ICCAT GBYP CORE MODELLING MSE GROUP
Report of the 6th Meeting
ICCAT Secretariat, Madrid, Spain
25 and 26 September 2017

1) Opening of the CMMG meeting

The meeting opened at 17:10 am on 25 September, and adopted the draft agenda. It was decided to continue the meeting in the following days, taking advantage of any time opportunity, if needed, during the other SCRS meetings later in the week.

The following participated. Members: Haritz Arrizabalaga, Doug Butterworth, Tom Carruthers (via Skype), Paul De Bruyn, David Die, Antonio Di Natale, Nick Duprey, Ana Gordoa, Laurie Kell, Toshihide Kitakado, Gary D. Melvin, Clay Porch; invited experts: Franco Biagi, Alex Hanke, Ai Kimoto, Shuya Nakatsuka, Mauricio Ortiz, Tristan Rouyer, Michael Schirripa.

2) Nomination of the Chair

Doug Butterworth was nominated as Chair.

3) Nomination of the rapporteurs

Antonio Di Natale and Toshi Kitakado were nominated as rapporteurs.

4) Adoption of the agenda

The draft agenda (Annex 1) was adopted, taking into account the need to adapt the order of the various items in the light of the practical need of presenting a document to the SCRS Bluefin Tuna Species Group during its meeting later in the week.

5) Available documents

The chair informed the participants that several relevant documents had been made available on the ICCAT cloud: SCRS/2017/223, SCRS/2017/224, SCRS/2017/225, the Trial specifications document and the ABTMSE folder.

6) Confirmation of Report of July 2017 meeting and consideration of possible matters arising which are not covered under subsequent agenda items

The Group approved the report of the previous July 2017 meeting of the ICCAT GBYP Core Modelling MSE Group. The Group considered that the last item raised under point 9 of that report should be considered as a possible robustness trial.

7) Trials specifications document

a) Confirmation of revisions

Tom Carruthers led the Group through the updates to this document that had been made as a result of the decisions at the July meeting (which were blue-highlighted in the document. The major items were as follows:

i) Fishing mortality rate: a new model formulation was developed for fishing intensity and selectivity.
ii) Natural mortality rate: two different vectors for natural mortality-at-age were to be considered (previously one vector only).
iii) Maturity –at-age: two different vectors were to be considered (previously one vector only).
iv) Prior distributions: a table of specification for prior distributions had been added for clarification

The Group endorsed the changes made.

b) Re-review of abundance indices to be considered for use in candidate MPs (CMPs)

The Group reviewed the seven series selected at the previous meeting. It decided that all could be retained, and there was no need to consider adding more at this stage.

c) Finalisation of any other issues outstanding

No issues were raised under this agenda item.

8) **Consideration of report on refined conditioning of OMs**

a) Confirmation of adequacy of conditioning conducted

Tom Carruthers presented his report on progress on this item, which was provided in document SCRS/2017/223. Certain data inconsistencies (including the values of the current TACs) were noted and corrected, and the conditioning was updated during the course of the meeting taking these corrections and other suggestions (particularly towards establishing consistency with assumptions being made for the 2017 assessments) into account. The Trial specifications document would be amended to reflect these changes.

In considering the outputs for biomass and recruitment (e.g. Fig. 1a), the Group noted that the EBFT stock dominates because of its much greater size than the WBFT stock. It further noted that the plots of VPA and SS3 assessment results had played no part in the condition of the OMs; they were included only to assist comparison, and could be updated given the final assessments agreed by the SCRS Bluefin tuna Species Group.

A concern was raised regarding abundance scenario 3 which required a match to the recent substantial increase in biomass evident for the EAFT assessment. The conditioning had achieved this through a large recent spike in recruitment; this seemed implausible and might result in unrealistic projections of biomass into the future. Tom Carruthers was asked to revise the conditioning for the associated trials to avoid this feature.

The Group noted that the pattern of residuals for the fits to each abundance index were surprisingly similar across the 12 trials (three abundance scenarios x four natural mortality/maturity scenarios). Tom Carruthers explained that though individual indices could contain strong signals, each tended not to have much influence overall, also because of the considerable noise in the data. He also pointed out that although these residual patterns were very similar, the 12 trials reflected very different situations, for example as regards the associated values of MSY-based reference points.

The Group accepted the conditioning conducted as satisfactory, except in the case of abundance scenario 3. [Subsequent to the meeting the revised conditioning results requested were circulated, and agreed by the Group by email to be satisfactory.]

b) Approval of models to be used to generate future abundance index data

Tables in SCRS/2017/223 reported the residual standard deviations and auto-correlations for the fits of the abundance indices to be used for inputs to candidate MPs. These would be used in generating future abundance index data. It was noted that the standard deviations were generally rather high, with a median value below 0.5 for only one of the series; this suggests that CMPs will need to use multiple series to reduce the variability of their TAC outputs

A further table in SCRS/2017/223 gave these results when in addition a non-linearity parameter was introduced into the index-abundance relationship, allowing for the possibility of hyperstability or hyperdepletion. These results indicated some over-parametrisation of the OM, and the Group recommended that they be rerun including an informative prior to limit the range of the non-linearity parameters estimated.

The Group agreed that the approach excluding the non-linearity parameters be used for the Reference Set of OMs, but that robustness test be included which allowed also for inclusion of these parameters.

c) Refinement of and procedures for conditioning robustness trials

The Group reviewed the existing list of "first round" robustness tests set out in the Specifications document. It decided that these be revised as follows.

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 1% per annum.
3) Non-linear index-abundance relationships (see discussion above)
4) Alternative mixing scenario

Regarding 4), Tom Carruthers and Haritz Arrizabalaga would confer to agree how a trial that reflected a lesser extent of east-west mixing than for the Reference Set OMs could be set up in a relatively simpler manner.

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) Alternative assignments to stock of origin of historical catches from the South Atlantic (off Brazil).

9) Progress on the development of a software package, incorporating all the OMs and associated trials, which allows any potential CMP developer to apply their CMP and view the results

a) Consideration of package presented

The Group discussed the paper SCRS/2017/224 which introduces this package. One suggestion was that it would be useful to add yield and use the most recent data in Table 2 of the document (which provides measures of performance). The Group recommended that output plots should include a simple spider plot which some find to aid understanding, and that projection outputs should be limited to the next 30 years, even if the package continues computations further into the future.

b) Consideration of the example application provided

Two simple index-based MPs were introduced as examples of MPs for illustrative purposes, together with showing the code required to do this in the package.

Amongst suggestions made regarding output were averaging over equally weighted MPs, and that candidate MP developers should prepare concise standardised summaries (about 2 pages in length) to present their results.

