Report of the 2nd Meeting of the ICCAT GPYP Core Modelling and MSE Group
21-23 January 2016,
Monterey, CA USA

I. Opening of the meeting

Dr. Joseph Powers, Chair and MSE Coordinator, opened the meeting. Mr. Driss Meski, the ICCAT Executive Secretary, welcomed the participants to the meeting of the ICCAT GBY Core Modelling and MSE Group.

The list of participants is attached in Annex 1

II. Confirmation of agenda and Selection of Rapporteur

A draft agenda was circulated prior to the meeting. The draft was revised to change the order of discussions and the revision was approved by the Group. The revised agenda is included in Annex 2.

Dr. Paul De Bruyn of the ICCAT Secretariat graciously agreed to Rapporteur the meeting.

III. Current progress in GBYP projects

The GBYP coordinator provided an overview of progress of the relevant ICCAT GBYP activities which are integral to the development of MSE. The fiscal year marks the completion of Phase 5 of the GBYP. The data collection activities and research results were reviewed.

The Group was informed about the data mining and data recovery activities, specifying the data that are already quality checked, controlled and included in the ICCAT BFT database. The trade, auction and market data sets are now validated and included in the ICCAT BFT database in separate files. The group reviewed the summary of data collected by the three previous GBYP aerial surveys on spawners and the activities of aerial surveys under Phase 5. The Group was advised about the tagging activities (both conventional and electronic) and the initial results about evidence of mixing both between the east and the west populations and within the Mediterranean. The results of the biological work were also presented, including the preliminary results of the genetic and microchemical analyses, showing the evidence of two clearly distinguishable populations (WATL and EATL), while the possible presence of multiple populations is currently not supported by the biological analyses conducted so far; the variable W/E mixing in some areas shows relevant inter-annual variability.

The Group discussed the available sources of evidence of bluefin tuna movements in different parts of the ICCAT area which were assembled by GBYP in the first five Phases and which could be considered in the MSE development. This discussion was picked up in the review of the work program in particular as regards the alternative hypotheses for population structure and connectivity and the priority for a comprehensive analysis of the individual and combined sources of information available through the GBYP and various related national research initiatives.

IV. Data Review and Specifications and MSE Modeling

Dr. Tom Carruthers, the ICCAT GBYP MSE Modeler, summarized the progress that has been made during Phase 5. In particular this has focused on the development of the Operating Model. Several issues arose in this context including the basic structure of the CPUE data and whether the level of aggregation used in the assessment is conducive to spatial MSE approaches to fleet structure, the level of aggregation of catch at size data, appropriate size/age stratifications, etc.

A draft Specifications Document was prepared and presented to the Group (Annex 3). It was decided to use this document as a template for discussions of this agenda item. It is expected that the draft will be updated in the future based on the discussions of the Group and the relevant decisions made by the Group as given below. The figures and tables noted in the following refer to the **Figures and Table**s of the Annex 3 document.

1. BASIC CONCEPTS AND STOCK STRUCTURE

Spatial strata – The Operating Model (OM) should include to flexibility to accommodate new sampling areas within the ICCAT sampling area framework. The OM is now stratified using the PSAT proposed map (stratification) given at the 2015 BFT Data Preparatory meeting. This is consistent with the 5 x 5 degree square ICCAT data framework. A finer scale denoted in **Figure 1.1B** in Annex 3 provides some better stratification, especially for Japanese CPUEs

Temporal strata – Several data sources appear to be limited to quarter of the year (especially crucial data such as micro-constituent data, stock origin data and CPUE) and so a quarterly stratification may be necessary. Customized options may be possible in order to avoid generic quarterly sectioning and to allow data to be split by appropriate time bins and known aggregations. However, it is unclear if this high level of complexity is necessary for the OM to be able to provide a representation of the underlying situation that is adequate for the MP testing purposes required. It was noted that the timing of movement within a temporal stratum may also be important. Nevertheless, the Group felt that more complexity in temporal strata would not likely be helpful. Therefore, it was agreed that a four-bin quarterly temporal stratification as given in **Table 1.1.A** of Annex 3 be used.

Mixing hypothesis – a key issue is the assignment of catches to the population of origin and the spawning site of origin. There is a lack of data to make this assignation, especially for the Mediterranean. It was agreed that, under current understanding of the spawning behavior, it is best not to hypothesize sub-populations within the Mediterranean. While they might exist, an attempt to model them is not presently supported by any analytical data. Therefore, it was agreed that the population structure given in **Figure 1.2B** of Annex 3 (using the description in **1.2A**) would be used.

2. PAST DATA AVAILABLE

The Group reviewed ABT MSE OM metadata v1_6.xslx a spreadsheet document prepared by the MSE Modeler on data which are being used and are available for the OM. However, it is expected that there are additional data available. This needs to be explored such that the best available data set is used. Review of data was conducted based on worksheet, but the Core Modeling Group and more importantly the Bluefin Working Group need finalise upon a base set of information. This should be facilitated through the Bluefin Working Group's Data Preparatory meeting.

3. BASIC DYNAMICS

Mixed stock model –

Size/Age Stratification - is needed for movement models at least at some aggregated level since as juveniles and adults movement behavior is different. Data for doing this will need to come from PSAT and size frequency information. These data should be linked to population of origin data, as well, especially if they are available by size. The Group agreed that the stratification should include more than one group, perhaps two groups or more ideally three. In the Western Atlantic an appropriate age stratification is to use three strata of fish aged as: 0 to2, 3 to 8 and 9+ years. For practical purposes, it was agreed that the same strata would be used for the Eastern Atlantic/Mediterranean. However, this should be reevaluated as future data becomes available.

Recruitment – there are several issues in modeling the recruitment process of multiple populations. These include: the magnitude and importance of the catch of age 0 fish, the relevant spatial measure of spawner-abundance to be used in the stock recruitment relationship (SRR) and the functional form of the SRR.

It was agreed that the spawner-abundance should be calculated as the spawning stock biomass (SSB) that occurs *within the relevant spawning area.*

While catches of age 0 fish are known to occur in many areas, there is a lack of reported catches of these ages. Fish are considered age 0 at birth and age quarterly, reaching an age of 1 exactly a year after birth. The fish do not age according to the calendar year beginning in January. This has impact on an age-length key set by calendar year. One way to avoid modelling problems with this situation is to adjust the measure of SSB to be lagged by one year in the model. Also, there is the consideration of when density-dependence occurs within the recruitment process and whether this is affected by catches of recruiting fish. However, at this time the Group agreed that the lagged model should be used.

It was agreed that the base SRR should the Beverton-Holt model with sexes aggregated and SSB calculated for spawning areas. As alternatives to the base, there should be an option to use a

Hockey-stick model (especially for the Western Atlantic) and the option to calculate SSB for the total population aggregated over area.

Maturity/Fecundity – a more appropriate maturity ogive than knife-edged should be used for the populations. Additionally, a per capita fecundity at age function which is *not* proportional to weight should be explored.

