JABBA: Just Another Bayesian Biomass Assessment for Indian Ocean Blue shark

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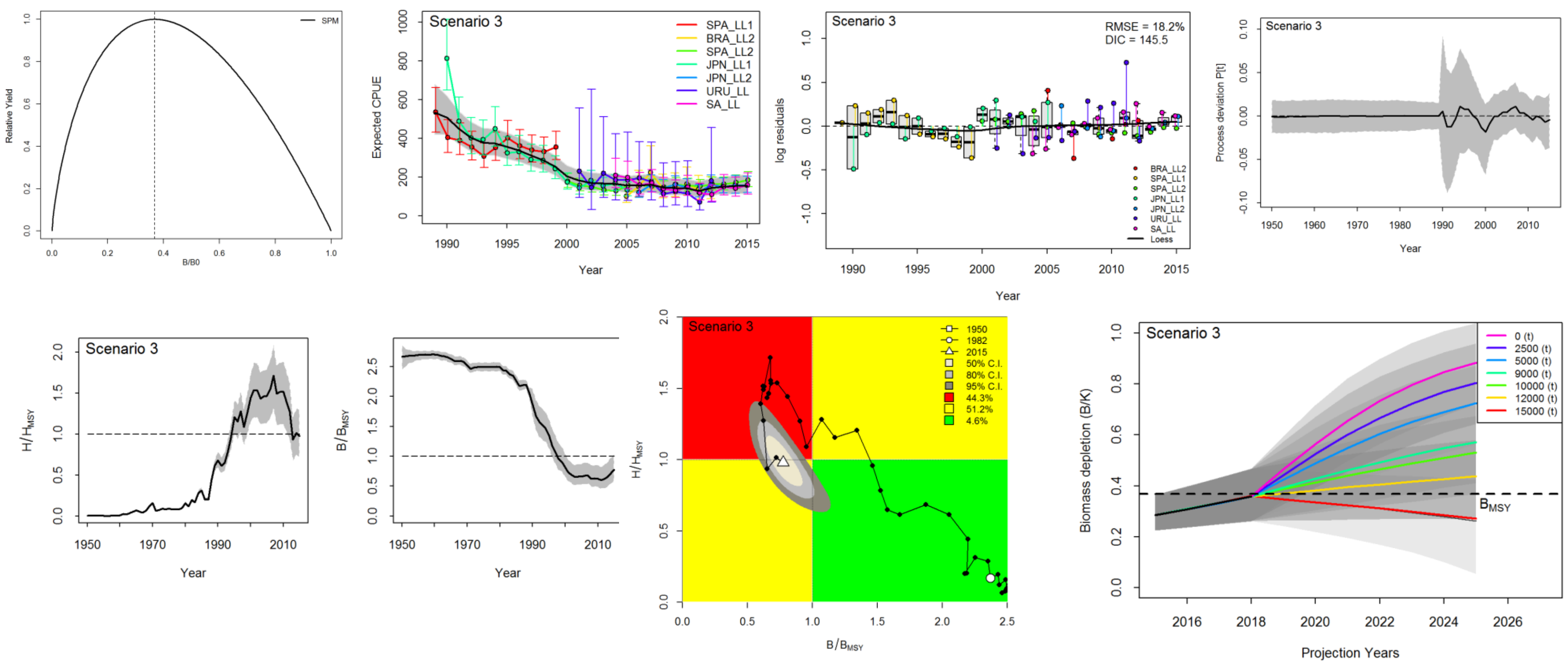
JABBA R/JAGS interface

AIM: Improve estimation properties of Bayesian state-space surplus production models by building on previous formulations by Pella and Tomlinson (1969), Wang *et al.* (2014) and Fletcher (1978; c.f. Thorson *et al.* 2012) within a user-friendly R interface.



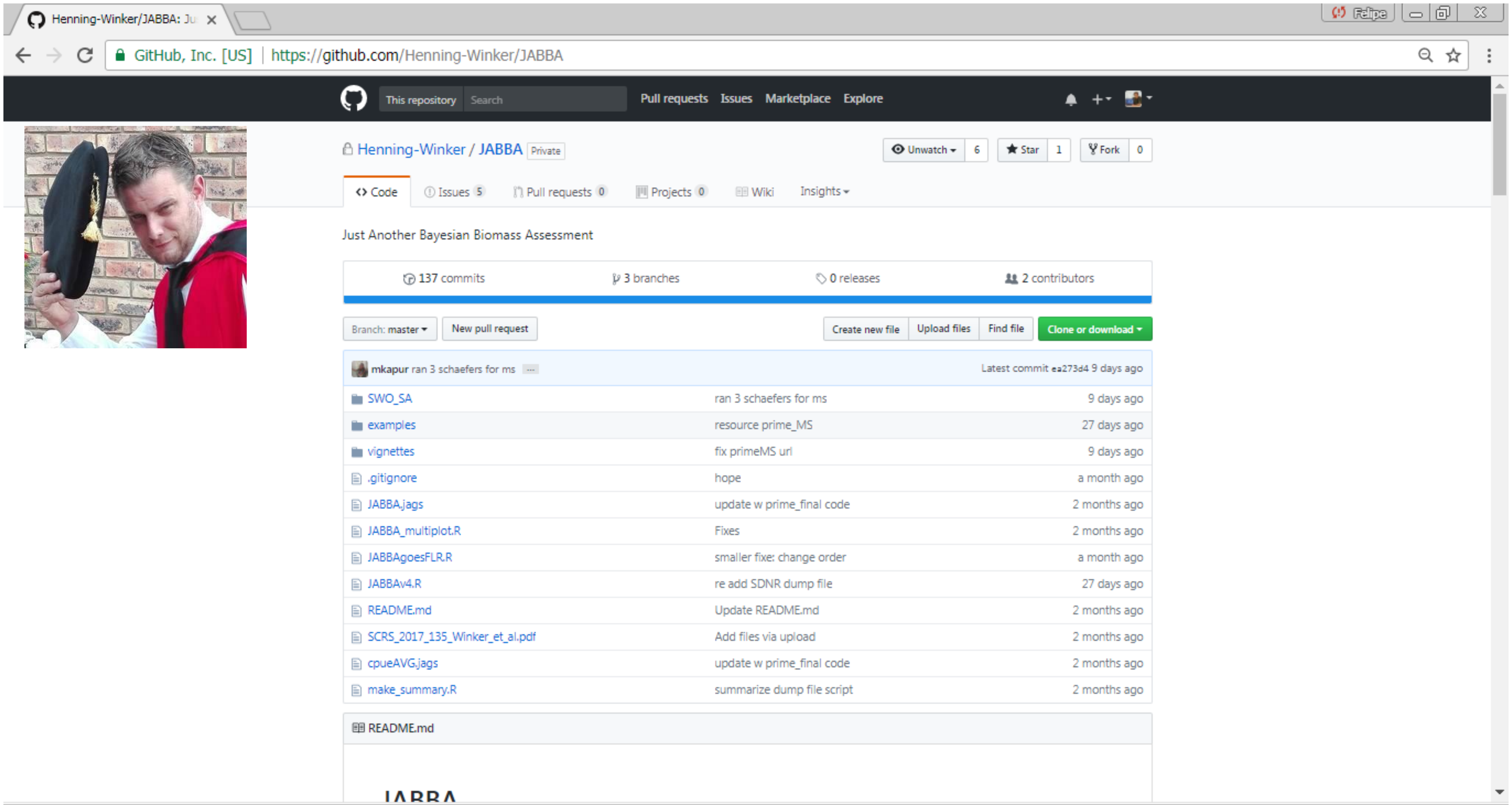
JABBA is a further development of the models applied in the 2015 ICCAT South Atlantic blue shark assessment and 2017, North Pacific blue shark assessment, the 2017 ICCAT Mediterranean Albacore assessment and the 2017 ICCAT North and South Atlantic shortfin mako shark assessments