10) Preparation of report to the SCRS and Commission

The Group discussed with the SCRS Chair the best way to present the progress on GBYP Modelling to the next Commission Meeting, considering the various options for the presentation and taking into account the very limited time available. At the end of the meeting the SCRS Chair advised that he had all the information he required to prepare his presentations.

11) Future plans

The Group noted the schedule set out at the July meeting (Annex 2), and that the agenda had been developed to address this. Arrangements would be made to report progress to the SCRS Bluefin tuna Species Group taking place later in the week, so that they were kept fully informed.

The Group discussed how to fit the current schedule (Annex 2) with the updated working needs. The Group recognized that the best opportunity for having a meeting with the stakeholders would be during an intersessional meeting of Panel 2 and agreed that that should be proposed to the Commission; this meeting should take place in the first part of 2019 with the possibility of a further meeting later in that year; two meetings of the CMMG for work towards finalizing the CMPs would also be needed in 2019, with one after the first Panel 2 meeting, and the other immediately preceding the September 2019 SCRS Bluefin tuna Species Group session. In the light of these discussions, Annex 2 was revised to provide an updated schedule (see Annex 3).

The Group discussed the need to involve specialists from different CPCs in the CMMG particularly from geographical areas which are not currently represented in the Group, so enhance the likely acceptance of a final MP proposed through extending “ownership” of the proposal.

The necessity of securing a number of candidate MP developers to work using the package developed towards proposing CMPs to the planned 2018 intersessional meeting was stressed. The Group recommended that Tom Carruthers be one of those developers. Participants in the meeting indicated the likely availability of such developers from a number of CMPs.

12) Any other business

After the meeting, the Specifications document was revised to incorporate the decisions at the meeting. This revised version is appended as Annex 4.

13) Closure

The meeting closed at 6-30 pm on Tuesday 26 September.

ANNEX 1: AGENDA

1) Opening of the CMMG meeting

2) Nomination of the Chair

3) Nomination of the rapporteurs

4) Adoption of the agenda

5) Available documents

6) Confirmation of Report of July 2017 meeting and consideration of possible matters arising which are not covered under subsequent agenda items

7) Trials specifications document
   a) Confirmation of revisions
   b) Re-review of abundance indices to be considered for use in candidate MPs (CMPs)
   c) Finalisation of any other issues outstanding

8) Consideration of report on refined conditioning of OMs
   a) Confirmation of adequacy of conditioning conducted
   b) Approval of models to be used to generate future abundance index data
   c) Refinement of and procedures for conditioning robustness trials

9) Progress on the development of a software package, incorporating all the OMs and associated trials, which allows any potential CMP developer to apply their CMP and view the results
   a) Consideration of package presented
   b) Consideration of the example application provided

10) Preparation of report to the SCRS and Commission

11) Future plans

12) Any other business

13) Closure

ANNEX 2: FUTURE PLANS

1) About April 2018 the various developers of CMPs meet to compare results and agree on refinements to take their CMPs further.

2) The September 2018 bluefin session narrows the set of CMPs based on their performance across the various OMs.

3) The 2018 SCRS meeting will append a first stakeholder-scientist interaction meeting to discuss desired MP properties and performance, informed by results from this first set of CMPs.

4) The ultimate aim of this exercise is to table a proposed set of MP options to Commission at its 2019 meeting for selection of a final MP there.

ANNEX 3: FUTURE PLANS - *Updated*

1) About April 2018 the various developers of CMPs meet to compare results and agree on refinements to take their CMPs further.

2) The September 2018 bluefin session narrows the set of CMPs based on their performance across the various OMs.

3) A first stakeholder-scientist interaction takes place during a Panel 2 intersessional meeting in about February 2019 to discuss desired MP properties and performance, informed by results from this first set of CMPs.

4) A subsequent meeting of the CMMG takes place to consider the results of CMP amendments informed by that stakeholder-scientist interaction.

5) If needed, a second stakeholder-scientist interaction takes place during a further Panel 2 intersessional meeting in about July 2019.

6) A meeting of the CMMG takes place before the September 2019 bluefin session to finalise a small number on CMPs to present to the Commission

7) A proposed set of CMPs is presented to the Commission at its 2019 meeting for a selection there of a final MP.

ANNEX 4

SPECIFICATIONS FOR MSE TRIALS FOR BLUEFIN TUNA IN THE NORTH ATLANTIC

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.

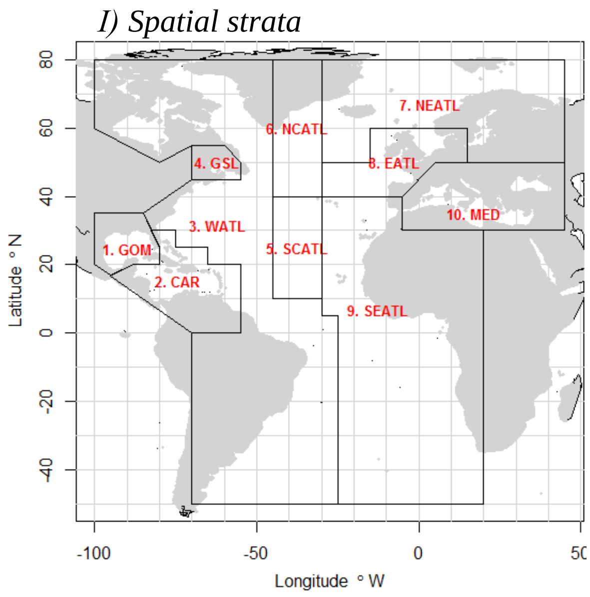


Figure 1.1. Spatial definitions tabled by the 2015 ICCAT data preparatory meeting (Anon. 2015) with simplification to a single Mediterranean area.

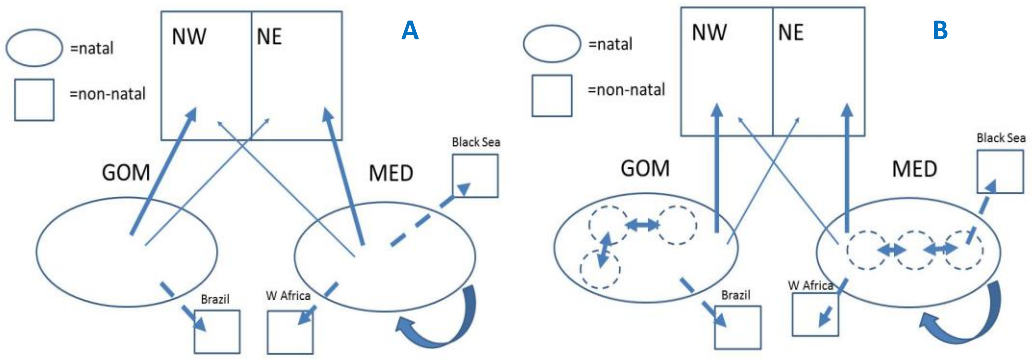
<u>Baseline</u>

Spatial areas at the resolution of the reported PSAT tagging data and the stock of origin data (which do not have sufficient resolution to divide the Mediterranean area into Eastern and Western sub areas)(Figure 1.1)

<u>Alternative low priority future options</u>

The MAST model (Taylor et al. 2011) areas which are the same Figure 1.1 but simplified such that the Central Atlantic is merged with the Western Atlantic.

