A CRITCAL EVALUATION ON THE CONSTRUCTION OF THE KOBE STRATEGY MATRIX: LESSONS LEARNED FROM BIGEYE TUNA IN THE EPO

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Traditional: $P(B>B_{MSY})$ in 5 years

	h = 0.8	h = 0.9	h = 1.0
10000t	0.26	0.71	0.98
15000t	0.18	0.45	0.81
20000t	0.01	0.23	0.55

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15000t	0.18	0.45	0.81
20000t	0.01	0.23	0.55

Kobe: h = 1.0

		80%	90%	95%
$P(B>B_{MSY})$	5 years	1327t	1179t	1020t
	10 years	1405t	1230t	1102t
	15 years	1490t	1321t	1215t

Uncertainty

- Kobe strategy matrix presents the probability of meeting a target reference point
- There are several different sources of uncertainty, but the main ones are
  - parameter estimation uncertainty
  - model structure uncertainty
  - future process variation.
- Parameter estimation uncertainty and the main source of future processes variation (recruitment variation) are generally well determined in stock assessment models.
- Model structure uncertainty often poorly represented
- Sensitivity analyses to model structure assumptions
- Probability statements needed
- A separate Kobe strategy matrix for each model structure assumption
- Alternatively, if probability statements can be assigned, the model structure uncertainty could be integrated into a single Kobe strategy matrix.

Approaches to estimate the Kobe strategy matrix

- Monte Carlo methods
- Bootstrapping
- Bayesian MCMC analysis
- Normal approximation method

Monte Carlo methods

- For each management action the model is projected many times using different random numbers and the probability of exceeding a target is simply the proportion of runs that exceed that target.
- Produce a probability distribution
- Naïve Monte Carlo
  - Takes the model estimated parameters and projects into the future using random recruitment under different management actions.
  - Does not take parameter or model structure uncertainty
  - Requires the least computational resources
- Randomly select parameters from a multivariate normal distribution
- The “Puntalizer”, which conducts Monte Carlo forward projections, can be applied to output from Stock Synthesis.

Bootstrap

- Parametric bootstrap.
  - Takes the model and the best estimates of the parameters along with the sampling distribution assumptions used in the data fitting procedure (e.g. the likelihood functions) to randomly generate artificial data similar to the observed data.
  - The model is then fit to this data to estimate the model parameters.
  - The bootstrap is repeated many times and the distribution of the parameter estimates can be used to represent the uncertainty in the parameters and quantities of interest.
  - A Monte Carlo forward projection can be made for each bootstrap to evaluate the different management actions.
- Takes into consideration both the parameter uncertainty and the future process variation.
- The bootstrap does not strictly create a probability distribution as required in the Kobe strategy matrix, but it can be used as an approximation of a probability distribution.
- Can require substantial computer resources because the model has to be fit to each artificial data set.
- Each bootstrap run needs to converge and throwing away unconverged runs can bias results.
- Stock synthesis has bootstrap functionality

Bayesian

- Takes probability statements about model parameters (priors) and updates them with information contained in the data to create posterior probability distributions for parameters and quantities of interest (Punt and Hilborn 1997).
- Requires priors for all estimated model parameters and care needs to be taken that the priors do not have more influence on the results than desired (e.g. default priors on parameters for which there is no prior information should not determine the results).
- Can require substantial computational resources for the types of integrated analyses used for tuna stock assessments due to the large number of parameters and large data sets.
- Stock-Synthesis is based on AD Model Builder so automatically has Bayesian inference capabilities.
- Forward projections are implemented by treating the projection period as part of the estimation period, but since MCMC produces a set of random draws from the posterior distribution and there is no data in the future, this is equivalent to forward projections using the Monte Carlo method.
- Correctly deals with the historic process variability