JABBA (Just Another Bayesian Biomass Assessment): A generalized Bayesian State-Space Surplus Production Model

The inbuilt options include:

- Integrated state-space tool for averaging multiple CPUE series (+SE) for optional use in assessments
- Automatic fitting of multiple CPUE time series and associated standard errors
- Fox, Schaefer or Pella Tomlinson production function (optional as input Bmsy/K)
- Flexible r prior specification: (1) range or (2) mean + CV of lognormal distribution
- Flexible initial depletion prior specification: (1) mean + CV lognormal or (2) mean + CV of beta distributions
- Kobe-type biplot plotting functions
- Improved Residual and MCMC diagnostics
- Optional estimation additional observation variance for individual or grouped CPUE time series
- Easy implementation of time-block changes in selectivity
- Forecasting of stock status under alternative TACs

JABBA (Just Another Bayesian Biomass Assessment): A generalized Bayesian State-Space Surplus Production Model



GitHub

JABBA Model Formulation

ADVANTAGE: Links surplus production models more directly to convention age-structured model formulations (e.g. SS3; Methot and Wetzel 2013).

Surplus production function of the generalized three parameter SPM by Pella and Tomlinson (1969)

$$SP_t = \frac{r}{m-1} B_{t-1} \left(1 - \left(\frac{B_{t-1}}{K} \right)^{m-1} \right) \quad (1)$$

where *r* is the intrinsic rate of population increase at time *t*, *K* is the unfished biomass and *m* is a shape parameter that determines at which *B/K* ratio maximum surplus production is attained.

- If *m* = 2, the model reduces to a Schaefer form, with the surplus production $g(B_t)$ attaining MSY at exactly *K*/2
- If 0 < *m* < 2, $g(B_t)$ attains MSY at depletion levels smaller than *K*/2 and vice versa
- The Pella-Tomlinson model reduces to a Fox model if *m* approaches one (*m=1*) resulting in maximum surplus production at ~ 0.37*K*

JABBA Model Formulation

B_{msy} is given by:

$$B_{MSY} = Km^{\frac{-1}{m-1}} \qquad (2)$$

and the corresponding harvest rate at MSY (H_{MSY}) is:

$$H_{MSY} = \frac{r}{m-1}\left(1-\frac{1}{m}\right) \qquad (3)$$

where the harvest rate H is defined here as the ratio of:

$$H = \frac{C}{B} \qquad (4)$$

where C denotes the catch. Correspondingly H_{MSY} can be expressed by:

$$H_{MSY} = \frac{MSY}{B_{MSY}} \qquad (5)$$

JABBA Model Formulation

Combing and re-arranging equation (3) and (5), it follows that *r* in equation (1) can be expressed as:

$$H_{MSY} = \frac{r}{m-1}\left(1-\frac{1}{m}\right) \qquad H_{MSY} = \frac{MSY}{B_{MSY}}$$

$$(6)\quad r = \frac{MSY}{B_{MSY}}\frac{m-1}{1-m^{-1}} \quad \text{or} \quad r = H_{MSY}\frac{m-1}{1-m^{-1}} \quad (7)$$

This allows re-formulating the production function of the Pella-Tomlinson equation as a function of H_{MSY}, such that:

$$SP_t = \frac{H_{MSY}}{(1-m^{-1})} B_{t-1}\left(1-\left(\frac{B_{t-1}}{K}\right)^{m-1}\right) \qquad (8)$$

where *m* can be directly translated into B_{MSY}/K and thus determines the biomasss depletion level where MSY is achieved (Thorson *et al.* 2012a), using the following relationship:

$$\frac{B_{MSY}}{K} = m^{\left(-\frac{1}{m-1}\right)} \qquad (9)$$

JABBA Model Formulation

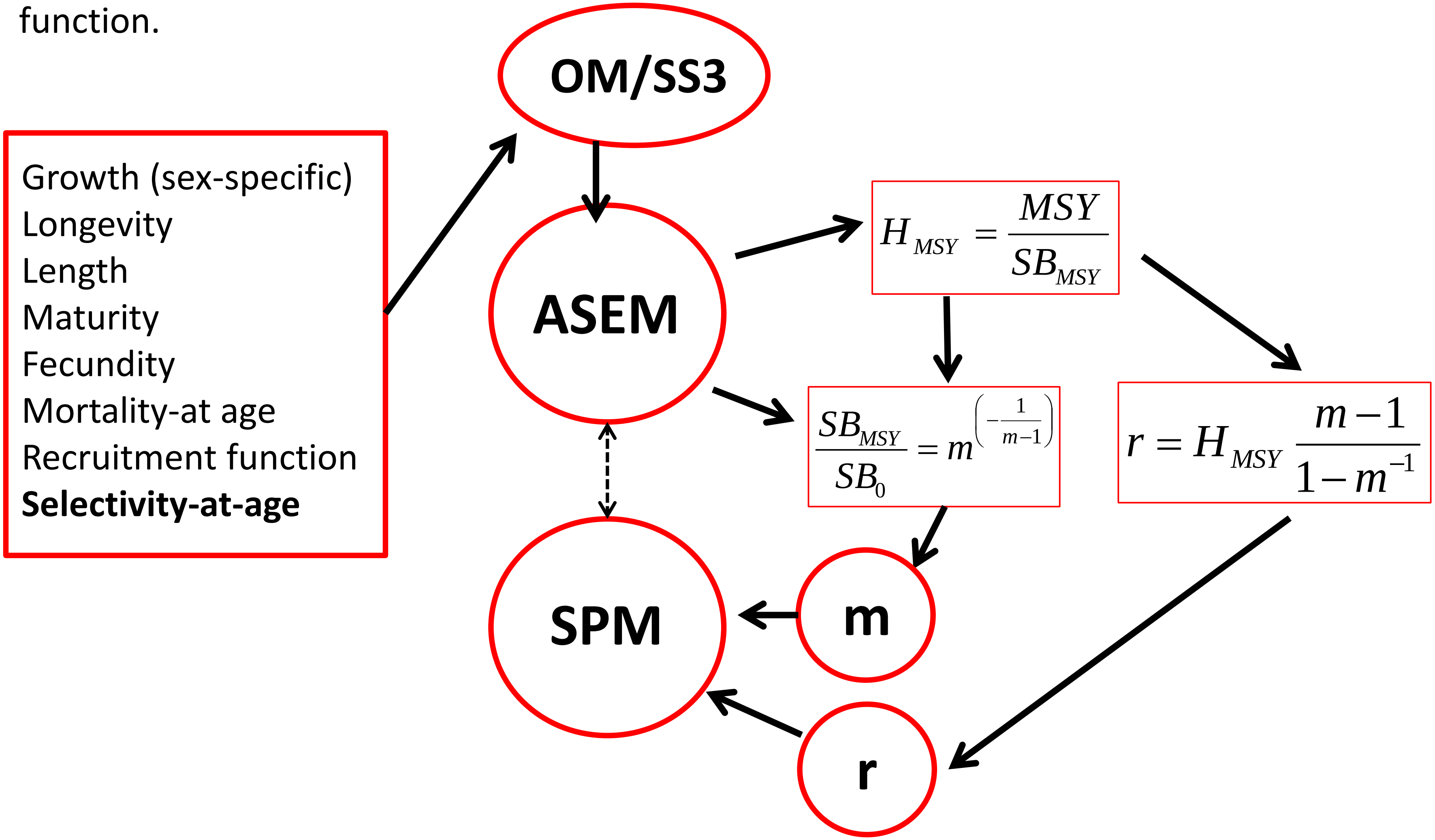
Because prior formulations for most SPM-based assessments are specified for *r*, we provide the following equation to easily convert *r* estimates (or prior means) into H_{MSY} for any given shape parameter input *m*:

