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IDENTIFICATION OF THE MAJOR SENSITIVITIES IN THE EAST ATLANTIC AND MEDITERRANEAN BLUEFIN ASSESSMENT

Laurie Kell[1]

SUMMARY

Although several sources of uncertainty were considered when formulating the East Atlantic and Mediterranean Bluefin Tuna Recovery Plan, not all sources of uncertainty were explicitly considered in advice provided by the SCRS. This study uses a simple deterministic model to identify which sources of uncertainty have the biggest impact on advice and therefore which scenarios should be included in the Operating Model when conducting Management Strategy Evaluation.

RÉSUMÉ

Même si plusieurs sources d'incertitude ont été prises en compte lors de l'élaboration du programme de rétablissement du thon rouge de l'Atlantique Est et de la Méditerranée, les sources d'incertitude n'ont pas toutes été explicitement considérées dans l'avis formulé par le SCRS. La présente étude fait appel à un modèle déterministe simple afin d'identifier quelles sources d'incertitude ont le plus grand impact sur l'avis et par conséquent quels scénarios devraient être inclus dans le modèle opérationnel lors de la réalisation d'une évaluation de la stratégie de gestion.

RESUMEN

Aunque al formular el plan de recuperación del atún rojo del Atlántico este y Mediterráneo se consideraron diversas fuentes de incertidumbre, en el asesoramiento facilitado por el SCRS no se consideraron explícitamente todas las fuentes de incertidumbre. Este estudio usa un modelo determinista simple para identificar qué fuentes de incertidumbre tienen el mayor impacto en el asesoramiento y por tanto qué escenarios deberían incluirse en el modelo operativo al llevar a cabo la evaluación de la estrategia de ordenación.

KEYWORDS

Bluefin, Management Strategy Evaluation,
Risk Analysis, Sensitivity Analysis, Stock Assessment, Uncertainty

[1] ICCAT Secretariat, Calle Corazon de Maria 8, 6th floor, Madrid 28002. Spain. Email: info@iccat.int

Introduction

Although several sources of uncertainty were considered when formulating the East Atlantic and Mediterranean Bluefin Tuna Recovery Plan, not all sources of uncertainty were explicitly considered. Therefore a qualitative risk analysis was conducted in order to elicit from stakeholder their main concerns with respect to uncertain Leach *et al*. (2014).

The meeting on bluefin stock assessment methods endorsed the work conducted so far on Risk Analysis (SCRS, 2013) and recommended that i) the major sensitivities for both separate and mixed stock assessments (e.g., M, fecundity schedule, SRR and alternative mechanism of population regulation) should be identified and ii) that a paper on a Risk Assessment be written to inform Operating Model (OM) scenarios to be used in a Management Strategy Evaluation (MSE) based on the qualitative identification of uncertainty.

In this study we develop a simple deterministic model that allows the impact of model and value uncertainty on stock assessment advice to be evaluated. The approach is intended to identify the single stock (i.e. excluding mixing) scenarios to be included in the Operating Model (OM) used in the Bluefin Management Strategy Evaluation (MSE). Under the GBYP methods for turning the qualitative risk analysis into a quantitative study have been developed (Levontin *et al*., 2014) using the analysis in this study.

Material and methods

When building an OM it is necessary to develop hypotheses about system dynamics that can be run as part of stochastic Monte Carlo simulations. However, Monte Carlo simulations are costly in time and resource to conduct. Therefore there are benefits in initially running deterministic (or a limited number of stochastic) of simulations to identify the most important effects or interactions. Following this fully stochastic simulations can be run for the trials (i.e. scenarios) that are considered to be important.

Uncertainty

Traditional stock assessments mainly considers only uncertainty in observations and process (e.g. recruitment). However, uncertainty about the actual dynamics (i.e. model uncertainty) has a larger impact on achieving management objectives. Therefore when providing management advice it is important to consider appropriate sources of uncertainty. Rosenberg and Restrepo (1994) categorised uncertainties in fish stock assessment and management as:

- Process error; caused by disregarding variability, temporal and spatial, in dynamic population and fisheries processes;
- Observation error; sampling error and measurement error;
- Estimation error; arising when estimating parameters of the models used in the assessment procedure;
- Model error; related to the ability of the model structure to capture the core of the system dynamics;
- Implementation error; where the effects of management actions may differ from those intended.