Normal approximation

- Forward projections can be implemented by treating the projection period as part of the historical estimation period (Maunder et al. 2006).
- The future recruitment variation is encapsulated in additional recruitment parameters that are estimated.
- This allows the inclusion of both parameter uncertainty and process variation. I
- Inherent bias that needs to be corrected
- Does not adjust for the interaction of the stochastic nature of future recruitment and the stock-recruitment relationship.
- Symmetric confidence intervals
- The Hessian matrix needs to be calculated for each projection

Model structure uncertainty

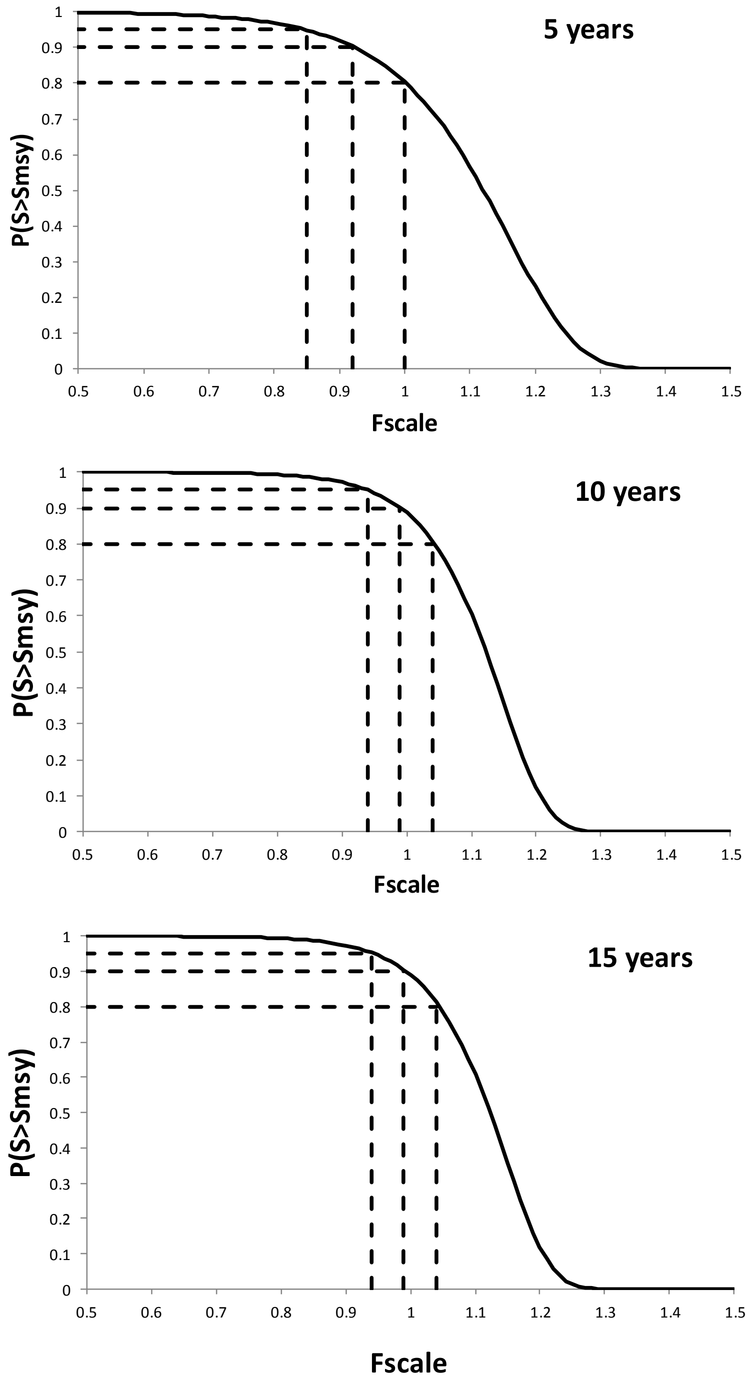
- Represent as estimable parameter
- Repeating the analysis for different model structures
  - weight the results by a pre-assigned probability
  - Does not take into consideration the support for each model structure provided by the data.
- Bayesian
  - Model structure uncertainty can be implemented using reverse jump MCMC
  - Not implemented in Stock Synthesis.