II) Stock mixing



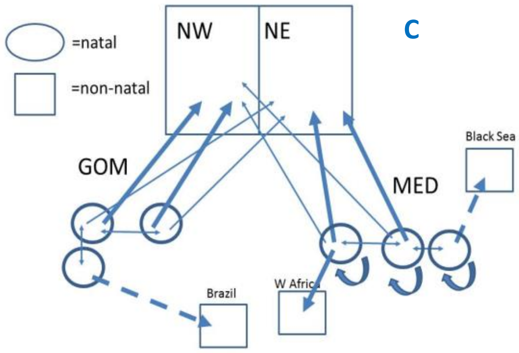


Figure 1.2. Mixing hypotheses suggested by Arrizabalaga et al. 2014).
(A) A two stock model with no sub-populations.
(B) A two stock model with sub-population structure.
(C) A complex 2+ stock model.

<u>Baseline</u>

A two-stock model similar to Figure 1.2A but adhering to the spatial structure of Figure 1.1A and including the mixing for West Africa which was discovered after the Tenerife meeting.

<u>Possible alternative options</u>

A two-stock model with no mixing

2. PAST DATA AVAILABLE

Table 2.1 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 2.1, field 'Used in OM'). Currently the operating model is fitted to ICCAT Task II landings data scaled upwards to annual Task I landings.

The ICCAT catch at size data set 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. In total 319 tags provided information on 929 quarterly transitions (Table 2.2).

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 research of AZTI, UMCES and DFO (Table 2.3).

There is uncertainty in regard to the stock of origin of bluefin 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 1.1A 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 W.Atl and E.Atl (Figure 1.1A) 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).

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, subyear 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, subyears and fleets, respectively.

The Task II CPUE data provide information about the approximate spatial / season distribution of the stock within years (Table 2.2). The standardized assessment indices provide the primary information about trend within area over years (Table 2.3).

Table 2.2. The Task II CPUE data used to derive the master index.

Flag	Gear	Details
Japan	Longline	1.38m fish
USA	Longline	13,156 fish
Canada	Rod and reel	9,131 tonnes
Morocco	Trap	15,996 tonnes
Spain	Baitboat	35,625 tonnes

Table 2.3. The standardized CPUE indices of the assessments that are used to derive trend information for the master index and also fit the operating models.

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	2010-2017, Q4, NE Atl
US (66cm - 114cm)	Rod and reel	1993-2015, Q3, W Atl
US (115cm - 144cm)	Rod and reel	1993-2015, Q3, W Atl
US (145cm +)	Rod and reel	1980-1992, Q3, W Atl
US (195cm +)	Rod and reel	1984-1992, Q3, W Atl
US	Longline	1987-1991, Q2, GOM
US	Longline	1992-2016, Q2, GOM
Japan	Longline	1976-2009, Q4, W Atl
Japan	Longline	2010-2017, Q4, W Atl
Canada	Rod and reel	1984-2016, Q3, W Atl
Italy	Trap	1993-2010, Q2, Med

Table 2.4. Fishery-independent indices used in the fitting of operating models.

Type	Details
French aerial survey	2000-2016, Q2, Med
Larval survey	2001-2015, Q2, Med
Canadian acoustic survey	1994-2015, Q3, GSL
Larval survey	1977-2016, Q2, GOM
Aerial survey	1975-2009, Q2, Med

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, subyears and areas (Figure 2.1).

The operating models are also fitted to the standardized indices used in the VPA stock assessments (Table 2.3) and range of fishery-independent indices (Table 2.4). These fishery independent indices include a western larval index in the Gulf of Mexico (Lamkin et al., 2014and 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).

There are four sources of derived data that are priorities moving forward:

- a defensible inverse age-length key for each stock preferably disaggregated by time,
- finalized fishery-independent larval surveys for both the Western and Eastern stocks,
- standardized abundance indices based on trip-level catch rate data and
- electronic tag data by age class

- (most importantly) a greater quantity of stock of origin data by age class spanning a greater range of subyear and area combinations.

Note that the preliminary operating model has been fitted to a relative abundance index derived from ICCAT task II catch and effort data, primarily those from the Japanese longline fleet. Set specific data are not available at this level, such as hooks per basket (depth), bait type and soak time that often substantially affect the derived index of abundance. It is important to produce a trip-level index that is standardized for these covariates if possible.

Further, currently the stock of origin data are relatively numerous but very sparse and only available for about 20% of subyear-area combinations (Table 2.3) (currently the operating model does not have stock of origin data for the Western Mediterranean and the Gulf of St Laurence). Coupled with sparse PSAT tagging data at this resolution (Table 2.2), there is limited information to estimate age-specific movement and allow the model to apportion catches to stock in these time-area strata correctly. There are however a large number of studies that may provide estimates of the stock of origin the data of which are not currently used to condition the operating model (e.g. otolith microchemistry, SNP, otolith shape and mitochondrial DNA analyses). Along with additional electronic tagging data by age class, provision of these stock of origin data by age class is arguably the highest priority for successfully conditioning future operating models.

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).

Table 2.1. Overview of data that may be used to inform operating models for Atlantic bluefin tuna. Cells shaded green reflect sources for which data are available ('Collab',the Core modelling group CMG, or the ICCAT secretariat) and whether data that are available have also been used in conditioning preliminary operating models ('used in OM?'). The table can be accessed: https://docs.google.com/spreadsheets/d/13pFaM3BTnzQ1B

NQGoYn4O2n1IeD18V3VTbN9Hv7139U/edit#gid=1352276725.