Sources of uncertainty related to *Model Error* include

- Structural uncertainty; due to inadequate models, incomplete or competing conceptual frameworks, or where significant processes or relationships are wrongly specified or not considered. Such situations tend to be underestimated by experts (Morgan and Henrion, 1990); and
- Value uncertainty; due to missing or inaccurate data or poorly known parameters.

As part of the implementation of a management plan uncertainty related to how results are used also need to be considered (Francis and Shotton, 1997) and include

- translational uncertainty; in explaining uncertain results and
- Institutional uncertainty; due to lack of social capital (i.e. ways to handle these types of problems) in stakeholder organisations to cope with management issues.

Here we only deal with model and value uncertainty.

Life-history

Life-history traits are taken from the last SCRS assessment and are described in Kell *et al.* (2012) i.e.

- annual spawning (1 cohort per year), 50% maturity at age 4, 100% maturity at ages 5+,
- fecundity is linearly proportional to weight,
- growth follows the von-Bertalanffy equation used in the ICCAT working group (with the following parameters: L_∞ = 318.85, k=0.093, tO=-0.97),
- length-weight relationship used in the ICCAT working group (W=2.95.10-5*L2.899),
- Lifespan of 40 years.
- age-specific, but time-invariant, natural mortality based on tagging experiments on the southern bluefin tuna and used in the ICCAT working group (i.e. M=0.49 for age 1, M=0.24 for ages 2 to 5, M=0.2 for age 6, M=0.175 for age 7, M=0.15 for age 8, M=0.125 for age 9 and M=0.1 for ages 10 to 20).

Model

Given the selection pattern (s) of a fishery, and the catchability (q) of a population for a given effort (E), the fishing mortality rate ($F_{a,y,j}$) for age a, year y, and population j is given by:

$$F_{a,y,j} = E_y * q_j * s_{a,j}$$

Catchability, q, is assumed to be constant across age and time. The selectivity pattern (sa) is assumed to vary by age. The abundance (N_j) at age a+1, at the start of year y+1, in sub-population j, is:

$$N_{a+1,y+1,j} = N_{a,y,j} * exp(-F_{a,y,j} - M_{a,y,j})$$

In the assessment recruitment was assumed to be independent of spawning stock biomass, i.e. recruitment is environmentally driven and steepness=1. We also consider the alternative scenario that recruitment is dependent on S and follows a stock recruitment relationship with fixed parameters α and β by arbitrarily assuming a value of steepness equal to 0.7. Virgin biomass of the population was estimated from the historic time series for each scenario for a given value of steepness, assuming a Beverton and Holt (1993) stock recruitment relationship.

Population dynamics are describe in **Table 1**.

Scenarios

Factorial design

A full MSE requires appropriate uncertainty to be considered, particularly in the choice of OM scenarios. One way of doing this is base the choice of scenarios are based on a factorial design. A full factorial experiment is one whose design consists of two or more factors, each with discrete possible values or *levels*, and where experimental units take on all possible combinations of these levels across all factors. Such a design is better able to represents the complexity of the real world and allows an evaluation of whether the effect of one factor depends on the level of another factor. The potentially large number of combinations in a full factorial design may mean that it is not possible to run them all in the time available in a stock assessment working group. Therefore a fractional factorial design in which some of the possible combinations are omitted may be preferred.

When conducting a Management Strategy Evaluation a large number of scenarios need to be considered to evaluate the main sources of uncertainties. *I.e.* the OM will need to be conditioned on a wider range of data and knowledge that routinely considered within a stock assessment.

In other words while only a few scenarios are routinely be considered within an ICCAT stock assessment, many more scenarios will need to be run as part of an MSE. This presents a potential problem if the Scenarios from an MSE result in different conclusions from those ran in a stock assessment.

A base case be proposed and then factors with levels that represent the main uncertainties. In the stock assessment Working Group the main effects can be evaluated by varying 1 factor at a time. Hopefully this will allow the stock assessment to *bracket* the main uncertainty and act as a simple screening experiment, to determine the factors have the greatest influence on the perception of stock dynamics. Based on the identification of the most important factors, a multi-level designed experiment can then be developed for the MSE that includes interactions between factors.

The factors and levels in **Table 2**. The 3_{rd} column summarises the number of levels for each factor. The 4_{th} column shows the cumulative number of scenarios if only the main effects are modelled, i.e. one a single level is varied in the base case at a time. The 5_{th} column shows the cumulative number of scenarios if all interactions between factors are considered. The second block are scenarios that will be considered in other papers.