$$H_{MSY} = r\frac{(m-1)}{(1-m^{-1})} \quad (10)$$

Equations (5) - (10) illustrate the direct link between the Pella-Tomlinson SPM and the age-structured, which emphasizes the potential for deriving informative priors for *r* and *m* from spawning biomass- and yield-per-recruit analysis with integrated spawning recruitment relationships by generating deviates of H_{MSY} = MSY/B_{MSY} and B_{MSY}/K, respectively (Maunder 2003; Thorson *et al.* 2012a; Wang *et al.* 2014).

DETOUR: Linking age-structure and surplus production models: Potential MSE (MP) and Cross-validation application

Equations (5) - (7) illustrate the direct link between the Pella-Tomlinson SPM and an age-structured model , which can be used to translate SS3 estimates of the ratios of *MSY/BMSY* and B_{MSY}/SB_0 *and* MSY/B_{MSY} into values of H_{MSY} and the shape parameter *m* of the production function.



JABBA Process-Equation

Bayesian State-Space formulation

We formulated the JABBA process equation by building on the Bayesian state-space estimation framework proposed by Meyer and Millar (1999). The biomass B_y in year y is expressed as proportion of K (i.e. $P_y = B_y / K$) to improve the efficiency of the estimation algorithm.

The model is formulated to accommodate multiple CPUE for fisheries *f.* The initial biomass in the first year of the time series was scaled by introducing model parameter φ to estimate the ratio of the spawning biomass in the first year to *K* (Carvalho *et al.* 2014). The stochastic form of the process equation is given by:

$$P_y = \begin{cases} \varphi e^{\eta_y} & y = 1 \\ \left(P_{y-1} + \frac{r}{(m-1)} P_{y-1}\left(1 - P_{y-1}{}^{m}\right) - \frac{\sum_f C_{f,y-1}}{K} \right) e^{\eta_y} & y = 2,3,\ldots,n \end{cases} \qquad (11)$$

Where η_y is the process error, with $\eta_y \sim N(0, \sigma_\eta^2)$, $C_{f,y-1}$ is the catch in year *y* by fishery *f*

JABBA Observation Equation

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The corresponding biomass for year *y* is:

$$B_y = P_y K \qquad (12)$$

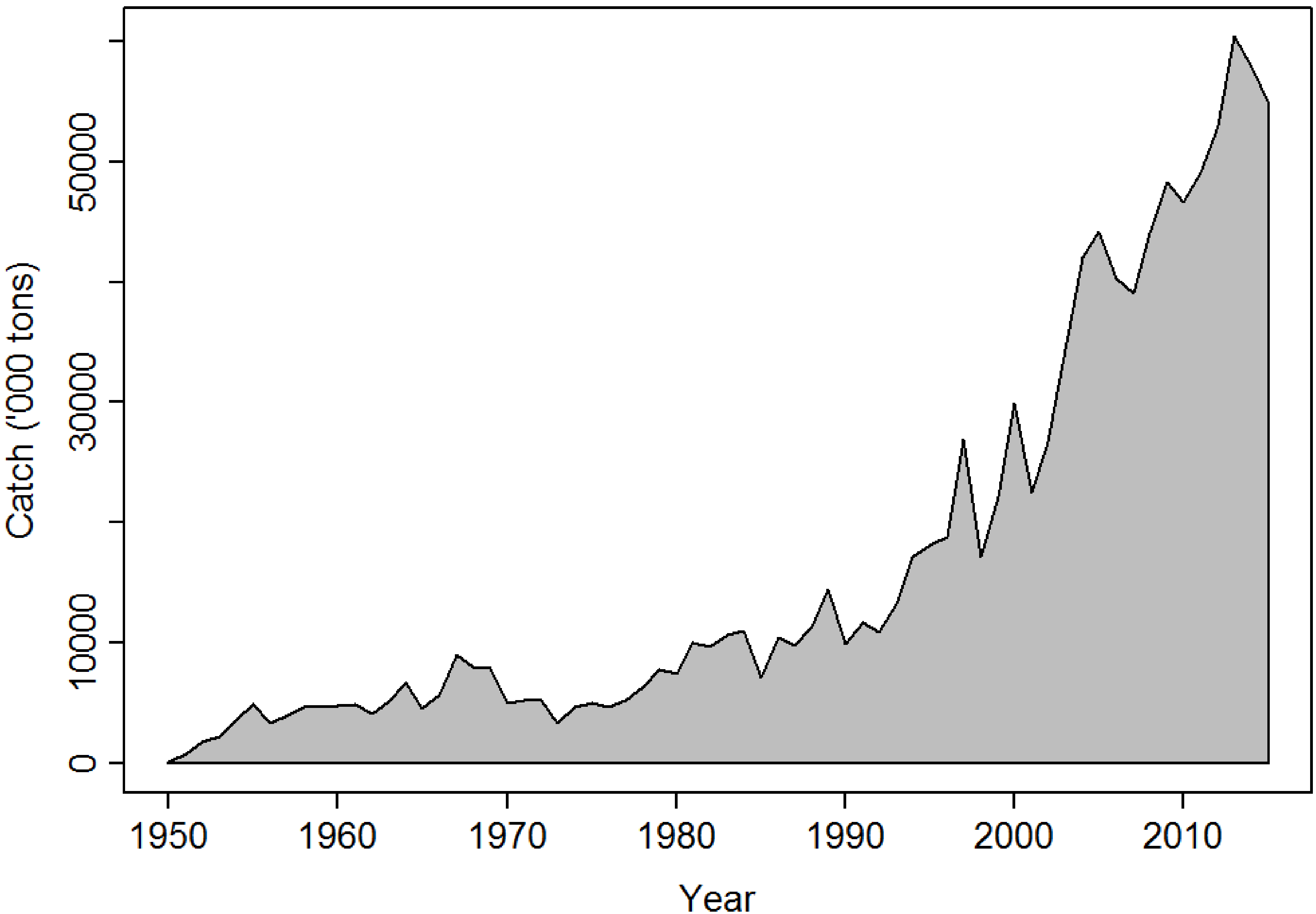
The observation equation is given by:

$$I_{f,y} = q_f B_{f,y} e^{\varepsilon_y} \qquad y = 1, 2, \ldots, n. \qquad (13)$$

where, q_f is the estimable catchability coefficient associated with the abundance index for fishery *f* and ε_y is the observation error, with

