 1 in which a Beverton-Holt stock recruitment relationship with fixed moderate steepness (R0 estimated) shifts to a higher steepness after 1975 (second R0 estimated), and the 'high recruitment' hypothesis that maintains a Beverton-Holt recruitment relationship with fixed moderate steepness throughout the time series. The third level for West recruitment evaluates the robustness of MPs to a future shift between these alternative recruitment scenarios.

Similarly, the East stock recruitment level 1 has two periods of differing unfished recruitment, level 2 assumes a hockey stick throughout and the third level, as for the West considers a shift

Commented [D54]: Needs to be explained more fulsomely
Also headings need to be clearer (e.g. past abundance)

Commented [CT55]: The previous hockey stick model required prior determination of the hinge point which is not straightforward for the mixing model. Hence a comparable B-H model was specified that could replicate a shift in R0 from low to high.

Commented [CT56]: There is no longer a level C

Commented [D57]: I feel like the goal was to match to the east VPA? Not the west VPA. But maybe I have forgotten. Not too sure how you match both in one abundance scenario?

Commented [D58]: I think it would be good to further explore the spawning fraction and see if younger and older are needed (when I examined CMPs using the old version for the tool age-of-maturity might not be that influential).

This might allow us to add another Axis of Uncertainty. Which I suggest should be a mixing axis.

Commented [D59]: This is a great explanation of the 3 different Western recruitment scenarios. Could we also add a explanation of the 3 eastern recruitment scenarios?

between recruitment scenarios after 10 years. Until very recently level 1 (low then high recruitment) was the prevailing hypothesis however recent assessments have estimated lower recruitments providing some support for level 2.

The rationale for level three in both stocks is that if recruitment shifts have occurred in the past they could occur in the future also.

Combinations for Reference Set

A full cross of (1, 2, 3) x (A, B) x (I, II, III, IV), i.e. 24 scenarios in total (16 of which require OM fitting since Recruitment levels 1 and 3 differ only in projection).

Commented [D60]: Don't all 24 need to be fitted? Not sure how I see Recruitment level 1 and 3 being equal except projection? Doesn't 1 west use B-H and 3 use Hockey-Stick?

Discussion will be required regarding whether, in addition to considering results for each of these scenarios individually, they should also be considered for all scenarios in combination, and if so how the scenarios should be weighted (if at all) in such a combination.

Spawn. Frac. / M :	**I**		**II**		**III**		**IV**	
Abundance:	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**
Recruitment: 1	OM_1	OM_4	OM_7	OM_10	OM_13	OM_16	OM_19	OM_22
Recruitment: 2	OM_2	OM_5	OM_8	OM_11	OM_14	OM_17	OM_20	OM_23
Recruitment: 3	OM_3	OM_6	OM_9	OM_12	OM_15	OM_18	OM_21	OM_24

B. Robustness trials

Currently available

Commented [CT62]: New robustness trials table documenting those now included in the ABTMSE package.

	Scenario	**One factor deviation from OM:**	
		1AI	**2AI**
1	**Half stock mixing**. The fraction of east area biomass that is West stock is halved, fraction of west area biomass that is East stock is halved.	ROM1_1	ROM1_2
2	**Low western mixing**. A strong prior is placed on very low fraction of West stock in the East area.	ROM2_1	ROM2_2
3	**Gulf of Mexico SSB**. Prior on higher GOM SSB in quarter 2 and lower GOM SSB in quarter 3	ROM3_1	ROM3_2
4	**'Brazilian catches'.** Catches in the South Atlantic during the 1950s are reallocated from the West to the East.	ROM4_1	ROM4_2
5	**Time varying mixing**. Future movement switches from half stock mixing (robustness scenario 1) to 150% stock mixing every three years.	ROM5_1	ROM5_2

6	**Persistent change in mixing.** Future movement permanently switches from half mixing to 150% mixing after 10 years.	ROM6_1	ROM6_2

Other Robustness trials: high priority

1) Future catches in both the West and the East+Med are each year 20% bigger than the TAC as a result of IUU fishing (of which the MP is not aware)
2) An undetected increase in catchability for CPUE-based abundance indices of 2% per annum (based on estimated change in catchability for one of the stock size indices over a 45-year period)
3) Non-linear index-abundance relationships

Commented [D63]: Is it that we want it to be 20% more than the TAC or 20% more than reported catches?