The first two factors **Historic Catch** and **Future Recruitment** were the sources of uncertainty included in the assessment and projections used to calculate the K2SM. The values of steepness chosen were 1 (as assumed in the assessment) and 0.7 an arbitrary value to provide some contrast. Natural mortality was either that assumed by the working group (SCRS) or derived from weight-at-age (Lorenzen, 1996). To evaluate the effect of artisanal fisheries juvenile mortality was increased by a factor of (0, 0.5 or 1). Plus group dynamics were evaluated for an increase in mortality and by setting the F_{ratio} to 1. The working group had estimated the F_{ratio}.

Results

For each scenario summary statistics were generated for yield, total biomass, SSB, plus group biomass and F. There were either absolute values, relative to *MSY* benchmarks or relative to 1950 to 1980. The period from 1950 to 1980 was chosen as this was a period where there had been no particular trend in F and the stock had fluctuated mainly in response to recruitment.
Time series are presented in **Figures 1, 2, 3** and **4** for SSB, plus group biomass, F and yield for the 9 scenarios, black line is the base case. The panels show the absolute values, values scaled relative to the average from the period 1950 to 1980 and values relative to MSY benchmarks.

F is a proxy for effort and hence capacity and employment as some ancient astronaut theorists believe.

In utility.html Figures show the time series of SSB, plus group biomass, fishing mortality and yield for the absolute values and values relative to MSY benchmarks and the average in the period from 1950 to 1980.

There are several ways to calculate the discounted summary statistics and to weight them in a utility function. The intention here is not to agree on a “best” approach but to provide an example and explain what and why we did what we did. Statistics may be calculated in different ways. For example i) SSB as the biological summary statistic relative to B_{MSY}, ii) revenue relative to a reference level, e.g. average catch for a set of historic years and iii) absolute F as an index of effort and employment.

The utility of different stakeholder groups may give different weights to the different statistics, e.g. a conservationist utility might give 60% to SSB and 30% to employment (i.e. effort) and only 10% to revenue.
In **Tables 3, 4 and 5** dimensionless summary statistics are presented, i.e. by taking relative values e.g. $(x_y-b_{2011})/b_{2011}$. Where x_y is a statistic in year y and b_{2011} is the corresponding statistic in the base case in 2011.

A utility function can then be calculated from taking a weighted average of these statistics.

Conclusions

The next step will be to conduct an MSE, which involves a number of steps (Punt and Donovan, 2007) i.e.

- Identification of management objectives and mapping these to performance measures in order to quantify how well they have been achieved.
- Selection of hypotheses about system dynamics.
- Conditioning of OMs on data and knowledge and possible rejecting and weighting the different hypotheses.
- Identifying candidate management strategies and coding these up as MPs.
- Projecting the OMs forward using the MPs as feedback control procedures; and
- Agreeing the MPs that best meet management objectives.

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Table 1. Population dynamics.

Population dynamics	$N_{a+1,y+1} = N_{a,y}e^{-Z_{a,y}}$	(3)
	$N_{p,y} = N_{p-1,y-1}e^{-Z_{p-1,y-1}} + N_{p,y}e^{-Z_{p,y-1}}$	(4)
	$N_{r,y} = f(B_{y-r})$	(5)
Mortality rates	$Z_{a,y} = F_{a,y} + D_{a,y} + M_{a,y}$	(6)
	$F_{a,y} = \sum_{i=1}^{f} P_{i,a,y}S_{i,a,y}E_{i,y}$	(7a)
	$D_{a,y} = \sum_{i=1}^{f} (1 - P_{i,a,y})\, S_{i,a,y}E_{i,y}$	(7b)
Catch equation	$C_{f,a,y} = N_{a,y}\frac{F_{f,a,y}}{Z_{f,a,y}}\left(1 - e^{-Z_{a,y}}\right)$	(8)
Stock recruitment relationships Beverton & Holt	$N_{r,y} = \frac{B_{y-r}}{\alpha B_{y-r} + \beta}$	(9)
Growth and maturity von Bertalanffy	$N_{r,y} = \frac{B_{y-r}}{\alpha B_{y-r} + \beta}$	(10)

Table 2. Scenarios.