Movement – It was agreed that the "Gravity" model movement be the base model in the OM whereby the Markov movement matrix is calculated. However, there may be bias due to a short time period of PSAT tracks which may terminate before the individual has an opportunity to move further. If tags at liberty for less than one time step are not included, this would not be an issue. Therefore, movement will be calculated only for those transitions recorded by tagging. As alternatives a Markov movement matrix by subyear and population should be considered, as well as movement calculated for all transitions except population-exclusive spawning areas.

Initial conditions – It was agreed that the initial (1960) conditions would be based on the equilibrium abundance by age using a fishing mortality rate averaged over the first five years of model predictions.

Fleet structure and exploitation history- It was agreed that the Base fleet structure model include six fleets as in **Table 3.1, A** (Annex 3). This was based on the five most contributory gear types for all Task I landings combined. However, this should be reviewed as there have been clear changes in selectivity over time within the fleets. A proposal for alternatives needs to be developed for review by the Group.

4. MANAGEMENT OPTIONS

Group agreed that the current process should be continued to ensure usability and ease of collaboration. Broad guidelines and constraints can be defined for future use. Management Procedures (MPs) can then be disseminated so that multiple users can have the opportunity to develop and evaluate their own rendition of an MP.

In order to do this there needs to be agreement on the general management structure that is to be used.

Spatial strata for which Total Allowable Catches (TACs) are set- the base assumption is that TACs will be set for the conventional West and East region definitions that are currently being used (where the East includes the Mediterranean, i.e. **Figure 1.1B;** Annex 3 as agreed above under spatial definitions). There is the possibility of separating a central Atlantic management region and this may be necessary depending on future management requirements. Indeed, any area separation can be accommodated provided it is consistent with agreed map in **Figure 1.1B**, but the Group is not currently in a position to provide guidance on additional stratifications that are not in line with this map.. The Group agreed that requests to do this should originate from and be communicated by the Commission, but nevertheless such options might best be explored through dialog.

Options for the frequency of setting TACs- there is always a trade-off between the frequency at which TAC decisions are made, the speed with which responses to stock changes can be made, and the ability to detect changes in abundance. Generally, an appropriate frequency can be evaluated through the MSE process. However as a base it was agreed to use a two-year cycle with options to utilize 3 or 4 years.

Upper limits on TACs- There might need to be a specification of an upper limit to the TAC that is allowed. Without a limit, an excessively high TAC could induce overcapitalization even if that catch initially cannot be achieved. However, this needs to be discussed with stakeholders. Base numbers would have to be agreed upon, and clarifications provided as to what the consequences are for different alternatives. At this stage it was agreed that for the base model there should be no upper limit on the TAC, and but that runs for various limits should explored as alternatives.

Minimum extent of TAC change- The goal is to avoid small insignificant changes. The minimum change that is worthwhile needs to be evaluated by stakeholders and the Commission. The initial base model will encompass no minimum, but feedback should be obtained to implement appropriate limits.

Maximum extent of TAC change- This is a critical discussion that is needed with stakeholders. If larger fluctuations are allowed, then this could necessitate a reduction in average long term catches. The effect of maximum TAC change is also impacted by the frequency of with which TAC decisions are made, as noted above. Changes could be based on tonnage or percent change, and positive and negative change limits could be specified as being different. The agreement for now is to limit changes to no more than 20% both positively or negatively for both the Eastern Atlantic/Mediterranean and the Western Atlantic. However it must be reiterated that stakeholders need to be involved in the selection of this constraint.

Technical measures-at this stage the Group is not in a position to evaluate technical measures such as size limits because of lack of data and the difficulty in quantifying benefits for various user types. Therefore, it was agreed that initially that this could be implicitly addressed through the selectivity prescriptions for future catches by the various fleets. This could be investigated in a simple manner as a management option. The reliability of these evaluations is likely to be poor, but these should nevertheless not be neglected and could be included in later stage. By-catch and discards are often related to minimum size, and this should also be kept in mind. If this is done, then discard mortality and retention functions should be explicitly stated and caveats acknowledged. Otherwise this could result in unrealistically optimistic outputs from the model. Therefore, if this is to be evaluated, it is suggested that this would not be presented as "base" specification, but rather a range of relationships be evaluated. Nevertheless this complexity is best avoided in the initial modeling.

5. FUTURE RECRUITMENT AND DISTRIBUTION SCENARIOS

Recruitment baselines proposed in Annex 3 reflect the current assessment conditions. For this exercise there is a requirement for density-dependence alternatives through the SRR. The MP is trying to address uncertainty in relationships about which little or nothing is known. Therefore, scenarios should be based on alternative biological, ecological or environmental hypotheses, rather than through parameter estimation alone. It was agreed that the time horizon of projections be long enough to encompass possible environmental changes, i.e. 30 years.

MSE projections for Southern Bluefin tuna and Indian Ocean albacore have utilized a grid of alternative scenarios. Generally, it was found that fixed parameters have the most effect but there are still some key interactions (such as dome shaped selectivity). At this stage for Atlantic BFT it may be better to look at main effects rather than full grid. Under Section 9: Trail Specifications, a table is proposed as original straw man and modelling will proceed based on that. Once initial evaluations have been made, additional issues and scenarios suggested by the simulations can be addressed.

6. FUTURE CATCHES

In Annex 3 the base options were considered to be appropriate and should be included:

a) Future catches will be taken to equal future TACs
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 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.

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

7. GENERATION OF FUTURE DATA

A key component to MSEs and MP evaluation is the effect of future data that is collected and how the management system responds to that data. Conceivably, any number of research surveys might be implemented in the future, but the initial evaluation needs to be linked with existing data sets that have some likelihood of continuing into the future.

Baseline suggestions for fisheries independent data - For the Eastern Atlantic, the larval survey is incomplete and restricted spatially and it cannot be guaranteed that it will be ongoing. Also, the basic relationship between larval abundance and SSB is subject to debate. Nevertheless, the larval survey is fisheries independent and due to the poor state of other CPUE series in region, may be fundamental for the MSE. The SCRS should emphasize to the Commission the importance of these data types to both the assessment and the MSE. Aerial surveys (juveniles and spawners) have been conducted and could be used as alternatives. While they may be useful for assessments, these may not be ideal for the MSE due to the short period over which they have been carried out to date, and they may be heavily impacted by environmental factors. Since the availability of fisheries-independent information is crucial, it was strongly agreed that these indices should be evaluated (both larval and aerial). Comparative analysis is needed to examine these indices to determine which may be more beneficial to include. There are also multiple additional sources such as acoustic and close kin data that should be considered in possible future iterations.

The current larval survey in the Gulf of Mexico is accepted as a base for the future.

Fisheries-dependant: For the eastern region, the trap index may be important to include to cover spatial range better. These traps are all close to Gibraltar; additional data series are available from Mediterranean traps and should be examined by the BFT Species Goup or at the BFT Data Preparatory Meeting. Effort is assumed to be constant for this series. An additional problem is the fishing strategy that changed after the enforcement of the quota; even if some in most of the traps fish were collected after reaching the quota and then released into the wild, there are doubts about how these releases can be considered, also taking into account that it was not possible to collect these data in some traps in recent years. This problem should be discussed by the BFT data preparatory meeting. Another option is the baitboat index, but that index has affected be the changing management regime and the practice of quota transfers in very recent years. The Group decided to initiate the evaluation using the JPN LL index with additional indices to be evaluated. Relying only on the JPN LL is of concern however. Index coverage of the eastern region is still poor. For the west, a combined JPN/USA/Canada index which is currently under development. is expected to be informative and will be evaluated.