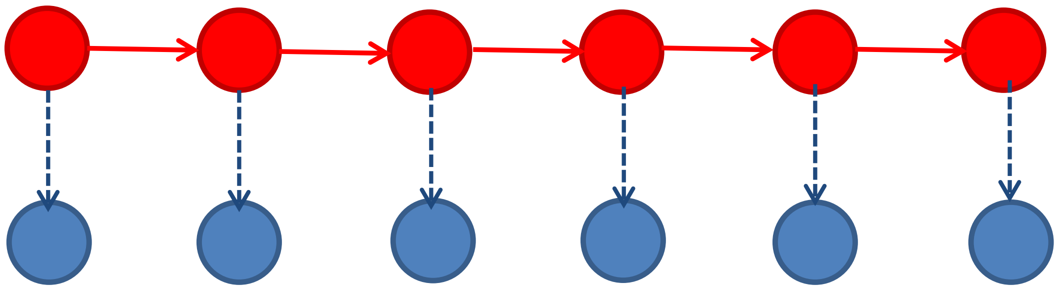
$$\sigma^2_{\varepsilon,y,f} = \hat{\sigma}^2_{SE,y,f} + \sigma^2_{Add,f} \qquad \varepsilon_{y,f} \sim N(0, \sigma^2_{\varepsilon,y,f}) \qquad (14)$$

Indian Ocean Blue shark (GAM)



Bayesian State-Space CPUE averaging tool

Unobservable (latent) states of the system: Abundance



Imperfect observations: CPUE

Process, State or Evolutionary equation

$$z_t = z_{t-1} \exp(r + \tau_t)$$

State variable

Underlying trend

Process error

$$\tau_t \sim N(0, \sigma_\tau^2)$$

Process variance

Observation equation

$$y_{y,i=1} = q_i z_i \exp(\varepsilon_{t,i})$$

Observation

Scaling coefficient

Observation error

$$\varepsilon_t \sim N(0, \sigma_\varepsilon^2)$$

Observation variance

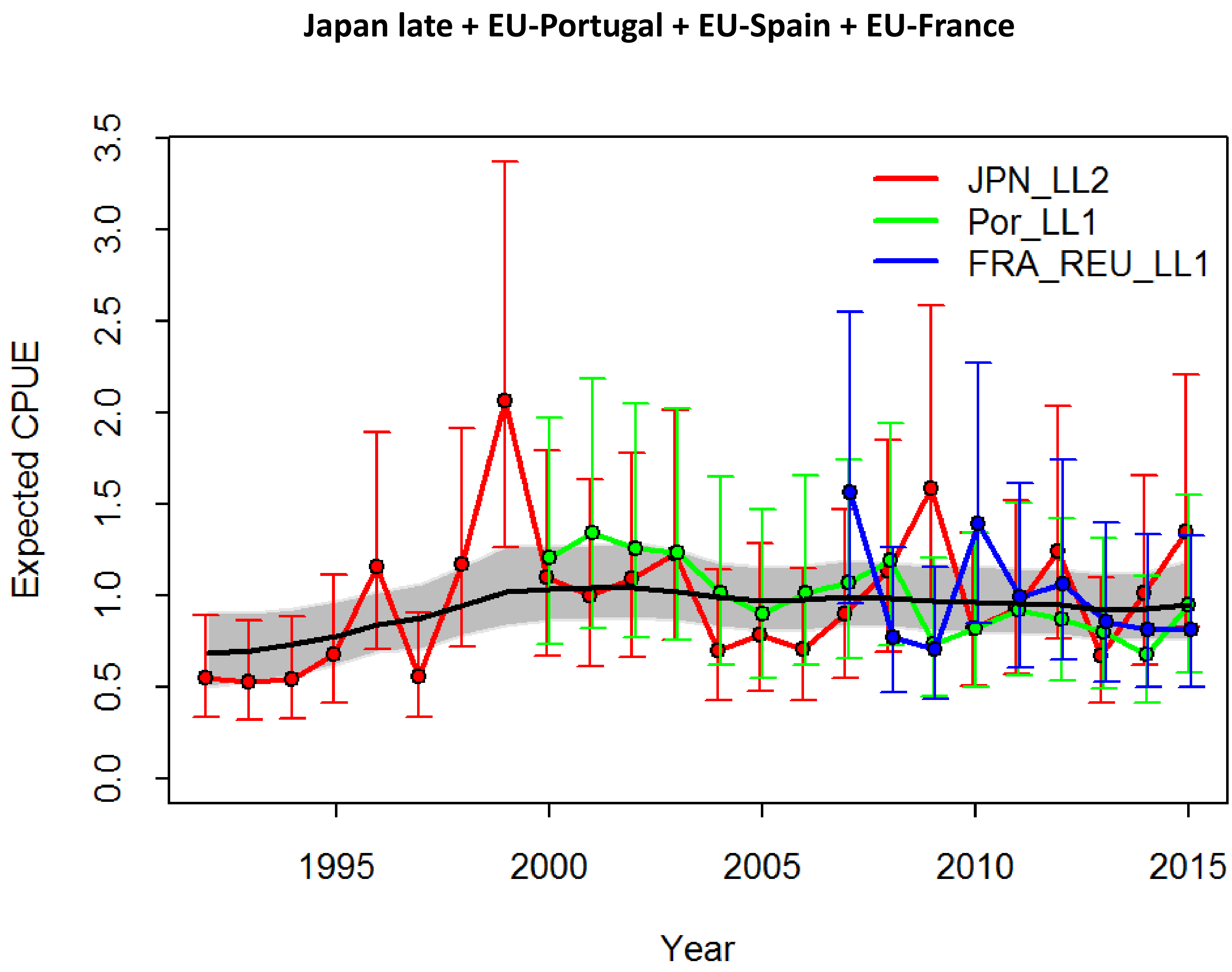
JABBA runs

Prior formulation: Summary

Parameter	Distribution	min/μ	max/CV
K	lognormal	600000	2
r	lognormal	0.267	0.07
$\varphi = B_{1950}/K$	lognormal	1	0.25
σ_{η}^{2}	inverse-gamma	4	0.01
$\sigma_{ADD,i}^{2}$	inverse-gamma	0.001	0.001
m	fixed	2	(Schaefer)
q	uniform	0.000000001	1