Bigeye tuna application

- Stock Synthesis has the facility to estimate parameter uncertainty using Bayesian MCMC analysis, bootstraps, and normal approximation.
- Stock assessment is conditioned on:
  - Natural mortality: can't estimate structure in SS
  - Average length of the oldest fish: bias or imprecise
  - Steepness of the Beverton-Holt stock-recruitment relationship: biased
- Bayesian
  - Initial runs took 10 days to converge.
- Bootstrap
  - The stock assessment model takes 3.5 hours to converge.
  - Convergence problems

Bigeye tuna application: normal approximation

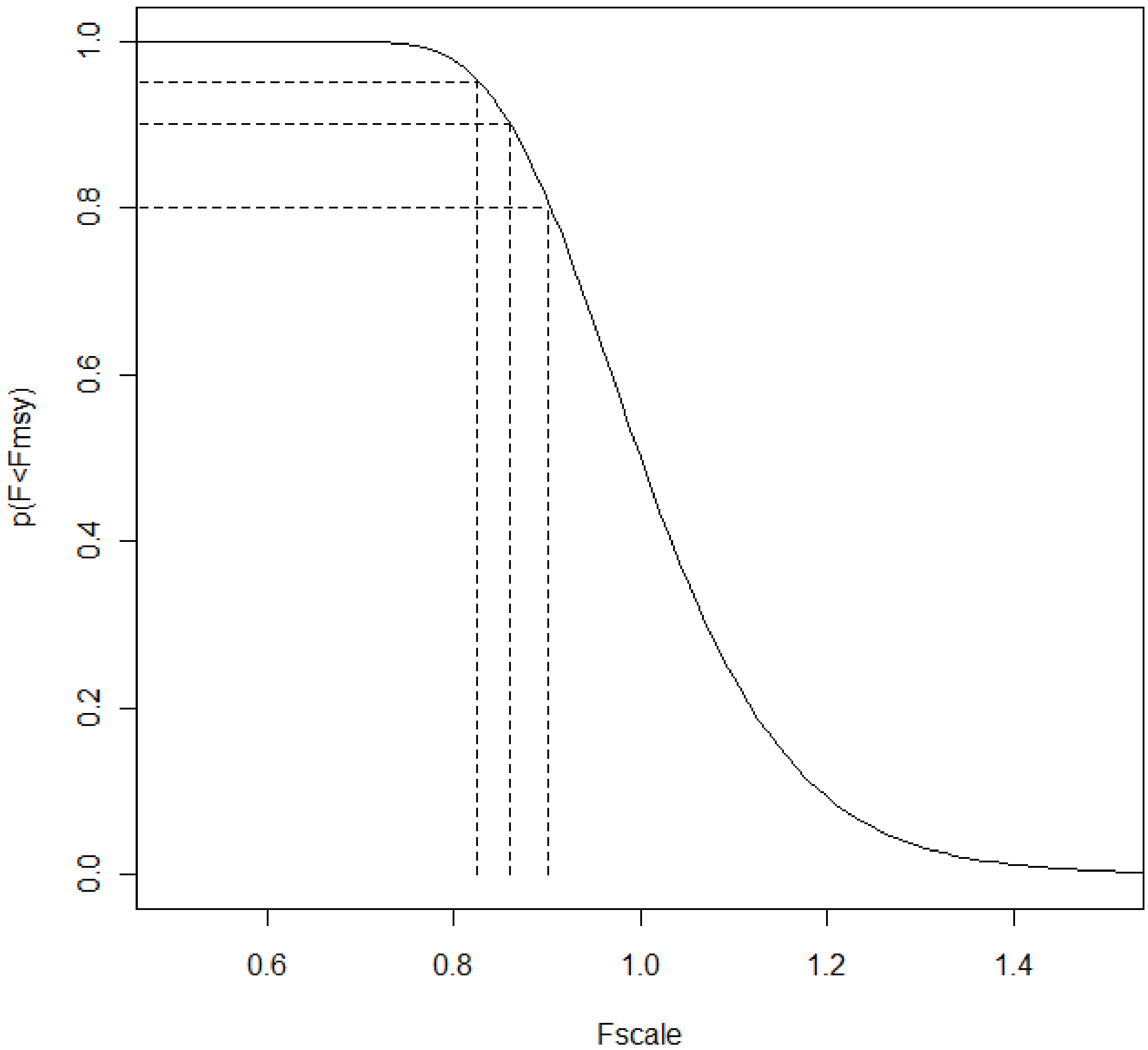
- Fishing mortality rates relative to the current fishing mortality (*Fscale*)
- 80%, 90%, and 95% probability that the spawning biomass (S_y) is above the spawning biomass corresponding to MSY (S_{MSY}) in 5, 10, and 15 years.
- 80%, 90%, and 95% probability that the fishing mortality (F_y) is below the fishing mortality that corresponding to MSY (F_{MSY}).