Other Robustness trials: low priority

1) Future recruitment change as in 3), but with prob of 0.05 for each of the first 20 years of projection
2) Decreasing catchability or step-changes in catchability.
3) Split Med Larval index

"Second round" issues

The following aspects of uncertainty are suggested to be postponed at this time for consideration rather in a "second round":

1) More than two stocks
2) More than two indices of abundance used as input to a MP
3) Use of CAL data in an MP
4) TACs allocated on a spatially more complex basis than the traditional west and East+Med
5) Changes in technical measures affecting selectivity
6) Changes in stock distributions in the future
7) Future changes in proportional allocation of TACs amongst fleets

10. PERFORMANCE MEASURES/STATISTICS

Projections under candidate MPs will be for 100 years (unless this leads to computational difficulties) commencing in 2017. Prior to that, for projecting for years between the last year of the condition and 2017, the catches will be set equal to the TACs already set, with abundance index data (and any further monitoring data such as catch-at-length) not yet available for those years being generated as specified under item 7. Note that considering a period as lengthy as 100 years is not to imply high reliability for projections for such a long time, but to be able take account of transient effects that persist for some time for a long-lived species.

I) **Summary measures/statistics**

a) Annual average catch for the first, second and third 10-year period of MP application (C10, C20 and C30, respectively).
b) Spawning biomass depletion calculated relative to the deterministic equilibrium in the absence of catches for the recruitment function that applies after 10, 20 and 30 years of MP application (D10, D20 and D30, respectively)
c) The lowest spawning biomass depletion over the 30 years for which the MP is applied (LD).
d) Spawning biomass depletion after 30 years, but calculated relative to the trajectory that would have occurred had no catches been taken over the full period for which MP application is being considered (DNC)
e) The lowest spawning biomass depletion over the 30 years for which the MP is applied, but calculated relative to the zero catch trajectory specified in d (LDNC).
f) Kobe or alternative Kobe indicators: catch/biomass instead of Fmsy (POF); and biomass/biomass at a theoretical maximum MSY (POS); and the probability of both underfishing and underfished status (probability green kobe zone: PGK).
g) Average annual variation in catches (AAVC) defined by:

$$AAV = \frac{1}{30}\sum_{y=2017}^{2046} \left|C_y - C_{y-1}\right| / C_{y-1} \qquad (13.1)$$

For each of these distributions, 5%-, 50%- and 95%iles are to be reported from 200 replicates. Note the reason for measures/statistics c) and e) is to compensate for regime changes. The choice of these percentiles may need further exploration with stakeholders.
Further stakeholder orientated measures may need to be included. These must be scientifically based, easily understood by stakeholders and such that managers may readily request the evaluation of any changes in options.

h) AAVC but for downward adjustments only

II) **Summary plots**
Catch and spawning biomass trajectories plotted as:

a) Annual medians with 5%- and 95%-ile envelopes
b) 10 worm plots of individual realisations

Note that repetitions for different options for selectivity may be needed.

III) **Level of reporting**

Baseline

a) Catch-related measures/statistics by traditional West and East+Med regions.
b) Spawning biomass depletions measures/statistics by separate stocks

Commented [D64]: So are these calculated for each OM? Or is this across all OMs?

e.g. is C10 the average catches in OM1 for years 2017-2026? Or, is it the average annual catch across all the OMs?

Alternative options

Many can be conceived, likely related primarily to catch and depletion by some combination of stock and/or spatial stratum. However these might be left for a "second round", as they would become more pertinent in the face of greater model complexities possibly introduced at that time, such as changing spatial distributions of stocks and/or catches (resulting from changed proportional allocations to different fleets).

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APPENDIX 1 – Alternative Hypothesis and OM construction

1. Basic concepts and stock structure

i. Spatial strata

Alternative low priority future options

The MAST model (Taylor et al. 2011) which has strata the same as Figure 1.1A, but simplified such that the Central Atlantic is merged with the Western Atlantic.

Commented [D65]: Should be clear about this being right or left map

ii. Stock mixing

Possible alternative options

A two-stock model with no mixing