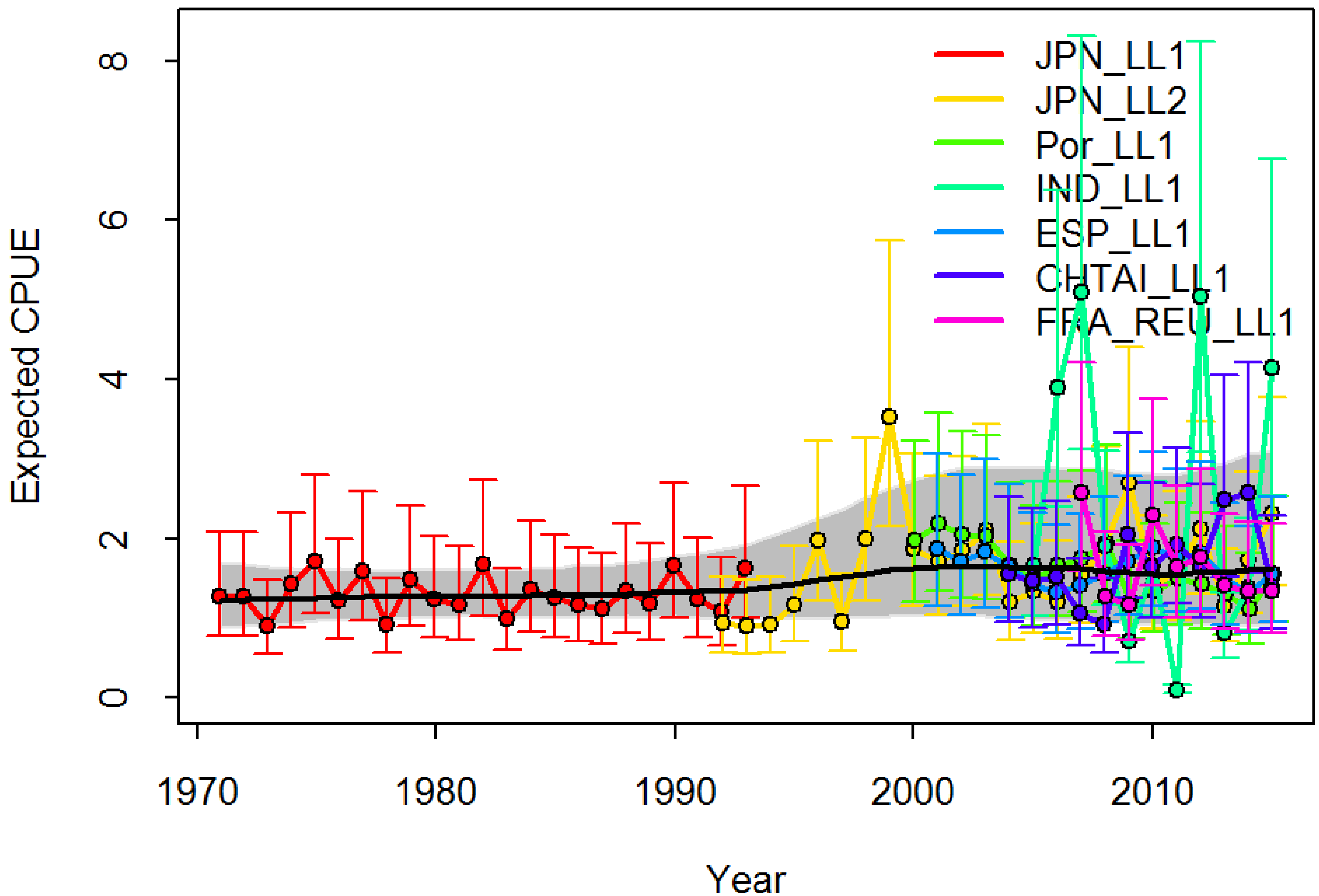
Minimum observation error CV was fixed at 0.25, so that: $\sigma_{\varepsilon,y,f}^{2} = 0.25_{Add,f}^{2} + \sigma_{Add,f}^{2}$

Base-case model



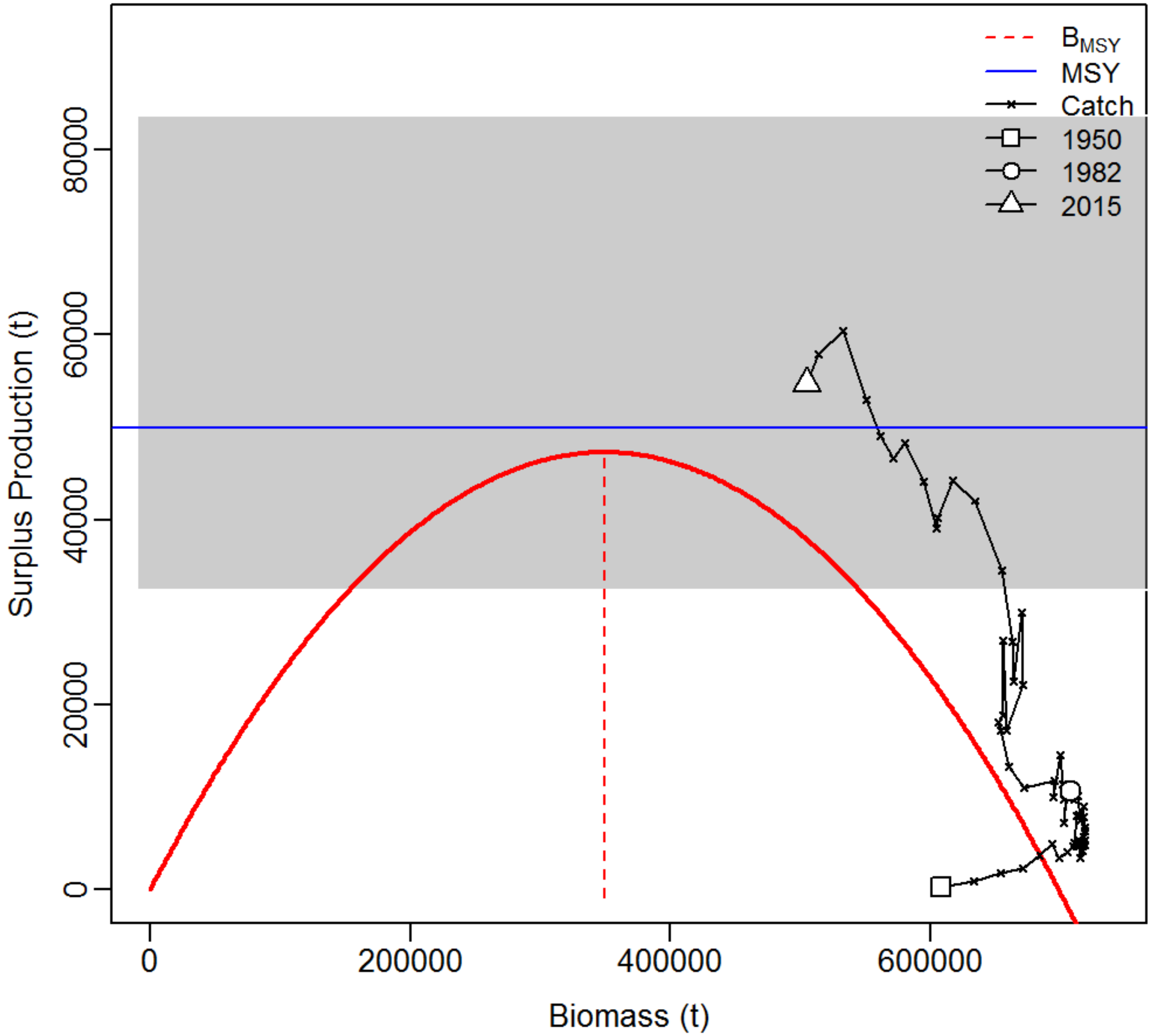
Alternative model

During the 2017 IOTC blue shark assessment, the formulation of alternative scenarios specifically focused on identifying and improving poor fits to CPUE series that may arise from fitting of multiple standardized CPUE time series with conflicting trends.