Catch-at-length series might also be considered for inclusion, but this raises further technical complications regarding the specification of how the size frequencies have been generated; the main problem has been already identified by the BFT Species Group. There are several ways length data will be improved, including improved farm data from stereoscopic cameras and possible market data. This issue is temporarily secondary and can be incorporated later, after the BFT Data Preparatory Meeting.

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 with statistical properties as specified in Annex 3. However, future modifications might include gamma distributions for generating residuals.

8. PARAMETERS AND CONDITIONING

Fixed parameters –For the baseline it was agreed that the current assessment values would be used with the modification of the maturity ogive as discussed above. Possible uncertainties in the biology of the stocks should be incorporated and these alternative hypotheses should be modelled. The OM needs to incorporate a full ranges of possibilities.

Natural mortality rates need to be revised in future as for west, because the present a constant M at age assumption will likely be changed. It is likely that the west will use a Lorenzen-type M at age relationship in the future.

Estimated parameters – **Table 8.3** of Annex 3 understates number of parameters that will probably be estimated. It was agreed that with most of the existing SRR data sets it is not advisable to estimate steepness. Additionally, no plus age group included in the document, and may be required. Furthermore, expanding to 35 age classes may be excessive since the number of age classes will affect the running time of model. Recruitment deviations: it was agreed that these deviations not be simplified as in Annex 3. It was suggested that it may be better to have 5 year blocks of deviations for the beginning of the series and then free these up over time when there are more data to inform them.

Characterizing uncertainty - It was proposed to concentrate on among-model uncertainty using the maximum posterior density estimates of model parameters and a prior model weight based on expert judgement. There are decisions that need to be made and this process should be conducted by a smaller group, where effectively a Delphi-type method may be the most appropriate. At this stage, uniform weighting will be applied until as alternatives are suggested and agreed upon.

9. TRIAL SPECIFICATIONS

Reference set – Four major uncertainty axes were suggested: future recruitment; current abundance; and natural mortality and maturity. But there are a number of unresolved issues for defining a reference set that needs to be addressed in the future. Additional input is needed from the Bluefin Working Group and others. The expectation is that a grid can be developed as for SBT, noting that the details of the scenarios will be changed as necessary. This is particularly relevant for current abundance estimates which should be not be totally *ad hoc* choices. The grid will define combinations for the Reference Set. On conditioning, it may be apparent some scenarios are not plausible (being inconsistent with the data) and need to be dropped. However, as an initial option, it was suggested to utilize the grid in **9. A** of Annex 3.

Robustness trials – there are a number of alternative states of nature that might be evaluated as robustness trials. These include: a Ricker SRR, effects of IUU, assignment of 1960's Brazilian catch to the western region together with its size compositions, or split this composition between western and eastern type compositions, density-dependent catchability, undetected changes in catchability in the future, etc. As these are developed, for reasons of parsimony the Group will attempt to highlight those trials which are likely to be most important.

10. PERFORMANCE MEASURES/STATISTICS

The performance measures must be consistent with current recommendations in regards to bluefin made by the Commission. Additionally, the Commission and stakeholders must be requested to define which performance indicators they wish to monitor. The reporting of the selected measures should include 5, 50 and 95 percentiles, but could be switched to quantiles or any other suitable level, possibly as clarified by managers.

Projections –Projections could be run out to 100 years and then summary statistics shown for appropriate time period identified. Baseline run should include 30 years but robustness could include 100 years. The use of MSY reference points in mixed stock is extremely complicated. The recalculation of MSY should only be necessary if non-stationary events are taking place (fluctuating M, selectivity etc.). The MP does not have to change these fluctuating factors after 20 years, so that the time period can be extended out without re-estimating MSY continuously. Kobe plots could be changed from MSY to (for example) 40% of B0. F as catch divided by a defined biomass is also very informative. In other words a redefinition of key reference points for a mixed stock fishery may be needed. Some explanation will need to be provided that the current management advice provided is based on the current estimates of MSY, which in turn depends on current selectivities, but that these estimates will change if selectivities change (and if estimates of natural mortality M are revised). It was agreed that projections go out to 100 years unless there are computational restrictions. A 30 year period will be maintained now, but this needs to be checked if important changes are occurring on a longer time scale. Alternatives to the typical Kobe indicators should be explored (catch/biomass instead of FMSY; and biomass/biomass at the theoretical maximum MSY, which corresponds (stock-recruitment effects aside) to the age at which unexploited cohort biomass per recruit reaches a maximum and could be taken in a pulse fishery). Although such an MSY is not actually achievable it does provide a reference point for catch and biomass, and can be calculated easily.

Summary measures/statistics –in addition to proxy reference points related to Kobe reference points discussed above, there is a need for more stakeholder-oriented measures. These need to be scientifically based, easily understood by stakeholders and flexible so that managers can evaluate scenarios that reflect changes in their objectives. Additionally, acceptable probabilities of achieving desired levels of the selected performance measures needs to be explored with stakeholders. However, estimates of probabilities in the tails of distributions are often not reliable, so reliance might be better placed on the median (e.g. rather consider different target years for the time at which a target biomass recovery level is anticipated to be reached).

Summary plots – It may be necessary to report on outcomes which affect different user groups differently. For example, fisheries with different selectivities or size ranges might desire summaries which allow them to explore their options. Summaries plots should be defined which allow that evaluation over broad categories of fisheries. To avoid complication it may be useful to show median trends for fisheries which may be fairly similar. These need to be presented in way that demonstrate actions that will have simultaneous effects on the different populations.

V. Future Tasks and Schedules

Schedule - the current meeting is an important initial step in specifying the structure of the BFT MSE. Additional steps were designated for the future. A schedule of future activities include:

2016 - Completion of specifications and initiation of simulation trials together with review of those trials. It is suggested that these activities be conducted associated with the ICCAT Bluefin Data

Preparatory Meeting in July and the Species Working Group meetings in September. It is expected that these activities will not be completed during 2016 but that a great deal of progress can be made. The Bluefin Data Preparatory Meeting in 2016 should provide the ICCAT GBYP MSE Modeler with the majority of data required for the processes that have been discussed. The BFT Working Group chair should coordinate with rapporteurs to make the necessity for this clear on the agenda and make contact with the data providers in question concerning the data that while will be required.

Additionally, a dialog needs to be established with the Commission on issues and decisions that the Commission will need to address. It is suggested that the July meeting of Panel 2 of the Commission be used as a mechanism for the ICCAT GBYP Core Modeling MSE Group and the SCRS to involve the Commission in the issues. The Panel 2 meeting should be used to communicate and explain broad issues to Commissioners. This needs to be included on the Panel 2 agenda as a dedicated item. This agenda item needs to be coordinated with that associated with that on the albacore MSE.