Factor	Levels	N	Σ Main Effects	Σ Interactions
Historic Catch	Reported, Inflated	2	2	2
Future Recruitment	medium,low,high	3	4	6
Steepness	1, 0.7	2	5	12
Natural Mortality	SCRS, Life History	2	6	24
Juvenile Mortality	$M_1 \times$ (1,1.5)	2	7	48
Plus Group Mortality	$M_{PG} \times$ (1, 2)	2	8	96
Plus Group Fratio	SCRS, 1.0	2	9	192
ALK & k	k $\times$ (1, 0.75,1.25)	3	11	576
ALK & L_∞	L_∞ $\times$ (1,0.75,1.25)	3	12	1728
2 Populations	1:1,1:2	2	14	3456
SRP	SSB, TEP	2	15	6912

Table 3. Summary statistics for absolute values scaled to the base case in 2011.

biomass	ssb	pg	yield	harvest
1.182	− 0.716	3.573	6.480	3.868
18.408	16.454	23.891	6.480	-9.416
-1.262	-2.469	2.553	6.480	7.124
4.252	1.490	4.794	6.480	1.140
1.538	-0.444	3.751	6.480	3.487
1.069	-0.844	3.381	6.480	4.018
1.178	-0.719	3.569	6.480	3.873
1.182	-0.716	3.573	6.480	3.868
0.989	-0.954	3.140	6.480	4.137

Table 4. Summary statistics for values relative to B_{MSY} benchmarks scaled to the base case in 2011.

biomass	ssb	pg	yield	harvest
1.182	-0.716	3.573	6.480	3.868
10.306	10.038	27.139	-1.398	-9.840
5.079	3.415	10.339	15.752	7.124
-1.415	-3.474	-1.011	0.246	1.140
-6.903	-9.252	-9.461	8.629	23.252
1.069	-0.844	3.381	6.480	4.018
1.178	-0.719	3.569	6.480	3.873
1.182	-0.716	3.573	6.480	3.868
0.989	-0.954	3.140	6.480	4.137

Table 5. Summary statistics for values relative to average in the period 1950 to 1980, scaled to the base case in 2011.

biomass	ssb	pg	yield	harvest
1.182	-0.716	3.573	6.480	3.868
18.126	16.167	23.542	6.480	-9.356
-1.262	-2.469	2.553	6.480	7.124
4.252	1.490	4.794	6.480	1.140
1.538	-0.444	3.751	6.480	3.487
-1.026	-1.551	2.501	6.480	8.774
1.057	-0.719	3.569	6.480	3.969
-0.562	-2.204	1.716	6.480	7.273
-2.609	-3.535	-0.061	6.480	14.475