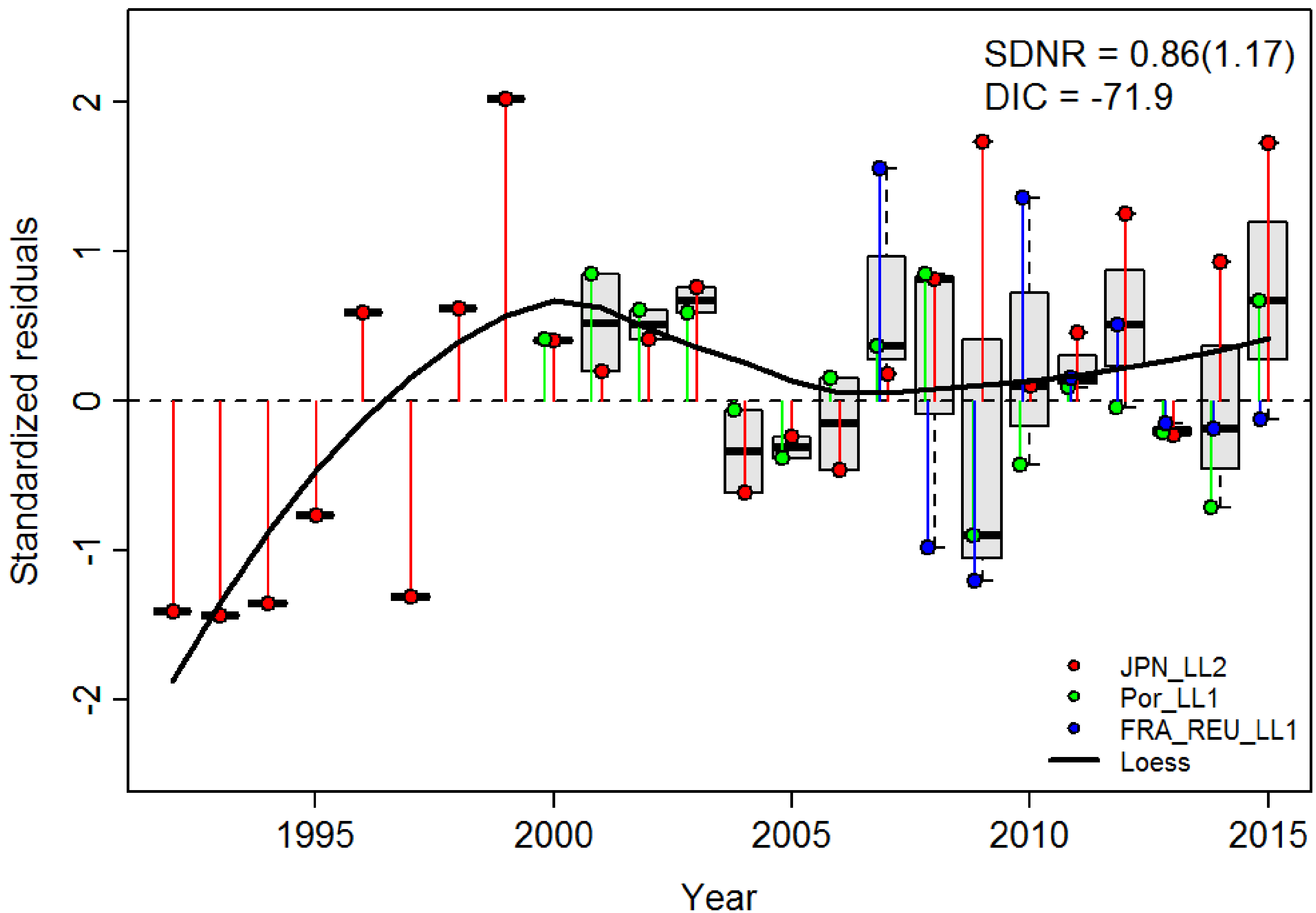
Schaefer Production Function

Base-case



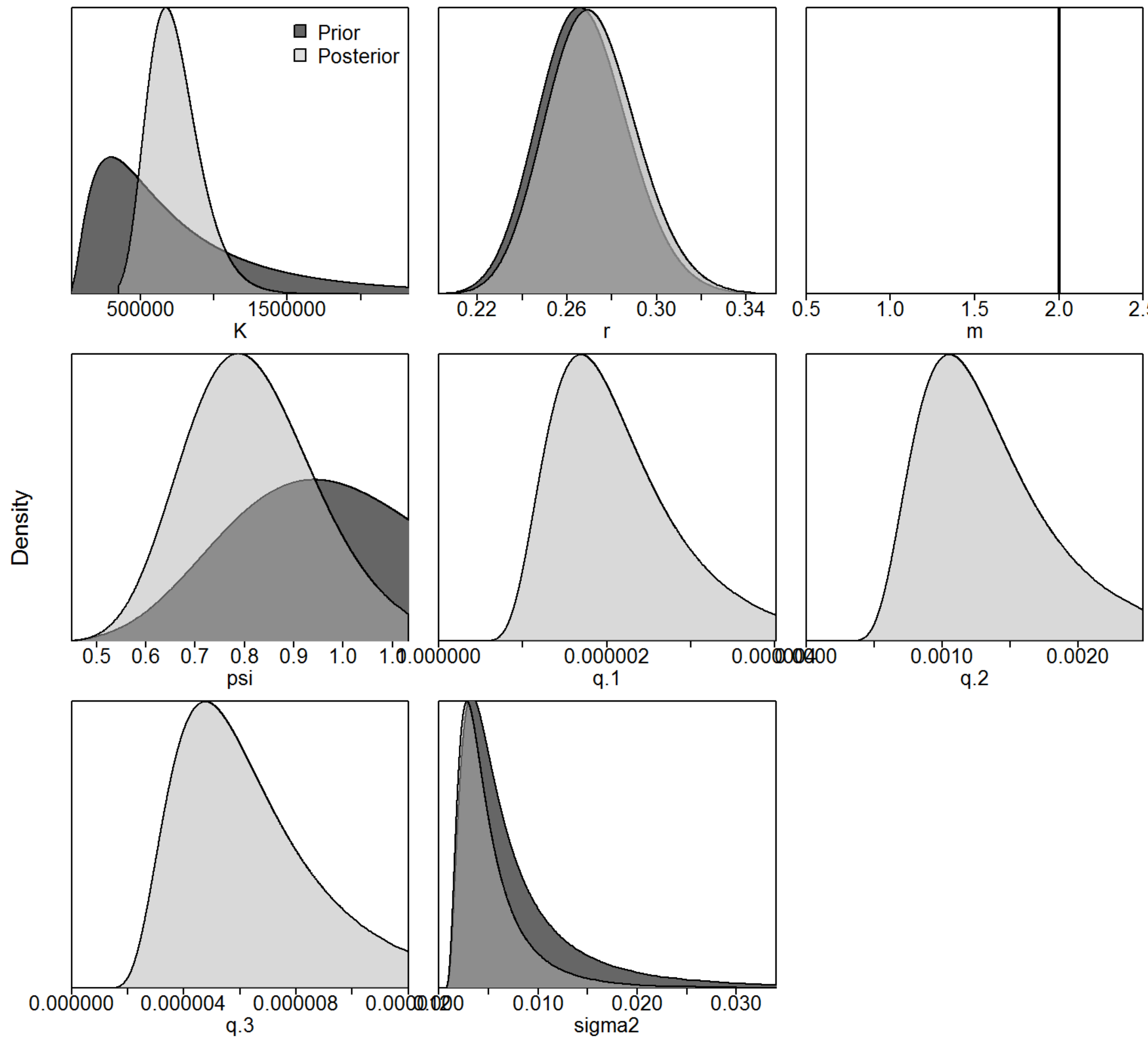
CPUE fits

Base-case



Prior vs. Posterior

Base-case

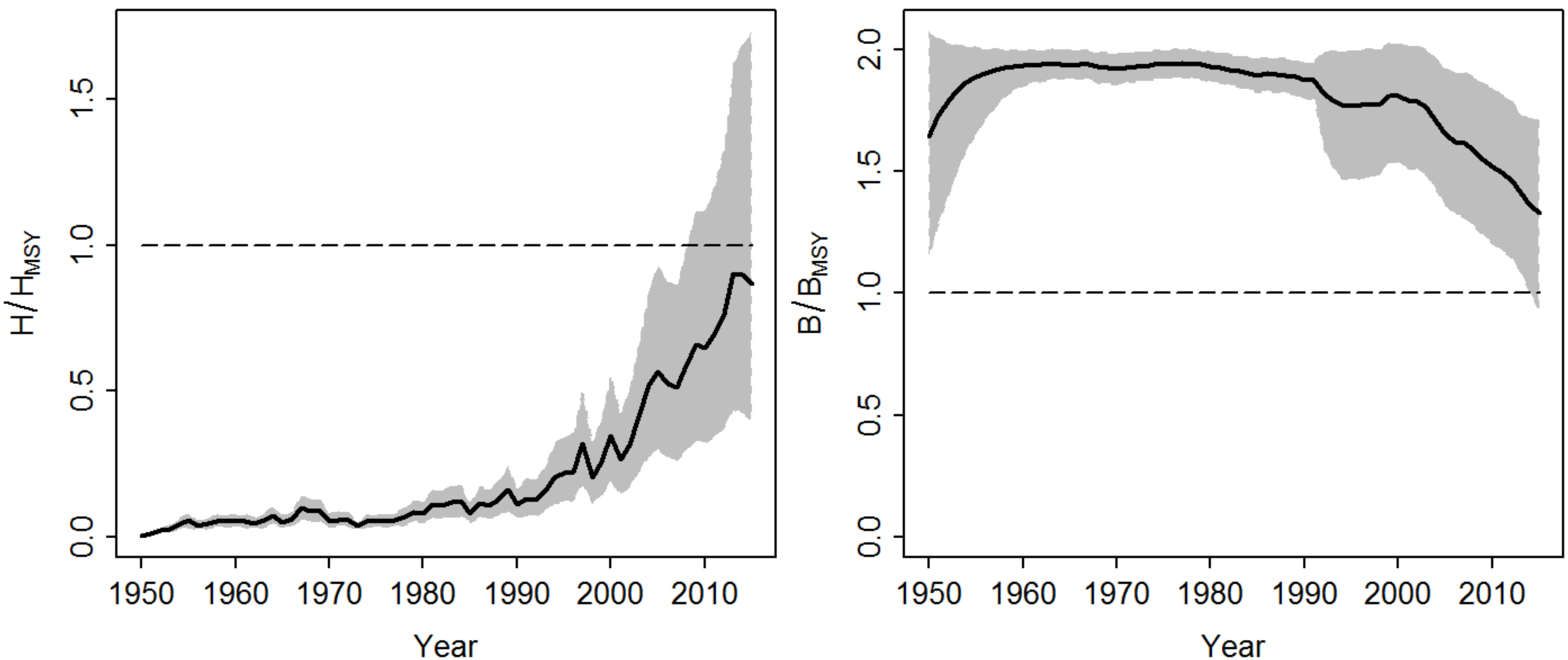


Model Estimates (Base-case)

	Median	2.50%	97.50%
K	698486	476589.9	1233646
r	0.271	0.235	0.313
ψ (psi)	0.824	0.57	1.042
σ	0.045	0.032	0.084
H_{msy}	0.135	0.117	0.156
SB_{msy}	349243	238295	616823
MSY	47355.78	32333.56	83741.82
P_{1950}	0.823	0.57	1.041
P_{2015}	0.666	0.46	0.861
B_{2015}/B_{msy}	1.333	0.92	1.722
H_{2015}/H_{msy}	0.869	0.396	1.738