It is expected that MSE modeler will be an important participant of these activities in 2016 including Group meetings associated with the Data Preparatory Meeting and the Species Working Group meeting. It is also expected that the MSE Coordinator participate in the SCRS's reporting to Panel 2 and in the Group's meeting at the Species Working Group.

In September, conditioning code should be in position to be reviewed. It is suggested that an outside reviewer be contracted to conduct this task

2017 – This year will be important in that there should be a review of the trials and their conditioning, with and possibly necessary modifications made in the light of those results. The meeting should take place early in 2017 and enable the development of a suite of meaningful scenarios to be used to initiate stakeholder involvement.

Progress on the bluefin assessment will need to be presented to the Commission in 2017 and that will be a priority. While the MSE effort will be ongoing, it needs to be made clear that the MSE process will not be complete at that time. By February 2017 (at the end of GBYP Phase 6) the modeling package will be completed by the GBYP MSE Modeler and distributed to volunteers to run trials of their candidate MPs by August and that these be reported at the September species group.

2018 – A complete proposal with MSE options should be presented to the SCRS in September with the goal of communicating that to the Commission at their annual meeting

Communications - a Github site will be used for submitting the code. Initially access will only be given to the MSE Modeler and Secretariat staff. Then once initial checks have been made and possibly waiting for peer review, this can be opened up to more people as necessary. This process needs to be discussed and developed. Code can be made openly available as soon as it is working. However, policies for use should be established by the SCRS.

VI. Close of the meeting

The meeting concluded on 23 January 2016

Annex 1. List of Participants

Driss Meski, Executive Secretary, ICCAT

MSE Core Modeling Group

Joseph Powers	Chair, Modeling and MSE Coordinator
David Die	SCRS Chair
Thomas Carruthers	Expert MSE Technical Assistant
Harritz Arrizabalaga	BFT Assessment Scientist
Douglas Butterworth	MSE Expert
Sylvain Bonhommeau	Eastern BFT Rapporteur
Toshihide Kitakado	MSE Expert
Clay Porch	BFT Assessment Scientist
Yukio Takeuchi	Western BFT Rapporteur
Antonio di Natale	Secretariat, GBYP Coordinator
Paul De Bruyn	Secretariat, Statistics Coordinator
Laurence Kell	Secretariat, Population Dynamics Expert

Unable to Attend

Richard Hillary	Independent Scientist
Polina Levonti	Independent Scientist
Miguel Santos	Deputy Executive Secretary

Observing Scientists

Campbell Davies	CSIRO Australia
Jim Ianelli	NOAA, NMFS USA
Ann Preece	CSIRO Australia
Shuya Nakatsuka	Far Seas Fisheries Laboratory Japan
Barbara Block	Stanford University USA
Rebecca Whitlock	Stanford University USA
Francisco Ferretti	Stanford University USA
Vaughan Pratt	Stanford University USA

Annex 2. Revised Agenda

I. Opening of the meeting

II. Confirmation of agenda and Selection of Rapportuer

III. Current progress in GBYP projects

IV. Data, Model Specifications and MSE Modeling
   - *i) Basic concepts and stock structure*
   - *ii) Past data available*
   - *iii) Basic dynamics*
   - *iv) Management options*
   - *v) Future recruitment and distribution scenarios*
   - *vi) Future catches*
   - *vii) Generation of future data*
   - *viii) Parameters and conditioning*
   - *ix) Trial specifications*
   - *x) Performance measures and statistics*

V. Future Tasks and Schedules

VI. Close of the meeting

Annex 3

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.

I) Spatial strata

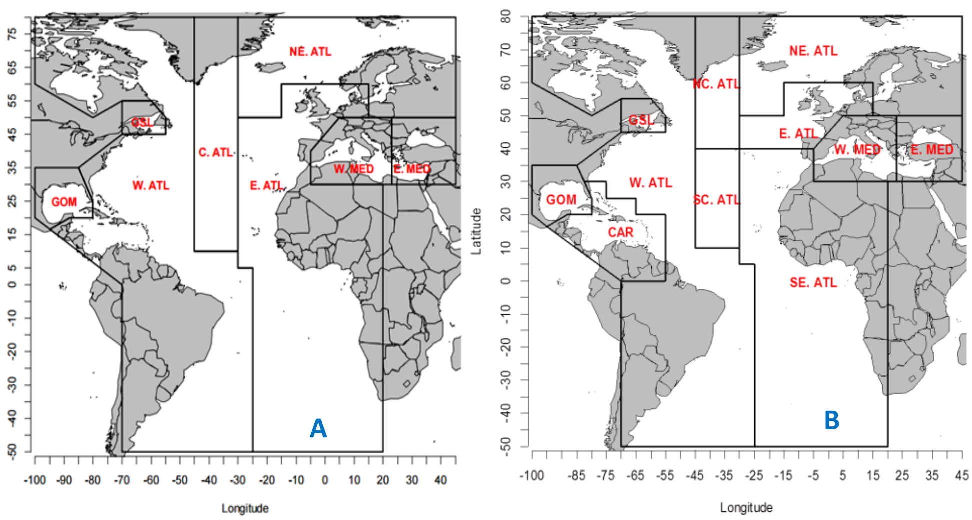


Figure 1.1. (A) Spatial definitions tabled by the 2015 ICCAT data preparatory meeting (Anon. 2015) and used in the fitting of preliminary operating models. (B). Spatial definitions for which PSAT tagging movements have been reported to NOAA (M. Lauretta).

Baseline

Spatial areas of the ICCAT data preparatory meeting (Anon. 2015, Figure 1.1A)

Alternative options

Spatial areas at the resolution of the reported PSAT tagging data (Figure 1.1B)

The MAST model (Taylor et al. 2011) areas which are the same Figure 1.1A but simplified such that the Central Atlantic is merged with the Western Atlantic and there is no division of the Mediterranean.

Spatial areas proposed by Kimoto et al. (2015) with alternative spatial stratification of the northeast Atlantic (to better characterize Japanese longline fishing activities).

II) Temporal strata

Table 1.1. Possible sub-year temporal strata for disaggregation of data and modelling of population dynamics.