Type of data (Informs)	Year range	Til	Spatial range	Can be by quarter?	By age-class?	Contact	Collab	Available to: TC	CMG	ICCAT	ALL	Used in OM?
1. CPUE indices (relative abundance, movement, performance at stakeholder level)												
1.1. ICCAT task II CPUE	1950-2014	∞	All	Y	N	Carlos Palma (ICCAT)	Y	Y	Y	Y	Y	Y
1.2. Japanese LL standardized spatial	1976-2013	∞	E, NE, W, C	Y	N	Ai Kimoto	Y	Y	N	N	N	for MPs
	1990-2013	∞		Y	N		Y	Y	N	N	N	for MPs
1.3. USA LL standardized spatial	1992-2014	∞	W	Y	N		Y	Y	N	N	N	for MPs
	1992-2004	∞	GOM	Y	N		Y	Y	N	N	N	for MPs
	2005-2014	∞	GOM	Y	N	Matt Lauretta (NOAA)	Y	Y	N	N	N	for MPs
1.4. USA HL standardized spatial	1980-2014	∞	W	Y	N		Y	N	N	N	N	Not yet
1.5. USA RR standardized spatial	1992-2014	∞	W	Y	N							
1.6. USA-CAN LL standardized spatial	1992-2014	∞	W, C	Y	N	M. Lauretta (NOAA) /	Y	N	N	N	N	Not yet
1.7. USA-CAN HL standardized spatial	1993-2014	∞	W, C	Y	N	A. Hanke (DFO)	Y	N	N	N	N	Not yet
1.8. CAN LL standardized		∞	W, GSL	Y	N		Y	N	N	N	N	for MPs
1.9. CAN HL standardized	1981-2014	∞	GSL	Y	N	Alex Hanke (DFO)	Y	N	N	N	N	Not yet
	1988-2014	∞	W	Y	N		Y	N	N	N	N	Not yet
1.10. TWN LL standardized	1960-2004	2004	W, NE, E	Y	N	Julia Huang (NTOU)		N	N	N	N	Not yet
1.11. MOR TRAP standardized	1981-2014	∞	WM	Y	N	N. Abid		N	N	N	N	Not yet
1.12. POR TRAP standardized			W, WM	Y	N			N	N	N	N	Not yet
1.13. ESP TRAP standardized			W, WM	Y	N	Jose Miguel de la Serna		N	N	N	N	Not yet
1.14 ITA TRAP standardised			CM	Y	N	Pierantonio Addis	Y	N	N	N	N	Not yet
1.15 ESP BB standarized 1	1952-1962		EATL	Y	N	Haritz Arrizabalaga						
1.16 ESP BB standarized 2	1963-2006		EATL	Y	N	Haritz Arrizabalaga						
1.17 ESP BB standarized 3	2007-2014		EATL	Y	N	Haritz Arrizabalaga						
1.18 Norway PS from task II	1955-1980		NEATL	Y	N	Leif Nottestad						
Master index for spatial rel. abudance					N							
2. Larval indices (SSB, movement)												
2.1. USA	1977-2013	∞	GOM	Y	N	Walter Ingram (NOAA)	Y	N	N	N	N	for MPs
2.2 ESP	01-'05 '12-'13	2018	W Med	Y	N	Franciso Alemany (IEO)	Y	N	N	N	N	for MPs
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	N
4. Catch composition (selectivity, depletion)												
4.1. ICCAT catch-at-size	1950-2015	∞	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	Not yet
4.3. Canadian fisheries				N	N	Alex Hanke (DFO)						Not yet
4.4 GBYP Historical catches	1910-1950	=	E, M	Y	N	Carlos Palma (ICCAT)	Y	N	Y	Y	Y	Not yet
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. SI archival tags (feasible movement)												
6.1. LPRC (n=4000)	2011-2015		W	Y	Y	Molly Lutcavage	Y	Y	N	N	N	Y
6.2. AZTI (n=20)	2007-2011		NE	Y	Y	Igor Arregui	Y	Y	N	N	N	Y

Table 2.1 continued.

Type of data (Informs)	Year range	Til	Spatial range	Can be by quarter?	By age-class?	Contact	Collab	Available to: TC	CMG	ICCAT	ALL	Used in OM?
7. PSAT tags (movement)												
7.1. LPRC (n=423)	2005-2009	ended	W	Y	Y	Molly Lutcavage	Y	Y	N	N	N	Y
7.2. DFO (n=135)	2013-2015	∞	GSL,W,GOM	Y	Y	Alex Hanke (DFO)	Y	Y	N	N	N	Y
7.3. Stanford (n=1783)	1996-2010	∞	W	Y	Y	Barbara Block	Y	Y	N	N	N	Y
7.4. GBYP (n = 103)	2012-2014	2015	E,MED	Y	Y	Antonio Di Natale	Y	Y	N	N	N	Y
7.5. WWF (n = 100)				Y	Y	Pablo Cermeno	Y	Y	N	N	N	Y
7.6. SEFSC (NOAA)	2011-2013		GOM,W,GSL	Y	Y	Craig Brown	Y	Y	N	N	N	Y
7.7. Acadia (NS)			GSL	Y	Y	Mike Stokesbury	Y	Y	N	N	N	Y
7.8. UCA	2011	ended	W, C, WM	Y	Y	Antonio Medina	Y	Y	N	N	N	Y
8. Otolith microchemistry (stock of origin)												
8.1. UMCES, TAMU	2012-2013			Y	Y	David Secor	Y	Y	N	N	N	Y
8.2. NOAA					Y		Y	Y	N	N	N	Y
8.3. AZTI (n=189)	2009-2011	ended	E	Y	Y	Igaratza Fraile	Y	Y	N	N	N	Y
8.4. DFO / UMCES	2011-2013	∞	W, GSL	Y	Y	Alex Hanke (DFO)	Y	Y	N	N	N	Y
8.5 GBYP (n=1371)	2009-2014		All	Y	Y	GBYP	Y	Y	Y	Y		Y
9. Otolith shape analysis (stock of origin)												
9.1. GBYP (n=172)	2011-2013	2015	E, W, C, WM	Y	N	GBYP	Y	N	N	N	N	Not yet
10. SNP (population structure, genetic structure)												
10.1. Med HCMR					N	Gianpaolo Zmpicinini		N	N	N	N	Not yet
10.2. GBYP (n=789)	2011-2015		All		N	GBYP	Y	N	N	N	N	Not yet
10.3 NOAA/VIMS/CSIRO	2015		GOM/MED	N	N	John Walter		N	N	N	N	Not yet
10.4 GBYP Historical UB	200 BC - 1927		E, M	Y	N	Alessia Cariani	Y	N	N	N	N	Not yet
11. Other genetics on population structure (population structure, genetic structure)												
11.1. mtDNA					N	Barbara Block		N	N	N	N	Not yet
11.2. Micro Sat/ mtDNA (n=320 / 147)	2003	ended	GOM, WM	Y	N	Carlsson		N	N	N	N	Not yet
12. Fish. Ind. surveys (relative abundance, movement)												
12.1. ICCAT Aerial	2010-2015		M	Y	N	Antonio Di Natale	Y	N	N	N	N	Not yet
12.2. USA Aerial	2015-		W	Y	N	Molly Lutcavage		N	N	N	N	Not yet
12.3. USA Acoustic	2015-		W	Y	N	Molly Lutcavage		N	N	N	N	Not yet
12.4. SOG Hydro acoustic curtain (OTN)	proposed		W, WM	Y	N	Mike Stokesbury		N	N	N	N	Not yet
13. Growth, aging (age-length keys, length-age keys)												
13.1. Age-length keys (NOAA)				Y	N	John Walter		N	N	N	N	Not yet
13.2. Age-length keys (IEO)	2010-2012	ended	E, WM	Y	N	Enrique Rodriguez-Marin		N	N	N	N	Not yet
13.3. Age-length keys (DFO)	2010-2013	ended	GSL, W	Y	N	Alex Hanke (DFO)		N	N	N	N	Not yet
13.4. Derived from tagging	1963-2012	ended	Es, W s	Y	N	Lisa Allioud	Y	Y	N	N	N	Y
13.5 Age-length keys (GBYP)	2011-2015		E, M	Y	N	Antonio Di Natale	Y	N	Y	Y		Not yet
13.5 Ageing calibration (GBYP)	2014		E, M	Y	N	Antonio Di Natale	Y	N	Y	Y		Not yet
14. Maturity (Spawning biomass)												
14.1. Western (NOAA)	1975-1981	ended	GOM	Y	N	Guillermo Diaz (NOAA)	Y	N	N	N	N	Not yet
14.2 Mediterranean		rew	M	Y	N	GBYP	Y	N	Y	Y		Not yet
Other derived maturities from data prep					N							
15. Other ecological data (spatial distribution, covariates for CPUE standardization, steepness, natural mortality rate, spawning locations etc.)												
15.1. Larval ecology (IEO)		ended	WM	Y	N	Diego Alvarez Berastegui		N	N	N	N	Not yet
15.2. Habitat model				Y	N	Jean-Noel Druon		N	N	N	N	Not yet