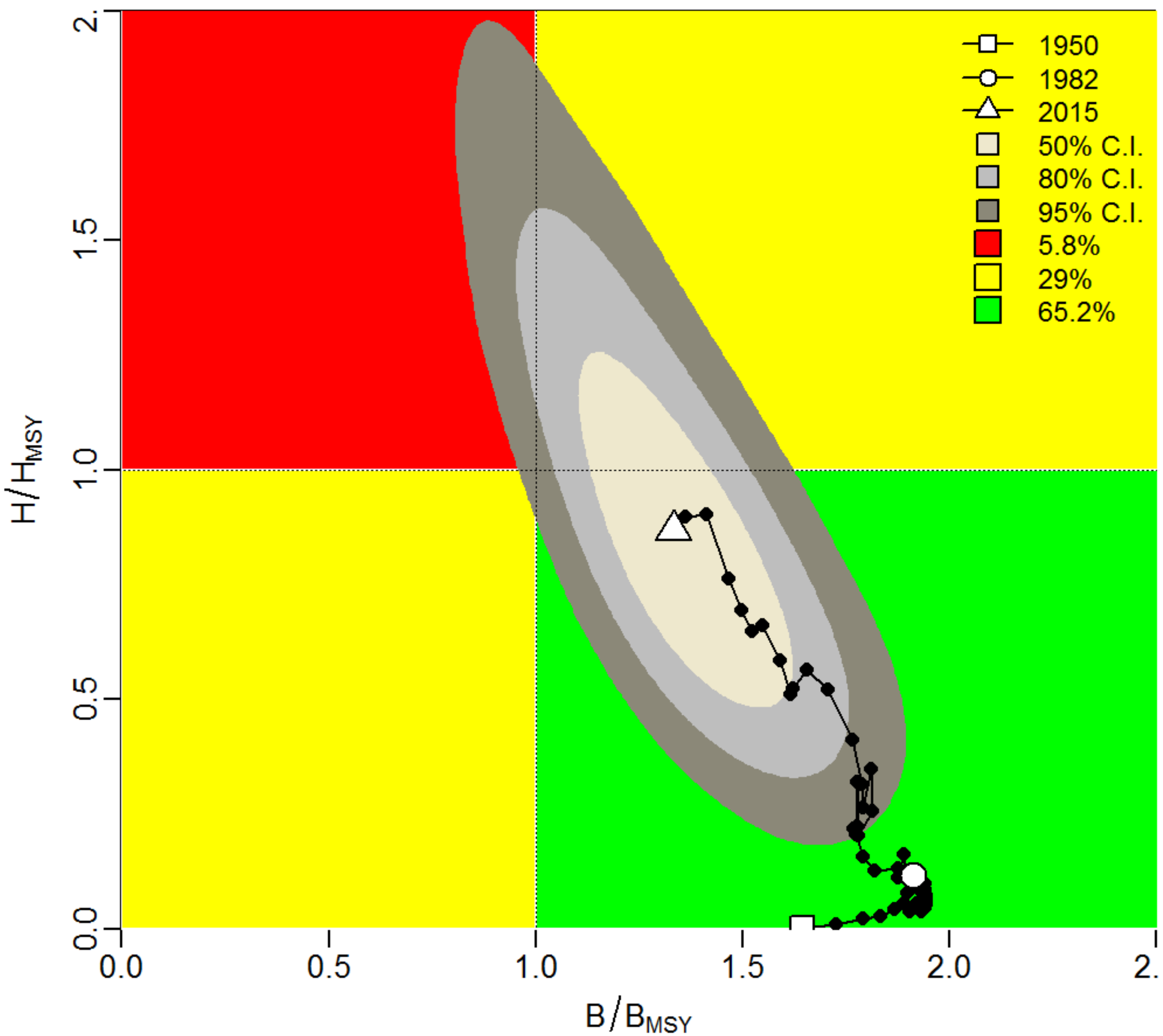
Time series of Reference Points

Base-case

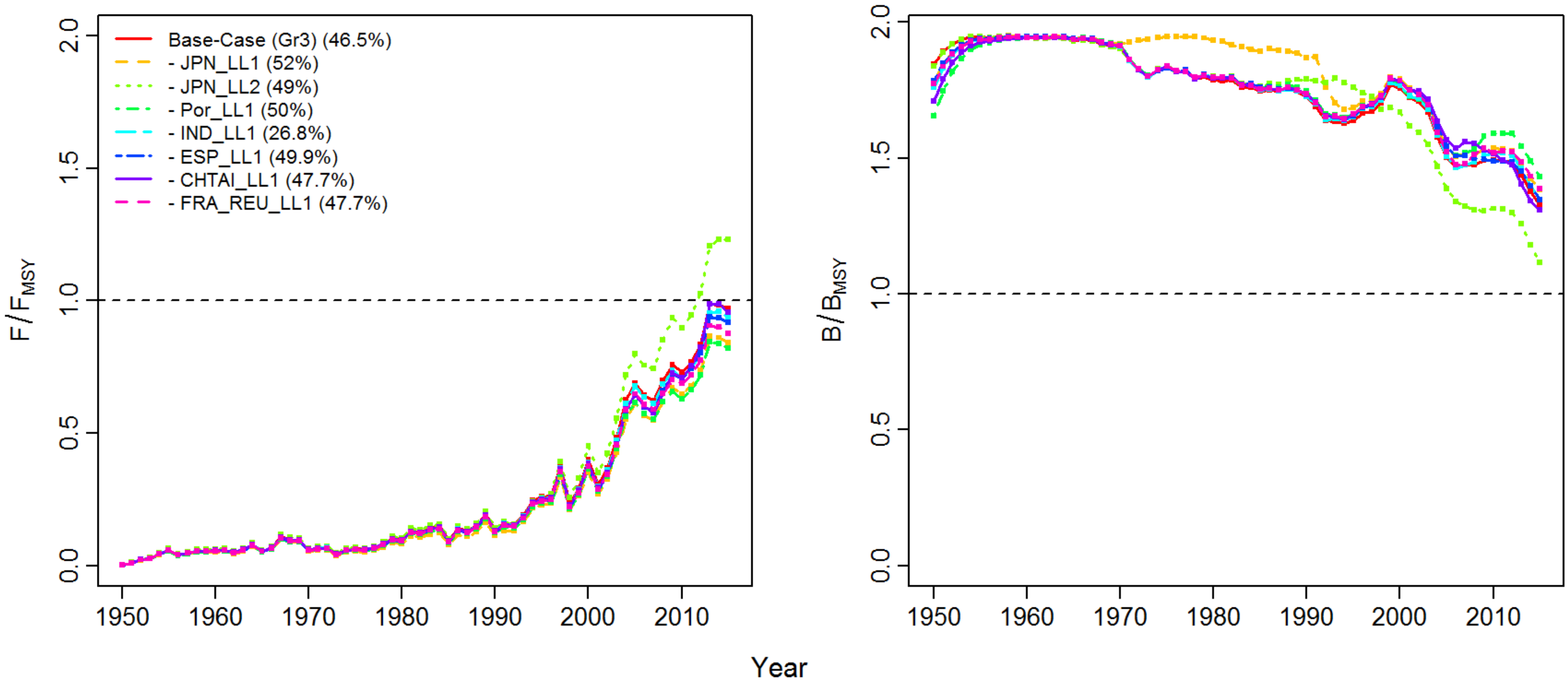


Kobe plot

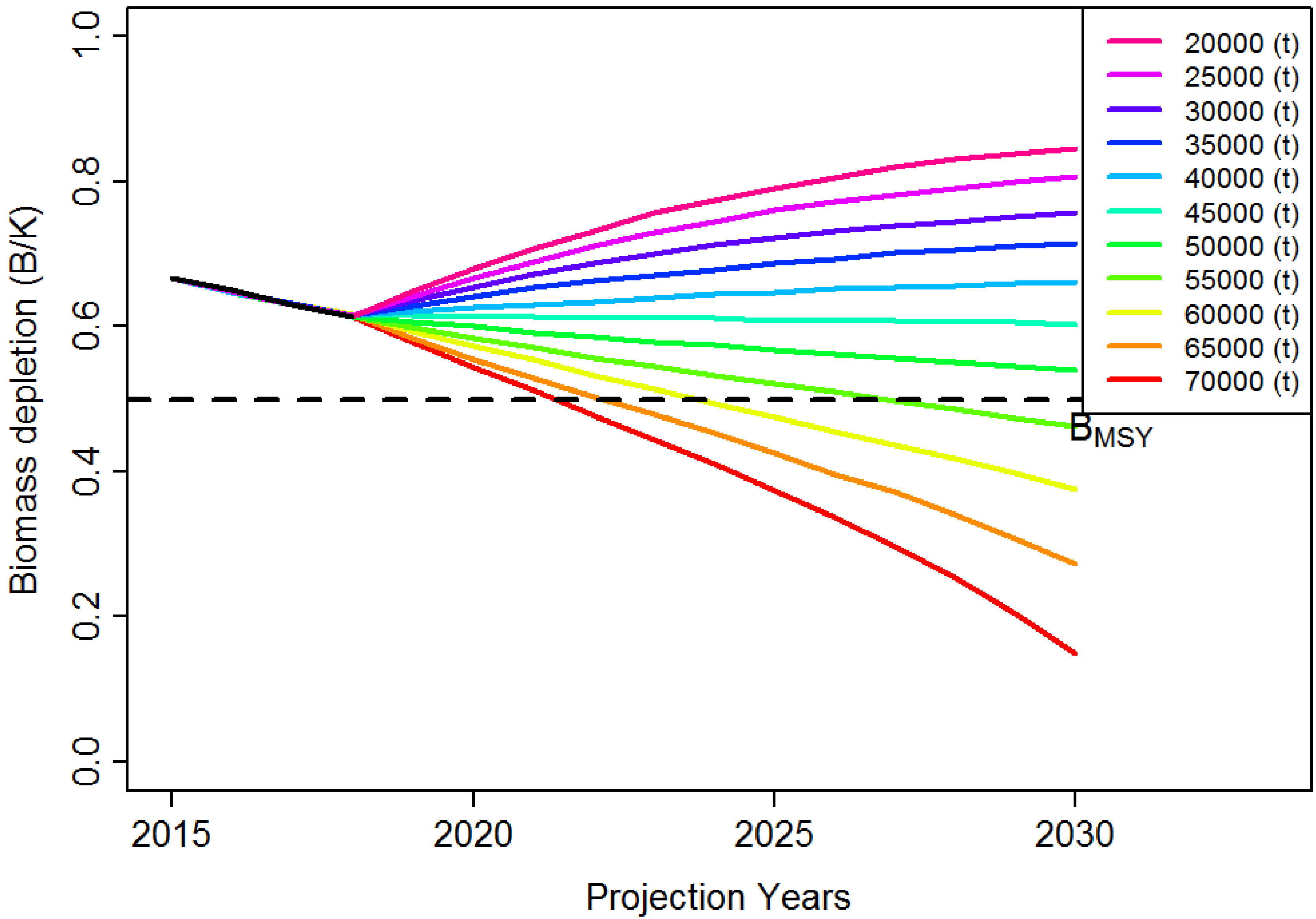
Base-case



Sensitivity runs (drop one from Base-case)



Projections (Base-case)



THANK YOU!