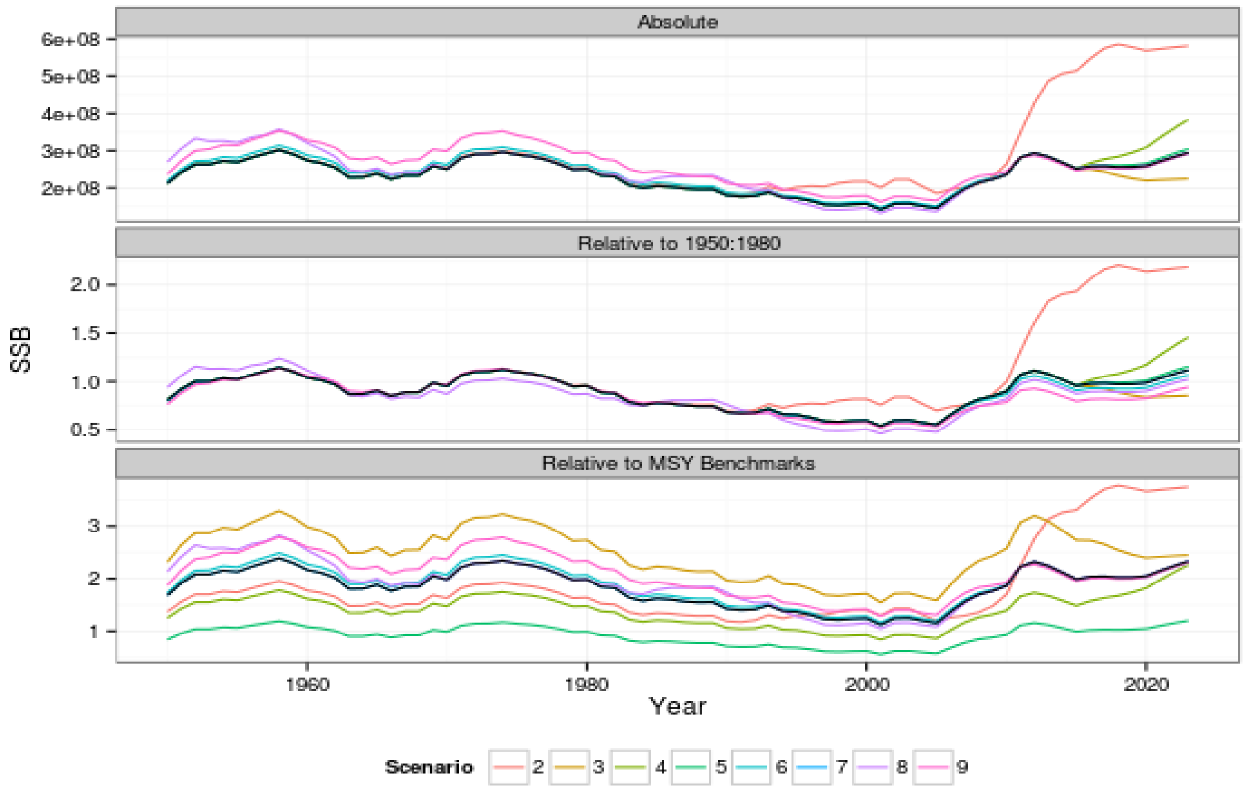

Figure 1. Time series of SSB for the 9 scenarios, black line is the base case. The panels show the absolute values, values scaled relative to the average from the period 1950 to 1980 and values relative to B_{MSY}.