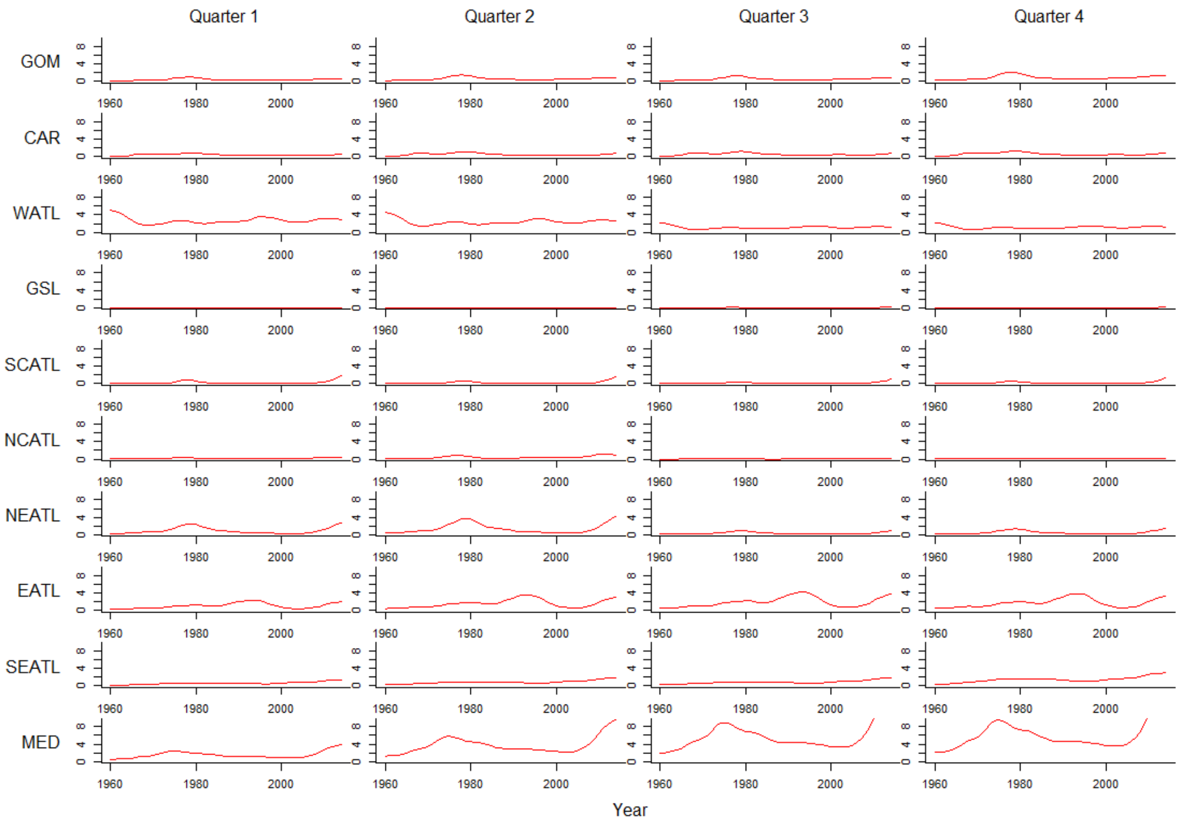


Figure 2.1. The master index. Areas correspond to those of Figure 1.1.

Table 2.2. The recorded quarterly transitions for electronic tags of NOAA, DFO, WWF, AZTI, UNIMAR, IEO, UCA, FEDERCOOPESCA, COMBIOMA, GBYP of known stock of origin (i.e. those tags entering either the Gulf of Mexico or the Mediterranean). For example, there are 20 tags that at some point entered the Gulf of Mexico (Western fish) that exhibited a movement from the Gulf of St Laurence to the Western Atlantic.