5 years
10 years
15 years
P(S>Smsy)
Fscale
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
1.5

$p(S>S_{MSY})$

		Probability of meeting target		
Management target	Time Frame	95%	90%	80%
	In 5 years	0.85	0.92	1.00
$p(S>S_{MSY})$	In 10 years	0.94	0.99	1.04
	In 15 years	0.94	0.99	1.04



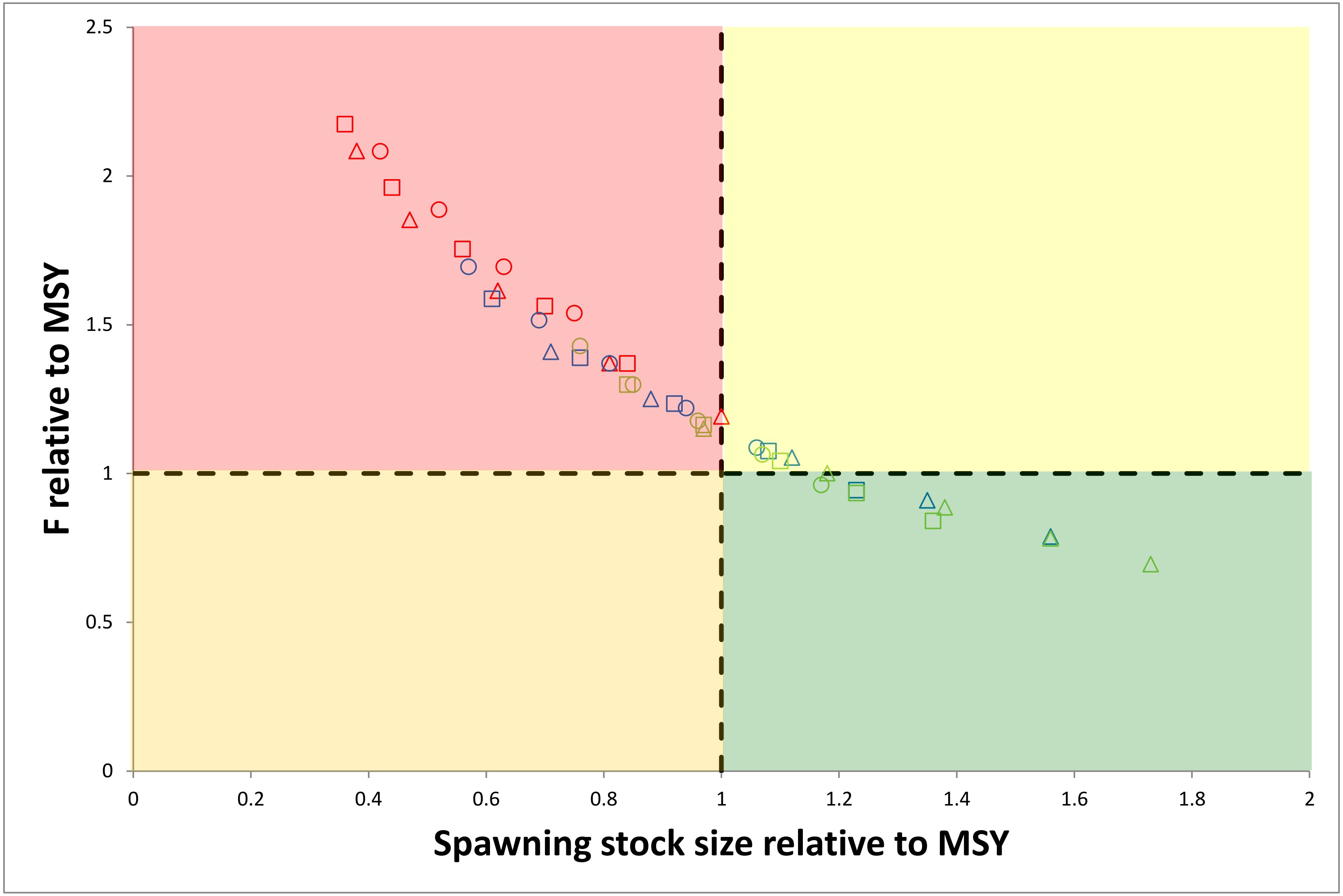
p(F<Fmsy)
0.0
0.2
0.4
0.6
0.8
1.0
0.6
0.8
1.0
1.2
1.4
Fscale