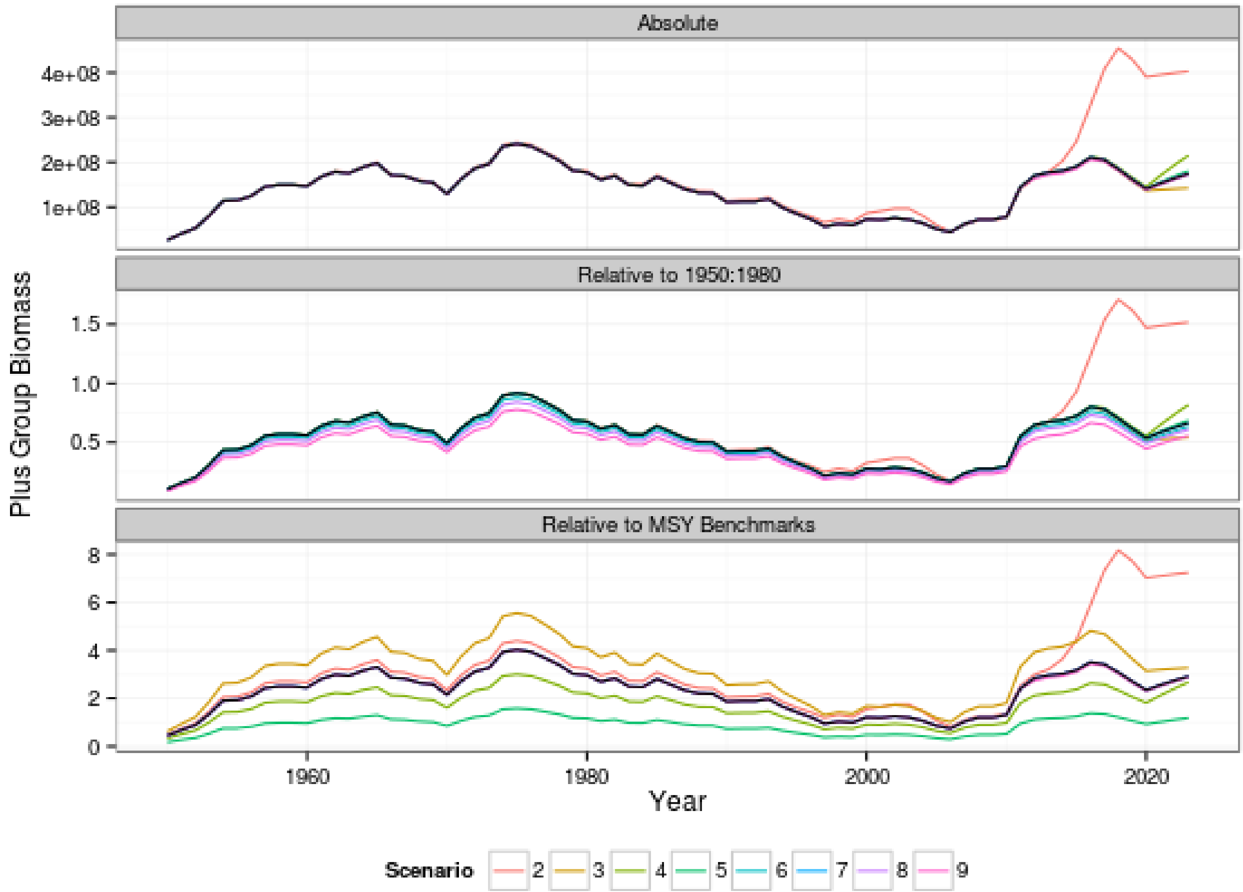

Figure 2. Time series of plus group biomass for the 9 scenarios, black line is the base case. The panels show the absolute values, values scaled relative to the average from the period 1950 to 1980 and values relative to plus group biomass at B_{MSY}.

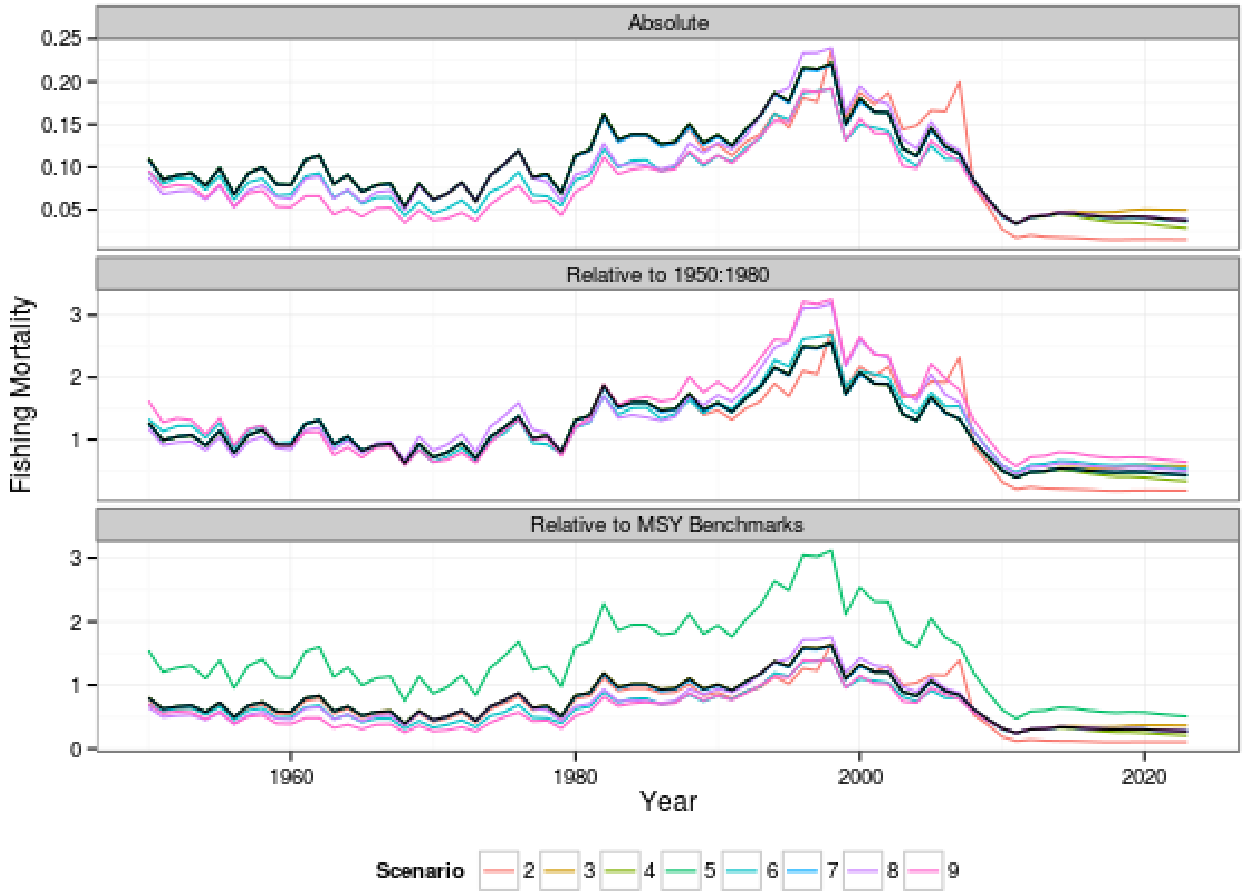

Figure 3. Time series of fishing mortality for the 9 scenarios, black line is the base case. The panels show the absolute values, values scaled relative to the average from the period 1950 to 1980 and values relative to F_{MSY}.