A. Quarterly	**B. Biannual**	**C. Custom**
January-March	October-March	1st January - 15th March
April-June	April-September	16th March – 15th May
July-September		16th May – 15th July
October-December		16th July – 31 December

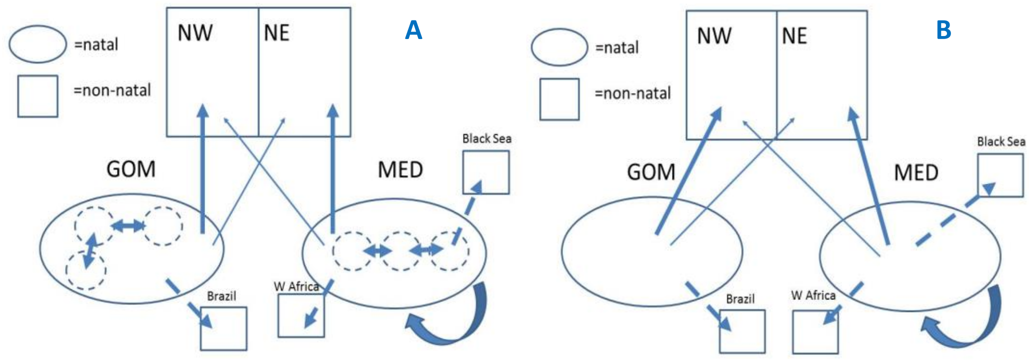
Baseline

Years 1960-2015 with a quarterly sub-year disaggregation (Table 1.1.A)

Alternative options

Biannual sub-year disaggregation (Table 1.1.B)
Custom sub-year disaggregation (Table 1.1.C)

III) Mixing hypotheses



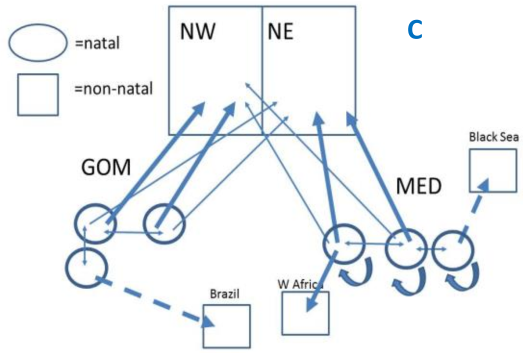


Figure 1.2. Mixing hypotheses suggested by Arrizabalaga et al. 2014).

(A) A two stock model with no sub-populations.

(B) A two stock model with sub-population structure.

<u>Baseline</u>

A two-stock model similar to Figure 1.2A but adhering to the spatial structure of Figure 1.1A.

<u>Alternative options</u>

A three-stock model with western and eastern Mediterranean stocks.
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) 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 index, a preliminary standardized CPUE index was derived from the following linear model:

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

where y, r, m and f refer to years, areas, subyears and fleets, respectively. In formulating this temporary catch rate index, three fleets were used: Japanese longline, US longline and the Canadian rod and reel fleet.

By including multiple fleets this index can be used to predict relative abundance indices over a wide range of year, subyears and areas including the Gulf of St Laurence and the Gulf of Mexico (Figure 2.1).

A Western larval index (Lamkin et al., 2014) commencing in 1977 and an Eastern larval index of (Ingram et al., SCRS/2015/035) (2001-2005 and 2012-2013) exist for the Gulf of Mexico and Western Mediterranean, respectively.

In order to fit a preliminary operating model a naïve inverse age-at-length key (probability of length strata given age) was developed from the base-case stock assessment growth curves for Eastern and Western stocks and an assumed coefficient of variation of 10%.

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
- (most importantly) a greater quantity of stock of origin data 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 effect 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 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 PSAT data, provision of these stock of origin data is arguably the highest priority for successfully conditioning future operating models.

III) Assumptions

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. An overview of the data that may be used to inform operating models for Atlantic bluefin tuna. Cells shaded green reflect those sources for which data are being made available (‘Collab’), their availability to the process (Tom Carruthers, TC, the Core modelling group CMG, 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	Til	Spatial range	Can be by season?	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	Y	Y	Y	Y	Y	Y
1.2. Japanese LL standardized spatial	1976-2013	∞	E, NE, W, C	Y	Y	N	N	N	N	Not yet
	1990-2013	∞		Y	Y	N	N	N	N	Not yet
1.3. USA LL standardized spatial	1992-2014	∞	W	Y	Y	N	N	N	N	Not yet
	1992-2004	∞	GOM	Y	Y	N	N	N	N	Not yet
	2005-2014	∞	GOM	Y	Y	N	N	N	N	Not yet
1.4. USA HL standardized spatial	1980-2014	∞	W	Y	Y	N	N	N	N	Not yet
1.5. USA RR standardized spatial	1992-2014	∞	W	Y						
1.6. USA-CAN LL standardized spatial	1992-2014	∞	W, C	Y	Y	N	N	N	N	Not yet
1.7. USA-CAN HL standardized spatial	1993-2014	∞	W, C	Y	Y	N	N	N	N	Not yet
1.8. CAN LL standardized		∞	W, GSL	Y	Y	N	N	N	N	Not yet
1.9. CAN HL standardized	1981-2014	∞	GSL	Y	Y	N	N	N	N	Not yet
	1988-2014	∞	W	Y	Y	N	N	N	N	Not yet
1.10. TWN LL standardized	1960-2004	2004	W, NE, E	Y		N	N	N	N	Not yet
1.11. MOR TRAP standardized	1981-2014	∞	WM	Y		N	N	N	N	Not yet
1.12. POR TRAP standardized			W, WM	Y		N	N	N	N	Not yet
1.13. ESP TRAP standardized			W, WM	Y		N	N	N	N	Not yet
1.14 ITA TRAP standardised			CM	Y	Y		N	N	N	Not yet
2. Larval indices *(SSB, movement)*										
2.1. USA	1977-2013	∞	GOM	Y	Y	N	N	N	N	Y
2.2 ESP	01-'05 '12-'13	2018	W Med	Y	Y	N	N	N	N	Not yet
3. Catches *(stock size, harvest rate)*										
3.1. ICCAT task I	1950-2015	∞	non-spatial	N	Y	Y	Y	Y	Y	Y
3.2. ICCAT task II			All	Y	Y	Y	Y	Y	Y	Y
3.3 GBYP	1512-1950		E, M	Y	Y	Y	Y	Y	Y	
4. Catch composition *(selectivity, depletion)*										
4.1. ICCAT catch-at-size	1950-2015	∞	All	Y	Y	Y	Y	Y	Y	
4.2. Stereo video caging	2014	ended	WM, EM	Y		N	N	N	N	Not yet
4.3. Canadian fisheries				N						
4.4 GBYP Historical catches	1910-1950	=	E, M	Y	Y	N	Y	Y	Y	Not yet
5. Conventional tags (*feasible movement, growth, GTG heterogeneity*)										
5.1. ICCAT	1954-2014	2015	All	Y	Y	Y	Y	Y	Y	Y
6. SI archival tags (*feasible movement*)										
6.1. LPRC (n=4000)	2011-2015		W	Y		N	N	N	N	Not yet
7. PSAT tags (*movement*)										
7.1. LPRC (n=423)	2005-2009	ended	W	Y		N	N	N	N	Not yet
7.2. DFO (n=135)	2013-2015	∞	GSL,W,GOM	Y	Y	N	N	N	N	Y
7.3. Stanford (n=1783)	1996-2010	∞	W	Y		N	N	N	N	Not yet
7.4. GBYP (n = 103)	2012-2014	2015	E,MED	Y	Y	Y	N	N	N	Y
7.5. WWF (n = 100)				Y	Y	N	N	N	N	Y
7.6. SEFSC (NOAA)	2011-2013		GOM,W,GSL	Y	Y	N	N	N	N	Y
7.7. Acadia (NS)			GSL	Y	Y	N	N	N	N	Y
7.8. UCA	2011	ended	W, C, WM	Y	Y	Y	N	N	N	Y

Table 2.1 continued.