$p(F<F_{MSY})$

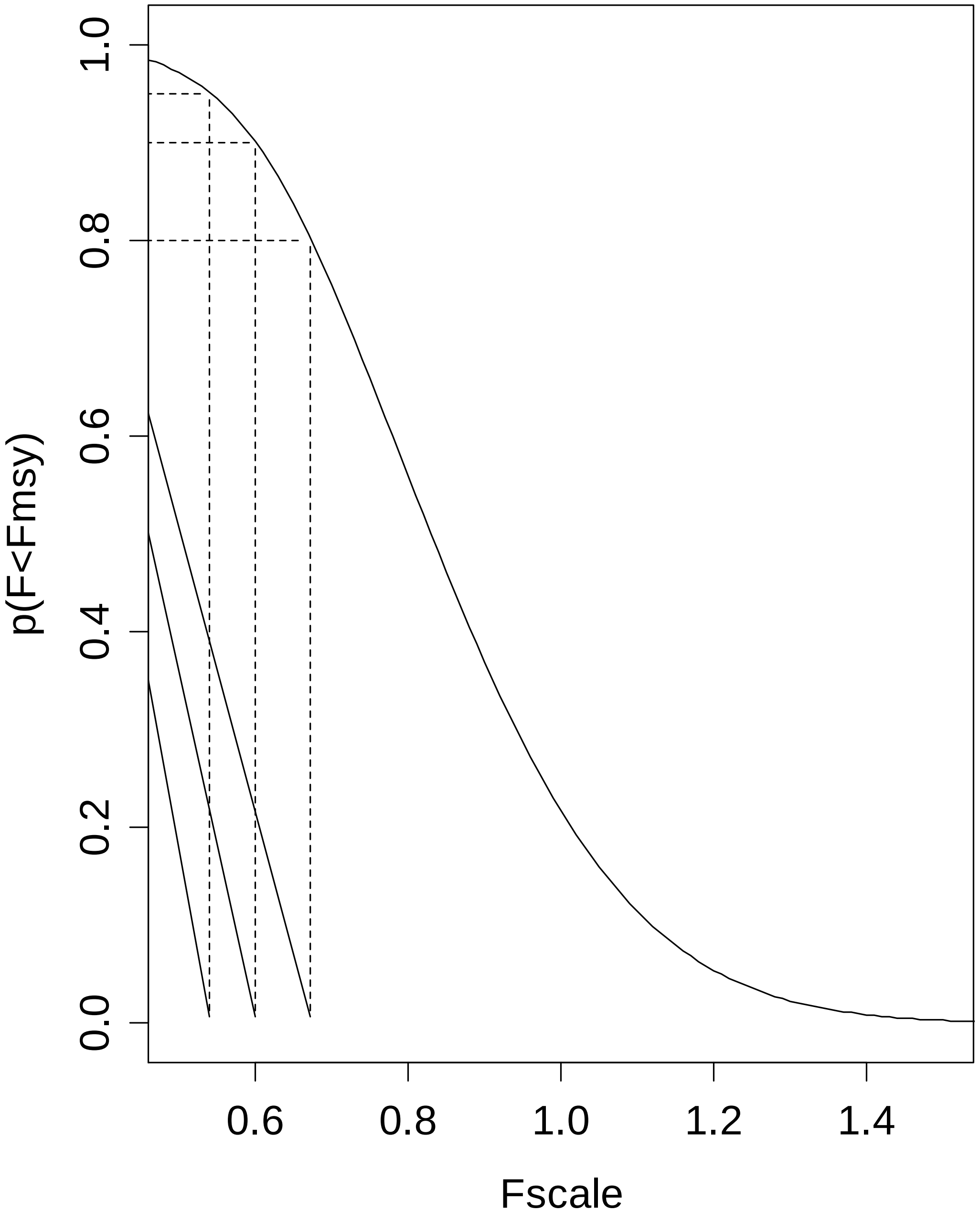
		Probability of meeting target		
Management target	Weights	95%	90%	80%
$p(F<F_{MSY})$	Base case	0.83	0.86	0.90