TO AREA:

	Eastern										Western									
FROM AREA:	GOM	CAR	WATL	GSL	SCATL	NCATL	NEATL	EATL	SEATL	MED	GOM	CAR	WATL	GSL	SCATL	NCATL	NEATL	EATL	SEATL	MED
Jan-Mar																				
GOM											12	1	1							
CAR											2		2							
WATL			1								3	2	13			2		2	2	
GSL																				
SCATL																			1	
NCATL																			1	
NEATL																				
EATL								1	1	1								1		
SEATL									3	1			1					2	2	
MED										17										
Apr-Jun																				
GOM											1		10	1						
CAR																				
WATL									1				5	2		2		3		
GSL																				
SCATL																				
NCATL													2			2		1		
NEATL																				
EATL									1				2					5		
SEATL								1	1	1			2			1		2		
MED							3	2	2	1				1						
Jul-Sept																				
GOM																				
CAR																				
WATL											1		39	2						
GSL											3		20	1						
SCATL																				
NCATL																1				
NEATL						1	1													
EATL								2	1							1	3	4		
SEATL									2	1										
MED									2	1										
Oct-Dec																				
GOM											4	1								
CAR																				
WATL											14	7	49		1			1	2	
GSL											1		1							
SCATL																				
NCATL																		1	1	
NEATL													1			1			1	
EATL									1				1						2	
SEATL								3	3	1										
MED									3	1										

Table 2.3. Distribution of fish that were sampled and assigned stock of origin across years, areas and quarters (N=3465).

Year	N	Area	N	Quarter	N
1974	2	**GOM**	304	1	413
1975	152	**WATL**	1992	2	876
1976	67	**GSL**	621	3	1679
1977	26	**NCATL**	1	4	497
1978	98	**NEATL**	4		
1996	75	**EATL**	48		
1997	34	**SEATL**	239		
1998	43	**MED**	256		
1999	21				
2000	6				
2002	55				
2009	81				
2010	145				
2011	1064				
2012	705				
2013	497				
2014	394				

3. BASIC DYNAMICS

I) Overview

The current operating 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).

The standard age-structured equations are complicated somewhat by the subyear temporal structure in which ageing and recruitment occur in a particular subyear. In this version of the model, spawning occurs for all stocks in a subyear *ms*, after subyear 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 subyear m=1, age class a, and area r are calculated from individuals that have moved $\vec{N}$, in the previous year, final subyear n_m, of the same age class subject to combined natural and fishing mortality rate Z:

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

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

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

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).:

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

The fishing mortality rate at length is calculated from an index of fishing mortality rate *I*, an estimated catchability coefficient *q*, a season and area specific deviation *FD*, and a length selectivity ogive *s*, by fleet:

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

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

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

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

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

Recruitment is derived from a mean recruitment estimate for each stock over the whole time period $\bar{R}$ which is assumed to occur in user-specified spawning areas *rs*.

$$N_{s,y,ms,1,rs} = \bar{R}_s \exp\left(\varepsilon_{R,y} - \sigma_R^2/2\right) \quad (3.7)$$

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.

Under projections the operating models use various approaches for modelling recruitment including Beverton-Holt and 'hockey stick' forms that predict recruitment from stock-wide spawning biomass. Spawning stock biomass is calculated from moved stock numbers in the previous year, and subyear prior to spawning subyear *ms*, weight of individuals at age *w*, and the fraction of individuals mature at age *mat*:

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

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 subyears that are not the first subyear of the year and are not the spawning subyear 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 subyear, 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 subyear *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):

$$lnmov_{s,m,a,k,r} = \begin{cases} -1E10 & no\ movement\ from\ k\ to\ r \\ 0 & first\ assigned\ possible\ movement\ from\ k\ to\ r \\ \Psi_{s,m,k,r} & other\ possible\ movements\ from\ k\ to\ r \end{cases} \tag{3.14}$$

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 subyears.

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

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

In years prior to the initial model year (e.g. before 1961), 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 $\widehat{N}$). 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. 1901-1960) are calculated using the same equations (i.e. Eqn 3.11 and 3.12) as model years (e.g. 1961 – 2015). 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:

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

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

Baseline

Recruitment freely estimated (no stock-recruitment model assumed when fitting operating model to data)
Recruitment calculated from stock-wide SSB for projections only
Gravity movement model used to calculate Markov movement matrix by subyear and stock
Movement calculated only for those transitions recorded by tagging

Alternative options

Hockey stick SR relationship (West)
Recruitment calculated from spawning area SSB

Markov movement matrix by subyear and stock (following model updates the gravity model – a specific case of the more general Markov model – seemed an appropriate choice for the Baseline).

Movement calculated for all transitions except stock exclusive spawning areas

III) Fleet structure and exploitation history

Table 3.1. Fleet definitions. Note that some fleets may be partitioned.

No.	Fleet code	Gear code	Flag	Start	End	Areas	Quarters
1	LLOTH	LL	Not JPN	1960	2015	Any	Any
2	LLJPN	LL	JPN	1960	2015	Any	Any
3	BBold	BB	ALL	1960	2008	Any	Any
4	BBnew	BB	ALL	2009	2015	Any	Any
5	PSMedRec	PS	ALL	2009	2015	Med	Any
6	PSMedLOld	PS	ALL	1960	2008	Med	2
7	PSMedSOld	PS	ALL	1960	2008	Med	Not 2
8	PSWestOld	PS	ALL	1960	1986	Not Med	Any
9	PSWestnew	PS	ALL	1987	2015	Not Med	Any
10	TPOld	TP	ALL	1960	2008	Any	Any
11	TPnew	TP	ALL	2009	2015	Any	Any
12	RRCan	RR	CAN	1988	2015	Any	Any
13	RRUSA	RR	USA	1988	2015	Any	Any
14	All other fleets	-	-	1960	2015	Any	Any

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 1.1):

West: areas 1-4 (GOM, CAR, WATL, GSL).
East+Med: areas 5-10 (SCATL, NCATL, NEATL, EATL, SEATL, MED).

Alternative options

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).

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) Options for the frequency of setting TACs

Baseline

Every two years, for both West and East+Med (or alternative spatial strata) together

Alternative options

i) Every three years
ii) Every four years

III) Upper limits on TACs

[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

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

[Note the underlying rationale is to promote industrial stability.]

Baseline

West	20%
East +Med	20%

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.
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

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.

I) West

Functional forms fitted to assessment outputs for the years 1970+

a) Hockey stick
b) Beverton Holt with steepness *h* estimated

II) East + Mediterranean

Functional forms fitted to years 1950+

a) Beverton Holt with *h* = 0.98 for 1950-1982, 1983+ and 1950+
b) Beverton Holt with *h* = 0.70 for 1950-1982, 1983+ and 1950+

Note that 1950-1982 is "low" recruitment, and 1983+ is "high" recruitment.

III) Future regime shifts

<u>West</u>

a) None
b) After 10 years of projection, switch to other regime
c) Probability of 0.05 every projection year of switch to other regime

<u>East+Med</u>

a) 1983+ relationship continues unchanged
b) 1983+ relationship changes to 1950-1982 relationship after 10 years
c) Probability of 0.05 every projection year of a swop between 1983+ and 1950-1982 relationships

Note that for option c), it might be better to preclude changes over, say, the last 10 years of a 30-year projection period to ease interpretation of results through the reduction of transient effects.