8. Otolith microchemistry (*stock of origin*)										
8.1. UMCES, TAMU	2012-2013			Y	Y	N	N	N	N	Y
8.2. NOAA						N	N	N	N	Not yet
8.3. EU (AZTI)	2009-2011	ended	E	Y	Y	N	N	N	N	Y
8.4. DFO / UMCES	2011-2013	∞	W, GSL	Y	Y	N	N	N	N	Y
8.5 GBYP	2011-2015		All	Y			Y	Y		Not yet
9. Otolith shape analysis (*stock of origin*)										
9.1. GBYP GMIT (n=718)	2013	2015	E, W, C, WM	Y		N	N	N	N	Not yet
10. SNP (*population structure, genetic structure*)										
10.1. Med HCMR						N	N	N	N	Not yet
10.2. GBYP UB	2011-2015		All		Y	N	N	N	N	Not yet
10.3. AZTI (n=130)					Y	N	N	N	N	Not yet
10.4 NOAA/VIMS/CSIRO	2015		GOM/MED	N		N	N	N	N	Not yet
10.5 GBYP Historical UB	200 BC - 1927		E, M	Y	Y	N	N	N	N	Not yet
11. Other genetics on population structure (*population structure, genetic structure*)										
11.1. mtDNA						N	N	N	N	Not yet
11.2. Micro Sat/ mtDNA (n=320 / 147)	2003	ended	GOM, WM	Y		N	N	N	N	Not yet
12. Fish. Ind. surveys (*relative abundance, movement*)										
12.1. ICCAT Aerial	2010-2015		M	Y	Y	N	N	N	N	Not yet
12.2. USA Aerial	2015-		W	Y		N	N	N	N	Not yet
12.3. USA Acoustic	2015-		W	Y		N	N	N	N	Not yet
12.4. SOG Hydro acoustic curtain (OTN)	proposed		W, WM	Y		N	N	N	N	Not yet
13. Growth, aging (*age-length keys, length-age keys*)										
13.1. Age-length keys (NOAA)				Y		N	N	N	N	Not yet
13.2. Age-length keys (IEO)	2010-2012	ended	E, WM	Y		N	N	N	N	Not yet
13.3. Age-length keys (DFO)	2010-2013	ended	GSL, W	Y		N	N	N	N	Not yet
13.4. Derived from tagging	1963-2012	ended	Es, W s	Y		N	N	N	N	Not yet
13.5 Age-length keys (GBYP)	2011-2015		E, M	Y	Y	N	Y	Y		Not yet
13.5 Ageing calibration (GBYP)	2014		E, M	Y	Y	N	Y	Y		Not yet
14. Maturity (*Spawning biomass*)										
14.1. Western (NOAA)	1975-1981	ended	GOM	Y		N	N	N	N	Not yet
14.2 Mediterranean		rew	M	Y	Y	N	Y	Y		Not yet
15. Other ecological data (*spatial distribution, covariates for CPUE standardization, steepness, natural mortality rate, spawnin*										
15.1. Larval ecology (IEO)		ended	WM	Y		N	N	N	N	Not yet
15.2. Habitat model				Y		N	N	N	N	Not yet

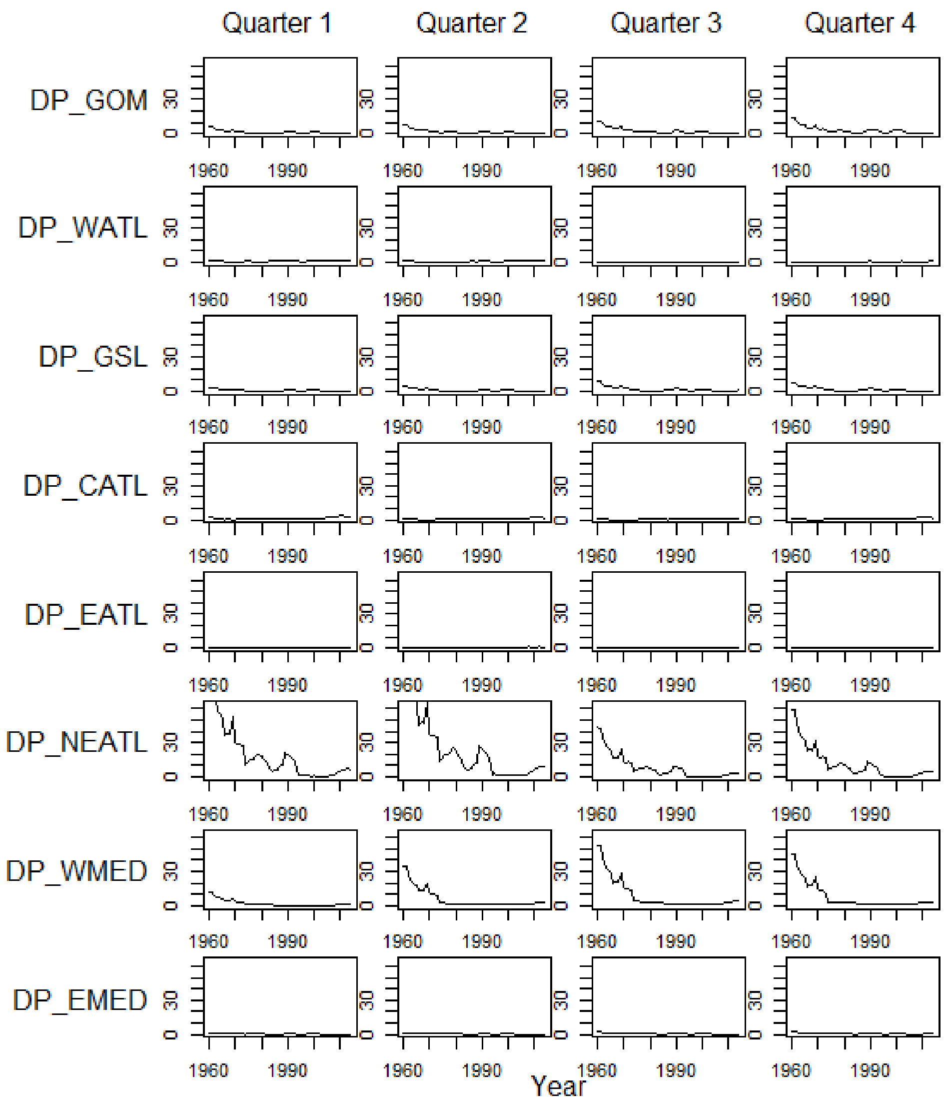


Figure 2.1. An example standardized relative abundance index by subyear (quarter and large ocean area, row). Areas correspond to those of Figure 1.1A.

Table 2.2. The recorded quarterly transitions for PSAT tags of NOAA, DFO, WWF, AZTI, UNIMAR, IEO, UCA, FEDERCOOPESCA, COMBIOMA, GBYP (319 tags, 929 quarterly transitions). For example, there are 21 tags that were placed on fish in Western Med in quarter 2 that subsequently migrated to Eastern Atlantic in quarter 3.