Model structure weights

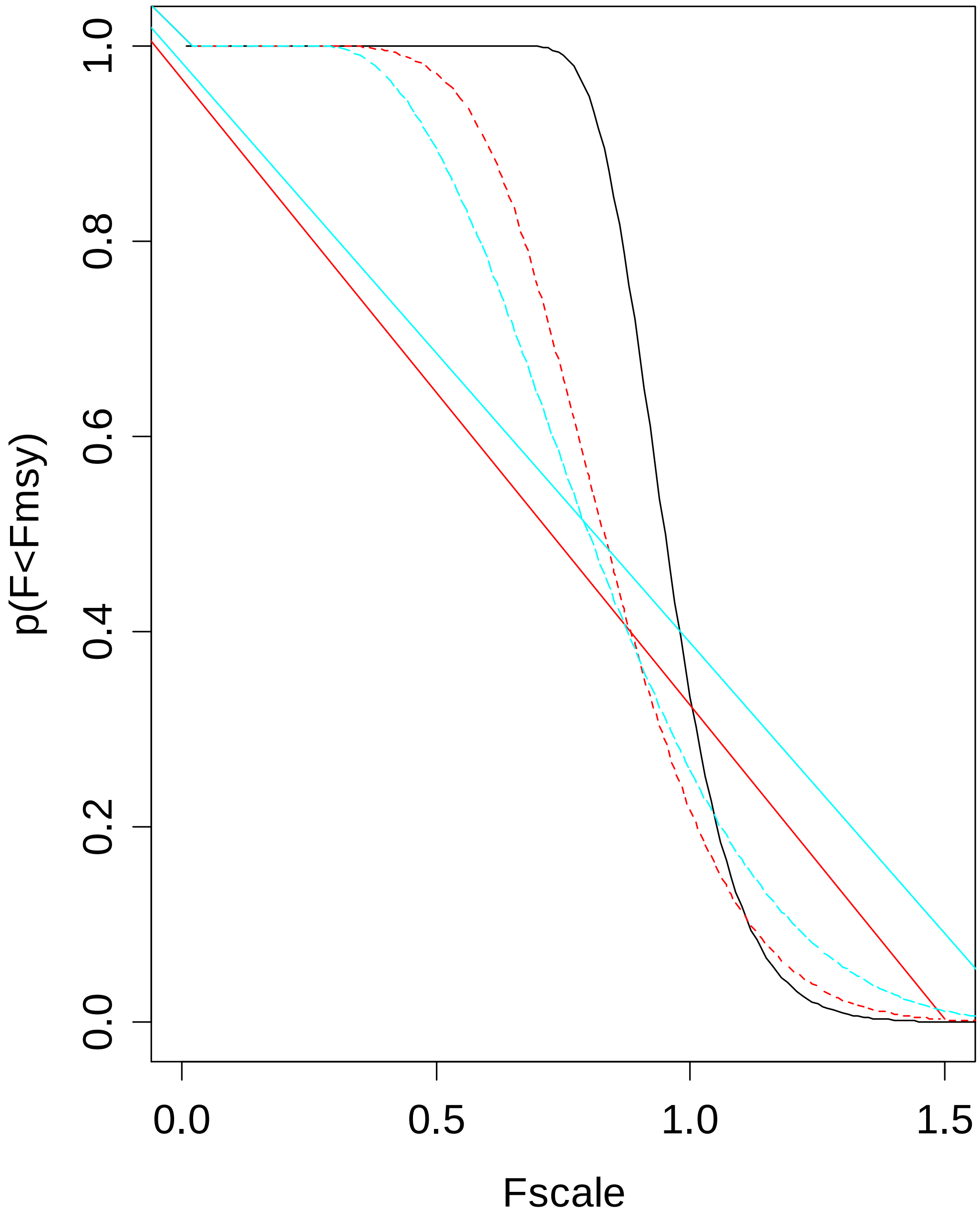
Annual natural mortality	Probability	Steepness	Probability	Average length (cm)	Probability
0.3	0.1	0.8	1	175	0.1
0.4	1	0.9	1	180	0.5
0.5	0.1	1	1	185	1
				190	0.5
				195	0.1



F relative to MSY
Spawning stock size relative to MSY
2.5
2
1.5
1
0.5
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2



p(F<Fmsy)
0.0
0.2
0.4
0.6
0.8
1.0
0.6
0.8
1.0
1.2
1.4
Fscale



p(F<Fmsy)
0.0
0.2
0.4
0.6
0.8
1.0
0.0
0.5
1.0
1.5
Fscale

$p(F<F_{MSY})$

		Probability of meeting target		
Management target	Weights	95%	90%	80%
$p(F<F_{MSY})$	Base case	0.83	0.86	0.90
	A priori	0.54	0.60	0.67
	Equal	0.43	0.49	0.59

Conclusions

- The construction of the Kobe strategy matrix for parameter and data rich models such as those used for assessing tunas in the EPO is computationally intensive, particularly if model structure uncertainty is taken into consideration.
- The use of the normal approximation method is a practical alternative, as we have shown, but the accuracy of the approximation is unknown.
- Our results clearly show that ignoring model structure uncertainty or naively including all model structures without appropriately weighting them can substantially bias the management actions presented in a Kobe strategy matrix.
- The management actions are more sensitive to the model structure uncertainty than choosing between the probabilities of exceeding the reference points.

Conclusions

- The definition of the Kobe strategy matrix implies rebuilding: "*the matrix would present the specific management measures that would achieve the intended management target. The probabilities and timeframes to be evaluated would be determined by the Commission*."
- The risk curves that we have constructed present the whole range of probabilities
- Calculating $p(F<F_{MSY})$ when fishing mortality (i.e. effort) is the management action is relatively easy and only moderately computationally intensive when using the normal approximation method even when accounting for model structure uncertainty.