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.

<u>Baseline</u>

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

<u>Alternative options</u>

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

<u>Baseline</u>

a) Future catches will be taken to equal future TACs (up to a maximum harvest rate of 95%).
b) The allocation of these future catches amongst fleets will be set equal to the average over 2012-2014
c) The spatial distribution per stratum (see item 1 above) of these future catches will be set equal to the average over 2012-2014
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.

<u>Alternative options</u>

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.

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.

Consideration is also needed of the “delays” associated in such data becoming available for input to an MP. The customary default is that for computation of the TAC for year *y*, the most recent data finalised and available will be for year *y*-2. Any changes to that will require motivation and specification.

I) Baseline suggestions

West

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

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 Lyon

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".

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 about the relationship assumed with the standard deviation of the log recruitments (σ) invariant over time.
b) The values of σ will be taken to be as estimated in the conditioning for the trial concerned.
c) Autocorrelation of residuals will be taken to be zero.

d) The conditioning results will be inspected for any indication of 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

Currently a 'master' relative abundance index is used for the Mixed stock model which provides an estimate of relative abundance across all time-area strata (e.g. by year, quarter and area). The approach taken here is to include multiple fleets by dividing their catches by this 'master' index to provide an index of fishing mortality rate (a partial F) leaving only catchability by fleet to be estimated rather than several thousands of individual F parameters (by fleet, year, quarter and area). Simulation testing reveals that this approach provides unbiased estimates of central quantities such as abundance, stock depletion, mixing rate and selectivity. However the construction of the 'master' index is critical and this is an important axis of uncertainty for operating models.

MP input series (e.g. as suggested in section *I*, above) may however be specific fleet indices, rather than this master relative abundance index, and hence require generation into the future. This will be effected by including these series in the conditioning with comparisons to the resource components which they are assumed to reflect, but with a very low weight in the log-likelihood so as not to impact estimates of other parameters in the model fit. The estimates of the catchability coefficients, and statistical properties of the residuals of this fit will be used in generating values for this series forward in time.

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

For the Baseline model, spawning is assumed to occur in areas 'GOM' for the West stock and 'W.Med' + 'E.Med' for the East + Mediterranean stock (Figure 1.1A).

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	N/A (hockey-stick)		0.98	
(Bev. -Holt)	Estimated		0.7	
Type	***Richards growth***		***von Bert. growth***	
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

Parameter	
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).

Table 8.3. The parameters estimated by the model. The example is for a possible bluefin tuna operating model of 8 areas (Figure 1), 4 subyears, 14 fleets, 32 years and 18 ages and 3 movement age classes.

Parameter	**Number of parameters**	
Mean total recruitment	1	1
Fraction of total rec. that is Eastern	1	1
Fraction of stock recruitment in SRA phase	n_{stocks}	2
Length a modal selectivity	n_{fleets}	14
Ascending precision of selectivity	n_{fleets}	14
Descending precision of selectivity	$n_{fleets-1}$	13
Recruitment deviations	$(n_{years} + n_{ages} + 1) \cdot n_{stocks} \cdot n_{ageclass}$	262
Fleet catchability (*q*)	n_{fleets}	5
F deviation (*FD*)	$n_{seasons} \cdot n_{areas}$	40
Movement	$n_{areas} \cdot n_{seasons} \cdot n_{stocks}$	80
	Total	432

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)	$-lnL_{rec}$
Fraction of recruitment that is eastern	logit-uniform(*LB* = -∞, *UB* = ∞)	$-lnL_{fracrec}$
Fraction of stock recruitment in SRA phase	logit-uniform(*LB* = -2.0, *UB* = 2.0)	$-lnL_{histrec}$
Selectivity	lognormal(μ = 0, σ = 0.9) (*LB* = -3.0, *UB* = 3.0)	$-lnL_{sel}$
Fleet catchability (*q*) (mean F)	log-uniform(*LB* = -10.0, *UB* = 1.0)	$-lnL_{q}$
Fishery independent index catchability	log-uniform(*LB* = -2.3, *UB* = 2.3)	$-lnL_{qI}$
Fishery dependent index catchability	log-uniform(*LB* = -6.0, *UB* = 4.0)	$-lnL_{qD}$
F deviation (*FD*, Eqn 3.4)	lognormal(μ = 0, σ = 0.2)	$-lnL_{FD}$
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)	$-lnL_{recdev}$
Some operating models		
Mean SSB by area (reference set, 2B)	lognormal($\mu_{Eastern}$ = *ln*(3E+5), $\mu_{Western}$ =*ln*(2.7E+4), σ = 0.01)	$-lnL_{muSSB}$
Eastern area SSB change (reference set, 2C)	lognormal(μ = *ln*(3), σ = 0.01)	$-lnL_{SSBinc}$

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:

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

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

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

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*:

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

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:

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

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

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

where exploitable biomass V is calculated as:

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

The model predicts stock of origin composition of catches $\widehat{SOO}$, from predicted catch numbers at age:

$$\widehat{SOO}_{s,y,m,r,f} = \sum_a \widehat{CAA}_{s,y,m,a,r,f} / \sum_s \sum_a \widehat{CAA}_{s,y,m,a,r,f} \tag{8.7}$$

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

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

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

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

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

The length composition data are assumed to be distributed multinomially. In traditional stock assessment settings catch composition data may often dominate the likelihood function due to the large number of observations. This is exacerbated by a failure to account for non-independence in size composition samples. There are two possible solutions: (1) manually specify the effective sample size (ESS) of length-composition samples or (2) use a multinomial likelihood function that includes the conditional maximum likelihood estimate of the ESS (perhaps even a freely estimated ESS, S. Martell personal communication). In this version of the code, ESS is user-specified.