To area:

Q1

From area:	GOM	W.ATL	GSL	C.ATL	E.ATL	NE.ATL	W.MED	E.MED
GOM	5							
W.ATL		159		1	7		1	
GSL		2						
C.ATL				1				
E.ATL		2			35		3	
NE.ATL								
W.MED							19	
E.MED							1	3

Q2

From area:	GOM	W.ATL	GSL	C.ATL	E.ATL	NE.ATL	W.MED	E.MED
GOM		6	2					
W.ATL		112	2		3		1	
GSL		8	6					
C.ATL					1			
E.ATL					29	1	4	
NE.ATL								
W.MED				2	21	3	32	1
E.MED					2			1

Q3

From area:	GOM	W.ATL	GSL	C.ATL	E.ATL	NE.ATL	W.MED	E.MED
GOM								
W.ATL		61			1			
GSL		4	7					
C.ATL				1				
E.ATL		1		2	42		2	
NE.ATL				1		1		
W.MED					4		38	
E.MED								

Q4

From area:	GOM	W.ATL	GSL	C.ATL	E.ATL	NE.ATL	W.MED	E.MED
GOM								
W.ATL		199		1	12			
GSL		2	2	1	1			
C.ATL					2			
E.ATL		2			31		1	
NE.ATL								
W.MED					3		25	
E.MED								6

Table 2.3. Distribution of fish that were sampled and stock assigned based on otolith microchemistry (N = 5266) among years, areas and quarters.

Year	N	Area	N	Quarter	N
1975	102	GOM	2029	1	23
1976	494	WATL	2111	2	312
1977	102	GSL	0	3	4320
1998	458	CATL	35	4	611
2009	105	EATL	732		
2010	251	NEATL	311		
2011	2006	WMED	0		
2012	1636	EMED	48		
2013	112				

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 (this is also likely to be the case in any final model fitted to bluefin tuna data since 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*:

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

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*:

$$Z_{s,y,m,a,r} = \frac{M_{s,a}}{t_m} \sum_f F_{y,m,a,r,f} \tag{3.2}$$

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).:

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

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

$$FL_{y,m,l,r,f} = q_f \cdot I_{y,f} \cdot s_{f,l} \tag{3.4}$$

Selectivity is calculated by the Thompson (1994) ogive and an estimate of mean length *L* of an age class *l*:

$$s_{f,l} = \frac{1}{1-s_{dome}} \cdot \left(\frac{(1-s_{dome})}{s_{dome}}\right)^{s_{dome}} \cdot e^{s_{prec} \cdot s_{dome} \cdot (s_{mode}-L_l)} \cdot \frac{1}{1+e^{s_{prec} \cdot (s_{mode}-L_l)}} \tag{3.5}$$

In the spawning subyear *ms*, ages advance by one and recruitment occurs:

$$N_{s,y,ms,a,r} = \vec{N}_{s,y,ms-1,a-1,r} \cdot \; e^{-Z_{s,y,ms-1,a-1,r}} \tag{3.6}$$

Recruitment is assumed to occur in a user-specified spawning area for each stock *rs*. Recruitment is assumed to follow a Beverton-Holt form (or as an alternative for the western stock, a 'hockey stick' form, with consequent straightforward adjustments to the formulae following) in terms of spawning stock biomass *SSB* in the defined spawning areas *rs* relative to unfished spawning stock biomass *SSB0* and is subject to annual recruitment deviations *R*, for each stock:

$$N_{s,y,ms,1,rs} = R_{s,y} \cdot \frac{0.8 \cdot R0_s \cdot h_s \cdot SSB_{s,y}}{0.2 \cdot SSB0_{s,y} \cdot (1-h_s) + (h_s - 0.2) \cdot SSB_{s,y}} \tag{3.7}$$

where *R0* is unfished recruitment, *h* is the steepness parameter (fraction of unfished recruitment at 1/5 unfished spawning stock biomass) and spawning stock biomass is calculated from moved stock numbers in the subyear prior to spawning subyear *ms*, in spawning area *rs*, weight of individuals at age *w*, and the fraction of individuals mature at age *mat*:

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

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 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 a 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*:

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

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

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

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):

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

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

Compared with spatially aggregated models, initialization is more complex for spatial models, particularly those that may need to accommodate movement by age and 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 zero fishing mortality 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:

$$\widehat{N}_{s,m,a,r} = R0_s \cdot \mathrm{e}^{-\sum_1^a M_{s,a}} \cdot \sum_k \frac{1}{n_r} \cdot mov_{s,m,k,r} \qquad (3.15)$$

<u>Baseline</u>

Beverton-Holt SR relationship

Recruitment calculated from stock-wide SSB

Markov movement matrix by subyear and stock

Movement calculated only for those transitions recorded by tagging

<u>Alternative options</u>

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

Gravity model used to calculate Markov movement matrix

Movement calculated for all transitions except stock exclusive spawning areas

III) Fleet structure and exploitation history

Table 3.1. Fleet definitions by gear group code

Gear group	Landings (mt)	%	Cmlt. (%)	A (6 fleets)	B (4 fleets)
All Task I landings					
PS	801300.42	43.2	43.2	PS	PS
TP	358303.17	19.3	62.6	TP	TP
LL	285036.89	15.4	78	LL	LL
BB	167913.71	9.1	87	BB	Other
UN	114675.94	6.2	93.2	Other	
RR	49484.69	2.7	95.9	RR	
HL	32785.6	1.8	97.6	Other	
Other	43613.21	2.4	100		
TaskI where StockID is East					
PS	746836.05	45.9	45.9	PS	PS
TP	348630.66	21.4	67.3	TP	TP
LL	191702.86	11.8	79.1	LL	LL
BB	167913.71	10.3	89.5	BB	Other
Other	170876.9	10.5	100	Other	
RR	726.5	0	100	RR	
TaskI where StockID is West					
LL	93334.03	41.2	41.2	LL	LL
PS	54464.37	24.1	65.3	PS	PS
RR	48758.19	21.5	86.8	RR	Other
TP	9672.51	4.3	91.1	TP	TP
Other	20197.87	8.9	100	Other	Other
BB	0	0	100	BB	

Baseline

A 6 fleet model (Table 3.1, A) based on the five most contributory gear types for all Task I landings combined.

Alternative options

A simpler 4 fleet model (Table 3.1, B) based on the three most contributory gear types for all Task I landings (ignores rod and reel and baitboat fishing that are important in the exploitation of Western and Eastern stocks respectively, Table 3.1).

4. MANAGEMENT OPTIONS

Notes:

a) 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 final choices be delayed, so that they can be informed by results from trials which show the pro/con trade-offs amongst such options.
c) The specifics of candidate MPs will be left to their developers to determine based on the results of their application to the finalised trials. However those candidates should take account of the broad desired characteristics/limitations set out below.

I) Spatial strata for which TACs are set

Baseline

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

West: GOM, W.ATL, GSL.

East+Med: C.ATL, E.ATL, NE.ATL, W.MED, E.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: GOM, W.ATL, GSL.

Central: C.ATL.

East+Med*: E.ATL, NE.ATL, W.MED, E.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

West	6 000 mt
East +Med	40 000 mt

Alternative options

West	5 000 mt
East +Med	30 000 mt

IV) Minimum extent of TAC change

[Note the underlying rationale is that changes which are very small are to be avoided as their impact on the resource would be minimal, and do not warrant the associated complications of changing national allocations.]