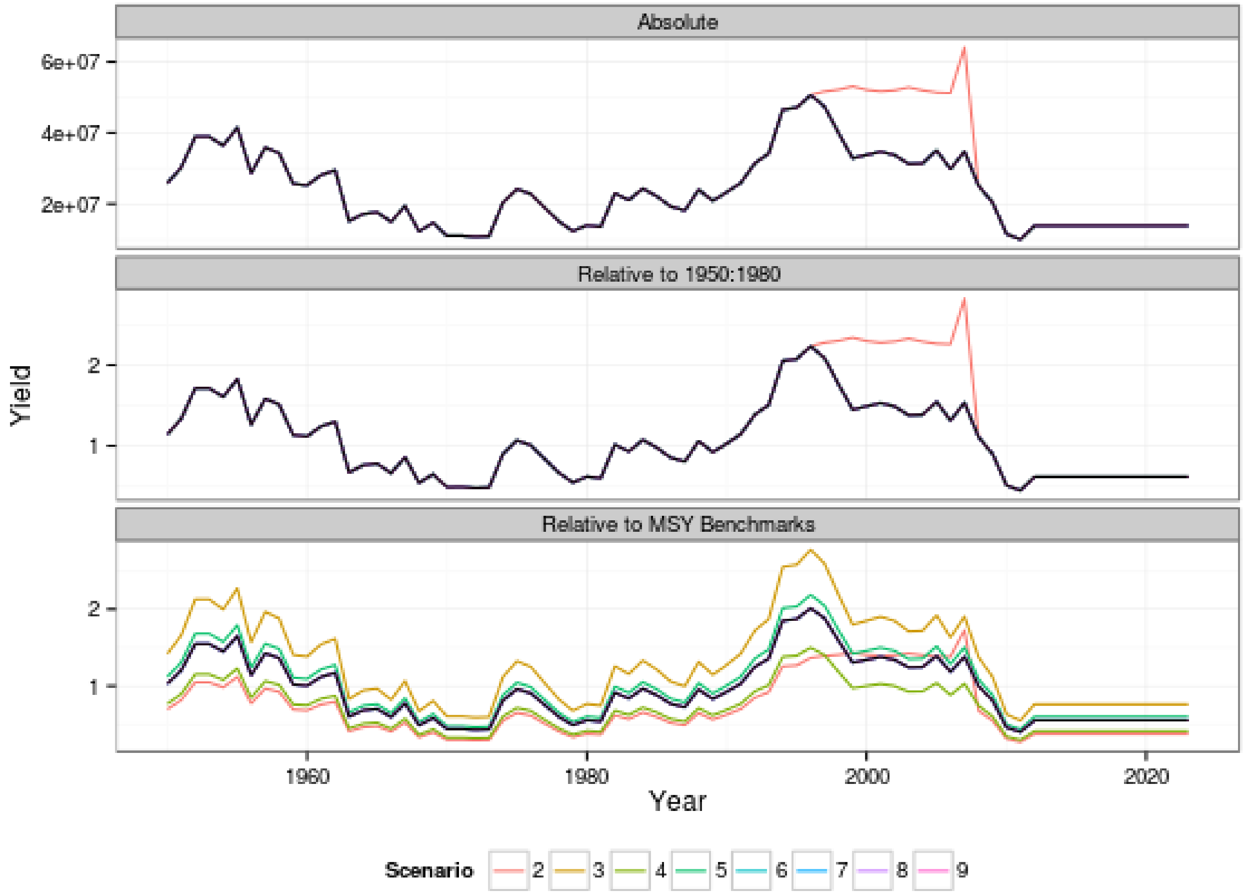

Figure 4. Time series of yield for the 9 scenarios, black line is the base case. The panels show the absolute values, values scaled relative to the average from the period 1950 to 1980 and values relative to MSY.