The negative log-likelihood component for length composition data is calculated as:

$$-lnL_{CAL} = -\sum_y \sum_m \sum_l \sum_r \sum_f CAL_{y,m,l,r,f} \cdot ln(\hat{p}_{y,m,l,r,f})/ESS_f \quad (8.11)$$

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

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

Similarly the negative log-likelihood component for PSAT tagging data of known stock of origin (SOO), released in year *y*, subyear *m*, area *r* and recaptured in year *y2*, subyear *m2*, and area *k* is calculated as:

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

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, subyear 3, and area 4, the probability of detecting the tag in year 3, subyear 2 for the various areas is calculated as:

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

where

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

The negative log-likelihood component for PSAT tagging data of unknown stock of origin PSATu, is currently weighted according to the compound probability that a fish is of a particular stock given the track history for that tag. For example for a tag *t*, tracked in series of years y_i, subyears m_i, and regions r_i, the weight *w*, of that tag for a specific stock is calculated as:

$$w_{t,s} = \frac{\prod_i [(\sum_a N_{si,yi,mi,ai,ri})/(\sum_s \sum_a N_{si,yi,mi,ai,ri})]}{\prod_i [1-(\sum_a N_{si,yi,mi,ai,ri})/(\sum_s \sum_a N_{si,yi,mi,ai,ri})]} \quad (8.16)$$

This is simply the product of fractions of that stock in those time-area strata divided by the product of the fractions of other stocks in those time-area strata. An alternative approach would be to compare the relative probabilities of the observed movements among the stocks although it is unclear whether this circularity (PSAT data are a primary source of information regarding movement) could lead to estimation problems.

The weighted negative log-likelihood function is similar to that of the stocks of known origin but includes the appropriate weighting term for each tag:

$$-lnL_{PSAT} = -\sum_t \sum_s \sum_y \sum_m \sum_{y2} \sum_{m2} \sum_r \sum_k PSATu_{t,s,y,m,y2,m2,k} \cdot ln(\hat{\theta}_{s,y,m,y2,m2,r,k}) \cdot w_{t,s} \quad (8.17)$$

The negative log-likelihood component for stock of origin data *SOO* is also calculated assuming a multinomial distribution:

$$-lnL_{SOO} = -\sum_{s}\sum_{y}\sum_{m}\sum_{r}\sum_{f} SOO_{s,y,m,r,f} \cdot ln\left(\widehat{SOO}_{s,y,m,r,f}\right) \quad (8.18)$$

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

$$-lnL_{muSSB} = \sum_{k} ln(\sigma_{muSSB}) + \frac{\left(\ln(\overline{SSB}_k) - \ln\left(\overline{\overline{SSB}}_k\right)\right)^2}{2 \cdot \sigma^2_{muSSB}} \quad (8.19)$$

where $\overline{\overline{SSB}}$ is the mean annual SSB estimated from the VPA stock assessments (around 300 000 tonnes in the East, 27 000 tonnes in the West) and operating model predicted spawning biomass $\overline{SSB}$ is calculated:

$$\overline{SSB}_k = \frac{1}{n_y n_m} \sum_{y}\sum_{s}\sum_{m}\sum_{a}\sum_{r} (\vec{N}_{s,y-1,ms-1,a,r} \cdot e^{-Z_{s,y,ms-1,a,r}} \cdot w_{s,a} \cdot mat_{s,a})^{area_{k,r}} \quad (8.20)$$

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.

In order to fit the operating models to assessment model spawning biomass increases (Factor 2 level C) a likelihood function is included for spawning biomass increases by area:

$$-lnL_{SSBinc} = \sum_{k} ln(\sigma_{SSBinc}) + \frac{\left(\ln\left(\frac{SSB_{k,y2}}{SSB_{k,y1}}\right) - \ln(SSBinc)\right)^2}{2 \cdot \sigma^2_{SSBinc}} \quad (8.21)$$

where SSB is the spawning biomass in eastern/western area k and $SSBinc$ is the fractional increase in VPA assessment spawning biomass in area k from year $y1$ to year $y2$ (this is 3 between years 2006 and 2015).

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):

$$-lnL_T = -[\omega_c \cdot lnL_c + \omega_i \cdot lnL_i + \omega_{SSB} \cdot lnL_{SSB} + \omega_{CAL} \cdot lnL_{CAL} + \omega_{PSAT} \cdot lnL_{PSAT} + \omega_{SOO} \cdot lnL_{SOO} + \omega_{muSSB} \cdot lnL_{muSSB} + \omega_{SSBinc} \cdot lnL_{SSBinc} + \omega_{rec} \cdot lnL_{rec} + \omega_{fracrec} \cdot lnL_{fracrec} + \omega_{histrec} \cdot lnL_{histrec} + \omega_{sel} \cdot lnL_{sel} + \omega_q \cdot lnL_q + \omega_{qI} \cdot lnL_{qI} + \omega_{qD} \cdot lnL_{qD} + \omega_{FD} \cdot lnL_{FD} + \omega_{mov} \cdot lnL_{mov} + \omega_{recdev} \cdot lnL_{recdev}] \quad (8.22)$$

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, subyear, area, fleet	Log-normal	lnL_c
Index of exploitable biomass (assessment CPUE index)	year, subyear, area, fleet	Log-normal	$lnLi$
Index of spawning stock biomass (e.g. a larval survey)	year, stock	Log-normal	lnL_{SSB}
Length composition	year, subyear, area	Multinomial	lnL_{CAL}
PSAT tag (known stock of origin)	stock, year, subyear, area, age class	Multinomial	lnL_{PSAT}
Stock of origin	year, subyear, area, age class	Multinomial	lnL_{SOO}

III) Characterising uncertainty

Baseline

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.

Alternative options

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

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

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 is done with the intention of capturing extremes.

	West	East
Future recruitment		
1	Hockey-stick	83+ B-H with *h*=0.98
2	B-H with *h* estimated	83+ B-H with *h*=0.70
3	Hockey-stick changes to B-H after 10 years	83+ B-H with *h*=0.98 changes to 50-82 B-H with *h*=0.98 after 10 years
Abundance		
A	Best estimate	
B	East-West area spawning biomass matches VPA assessment	
C	Recent eastern area SSB increases 3x to match VPA assessment	
Spawning fraction both stocks		Natural Mortality rate both stocks
I	Younger	High
II	Younger	Low
III	Older	High
IV	Older	Low

Note: when modifying current abundance a highly informative prior will be placed on either the spawning biomass by Eastern-Western area (B) or the trend (fractional increase) in the eastern area (C).

Combinations for Reference Set

A full cross of (1, 2, 3) x (A, B, C) x (I, II, III, IV), i.e. 36 scenarios in total.

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.

B. 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 1% per annum
3) Non-linear index-abundance relationships
4) Alternative mixing scenario

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) Alternative assignments to stock of origin of historical catches from the South Atlantic (off Brazil)

"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.

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.
c) The lowest spawning biomass depletion over the 30 years for which the MP is applied calculated relative to the deterministic equilibrium in the absence of catches for the recruitment function that applies after 30 years.
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.
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).
f) Kobe or alternative Kobe indicators (catch/biomass instead of Fmsy and biomass/biomass at a theoretical maximum MSY)
g) Average annual variation 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.

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

<u>Baseline</u>

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

<u>Alternative options</u>

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).