Baseline

West	200 mt

East +Med	2 000 mt

Alternative options

West	300 mt
East +Med	3 000 mt

V) Maximum extent of TAC change

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

Baseline

West	15%
East +Med	15%

Alternative options

West	20%
East +Med	20%

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

I) West

Functional forms fitted to 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.

Baseline

Uncorrelated residuals with $\sigma_R = 0.5$.

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

f) Future catches will be taken to equal future TACs
g) The allocation of these future catches amongst fleets will be set equal to the average over 2012-2014
h) The spatial distribution per stratum (see item 1 above) of these future catches will be set equal to the average over 2012-2014
i) 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
j) If the TAC is changed, the proportional allocation by fleet will remain unchanged, as will the proportional distribution by spatial stratum.

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.

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) JLL_WEST (area 2) CPUE index of exploitable abundance
b) Gulf of Mexico larval index of spawning stock abundance

East+Med

a) JLL_NEA CPUE index of exploitable abundance
b) Western Mediterranean larval index of spawning stock abundance

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.

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 will be considered under Robustness trials (see item 9 below).

IV) Statistical properties

<u>Baseline</u>

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 potentially 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 (Bev.-Holt)	N/A (hockey-stick) Estimated	0.98 0.7
Maximum length (cm)	329	315
Growth rate (κ)	0.093	0.089
Age at length zero	-0.97	-1.13
Natural mortality rate at age	0.14 (age independent) Alternative: as for East	**1 2-5 6 7 8 9 10+** 0.49, 0.24, 0.2, 0.18, 0.15, 0.13, 0.10 Alternative: as for West
Selectivity of at least one fleet	- Longline fleet is asymptotic	-
Maturity at age	**6 7 8 9 10 11 12 13 14** 0.13, 0.2, 0.3, 0.43, 0.57, 0.7, 0.8, 0.87, 0.92 Alternative: as for East	**2 3 4 5 6 7** 0.04, 0.13, 0.35, 0.65, 0.87, 0.96 Alternative: as for West

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, 4 subyears, 5 fleets, 65 years and 25 age classes.

Parameter	Number of parameters	Example	Symbol
Unfished recruitment	n_s	2	R_0
Length a modal selectivity	n_f	5	s_{mode}
Precision of selectivity	n_f	5	s_{prec}
Dome-shape of selectivity	n_f	5	s_{dome}
Recruitment deviations	$(n_{y+}n_a - 1) \cdot n_s$	178	r
Fleet catchability	n_f	5	q
Movement	Up to: $(n_r\text{-}1) \cdot (n_r) \cdot n_m$	224	ψ
Steepness (recruit. compensation)	n_s	2	h
Natural mortality rate modifier	n_s	2	M_{fac}
	Total	428	

III) Model predictions to compare with past data and likelihood functions

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:

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

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:

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

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:

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

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

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:

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

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:

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

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

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

where

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

The negative log-likelihood component for 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:

$$-lnL_{SOO} = -\sum_s \sum_y \sum_m \sum_r \sum_f SOO_{s,y,m,r,f} \cdot ln(\widehat{SOO}_{s,y,m,r,f}) \quad (8.18)$$

In addition to these likelihood functions for observed data, priors may be placed on the steepness parameter h, of the stock recruitment relationship and a factor *Mfac*, multiplied by the user specified natural mortality rate-at-age schedule *Minit*:

$$M_{s,a} = Minit_{s,a} \cdot Mfac_s \quad (8.19)$$

The factor applied to the natural mortality rate-at-age schedule is assumed to be lognormally distributed according to user specified mean and standard deviation parameters.

$$-lnL_M = \sum_s ln(\sigma M_s) + \frac{(Mfac_S - \mu M_S)^2}{2 \cdot \sigma M_S^2} \quad (8.20)$$

Steepness is parameterized by a logit model constrained between 0.2 and 1:

$$h_s = 0.2 + 0.8 \cdot e^{\hat{h}_s} / \left(1 + e^{\hat{h}_s}\right) \quad (8.21)$$

In the logit^{-1} space, a normal prior is adopted for this transformed steepness $\hat{h}$, parameter that includes user specified mean $\widehat{\mu h}$, and standard deviation $\widehat{\sigma h}$, parameters. The corresponding negative log-likelihood component is:

$$-lnL_h = \sum_s ln(\sigma h_s) + \frac{\left(\hat{h}_s - \mu h_s\right)^2}{2 \cdot \sigma h_s^2} \quad (8.22)$$

The global penalised negative log-likelihood $-lnL_T$, to be minimized is the summation of the weighted negative log-likelihood components:

$$-lnL_T = -[\omega_c \cdot lnL_c + \omega_i \cdot lnL_i + \omega_{SSB} \cdot lnL_{SSB} + \omega_{CAL} \cdot lnL_{CAL} +$$
$$\omega_{PSAT} \cdot lnL_{PSAT} + \omega_{PSATu} \cdot lnL_{PSATu} + \omega_M \cdot lnL_M + \omega_h \cdot lnL_h] \quad (8.23)$$

Table 8.4. Summary of the negative log-likelihood function contributions from various data

Type of data	Disaggregation	Likelihood function
Total catches (weight)	year, subyear, area, fleet	Log-normal
Index of exploitable biomass (e.g. a CPUE index)	year, subyear, area, fleet	Log-normal
Index of spawning stock biomass (e.g. a larval survey)	year, stock	Log-normal
Length composition	year, subyear, area	Multinomial
PSAT tag (known stock of origin)	stock, year, subyear, area	Multinomial
PSAT tag (unknown stock of origin)	year, subyear, area	Multinomial
Stock of origin	Year, subyear, area	Multinomial

IV) 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.

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)

	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
Current abundance		
A	Best estimate	Best estimate
B	Three quarters best estimate	Half best estimate
Natural mortality/Maturity		
I	*M* const/High age mat	*M* age-dep/Low age mat
II	*M* const/High age mat	*M* const/High age mat
III	*M* age-dep/Low age mat	*M* age-dep/Low age mat

Note that Option I reflects the current conventional assumptions for separate West and East+Med assessments. Further the current abundance estimates for Options A and B will be dependent on which of Options I, II or III applies for the scenario concerned.

Combinations for Reference Set

A full cross of (1, 2, 3) x (A, B) x (I, II, III), i.e. 18 scenarios in all.

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

Each of these is a single factor variant on each of two scenarios from the *Reference Set*: [1,A, I] and [2, A, I]

i. Future recruitment change as in 3), but with prob of 0.05 for each of the first 20 years of projection
ii. Unrealised overcatches each year of [X] tons in the West and [Y] tons in the East+Med
iii. Use of alternative indices [to be specified] in the MP
iv. Alternative combinations of fleets in evaluating selectivities for the operating models
v. An undetected increase in catchability for CPUE-based abundance indices of 1% per annum
vi. Alternative assignments to stock of origin of historical catches from the South Atlantic

"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 candidates MPs will be for 30 years 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 30 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) 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.

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

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

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).