Stock assessment of orange roughy in the Walter's Shoal Region

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Acknowledgements

- Thanks to the Cook Islands delegation for the nomination to do this work and the SIOFA Secretariat for organizing the contract
- Thanks to Graham Patchell for his years of dedicated data collection and analysis that has made this assessment possible
- Thanks to NIWA for the use of their excellent stock assessment package CASAL

Presentation structure

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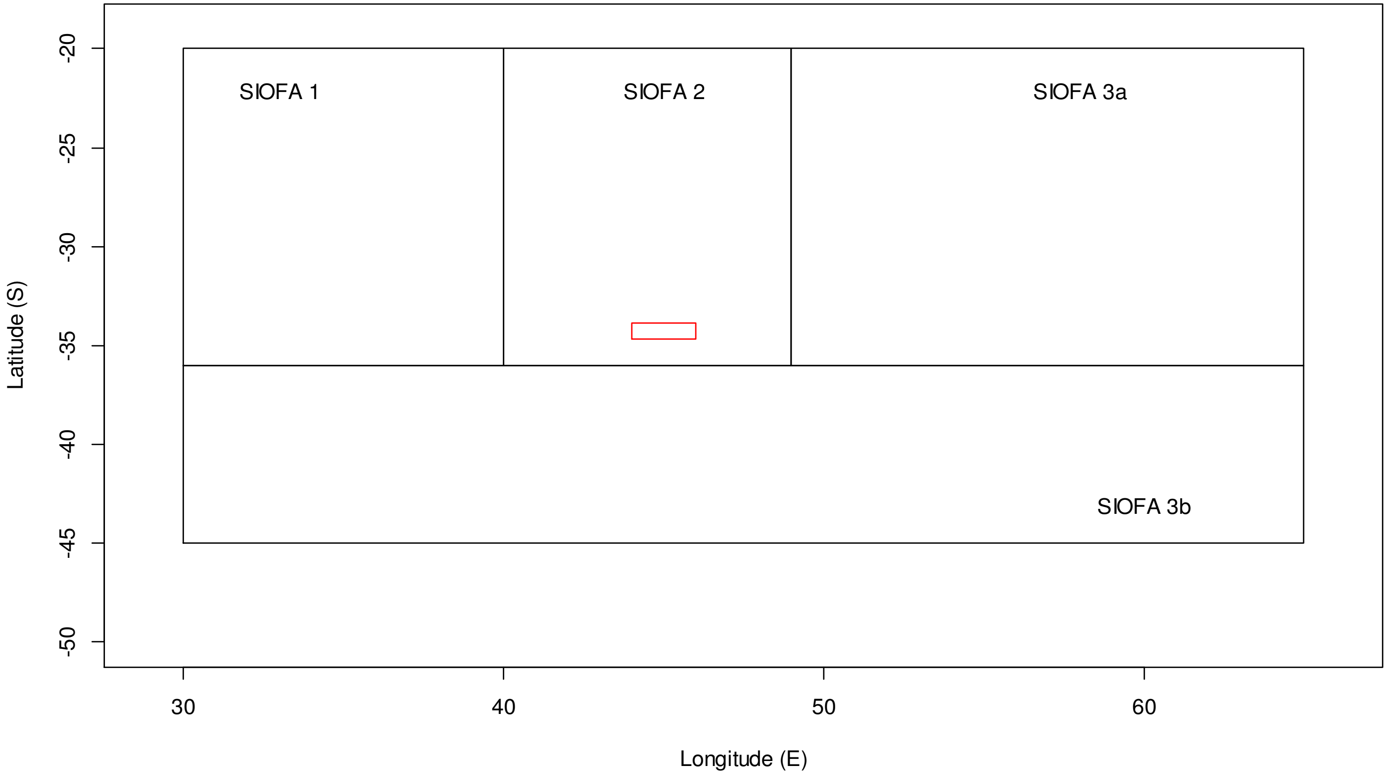
Introduction

- ISL contracted to perform a stock assessment for Walter's Shoal Region (WSR) orange roughy
- Specified area with well defined catch history from 2002 onwards
- Sexed length-weight data available from many features in the area from 2004 onwards
- Sexed age-length data collected in 2017 from Sleeping Beauty
- Acoustic biomass estimates of spawning aggregations available from several features:
  - Estimates recently reviewed and refined
  - Recent AOS target strength data also available

Methods: stock hypothesis



WSR contains 11 named features from which spawning orange roughy have been caught

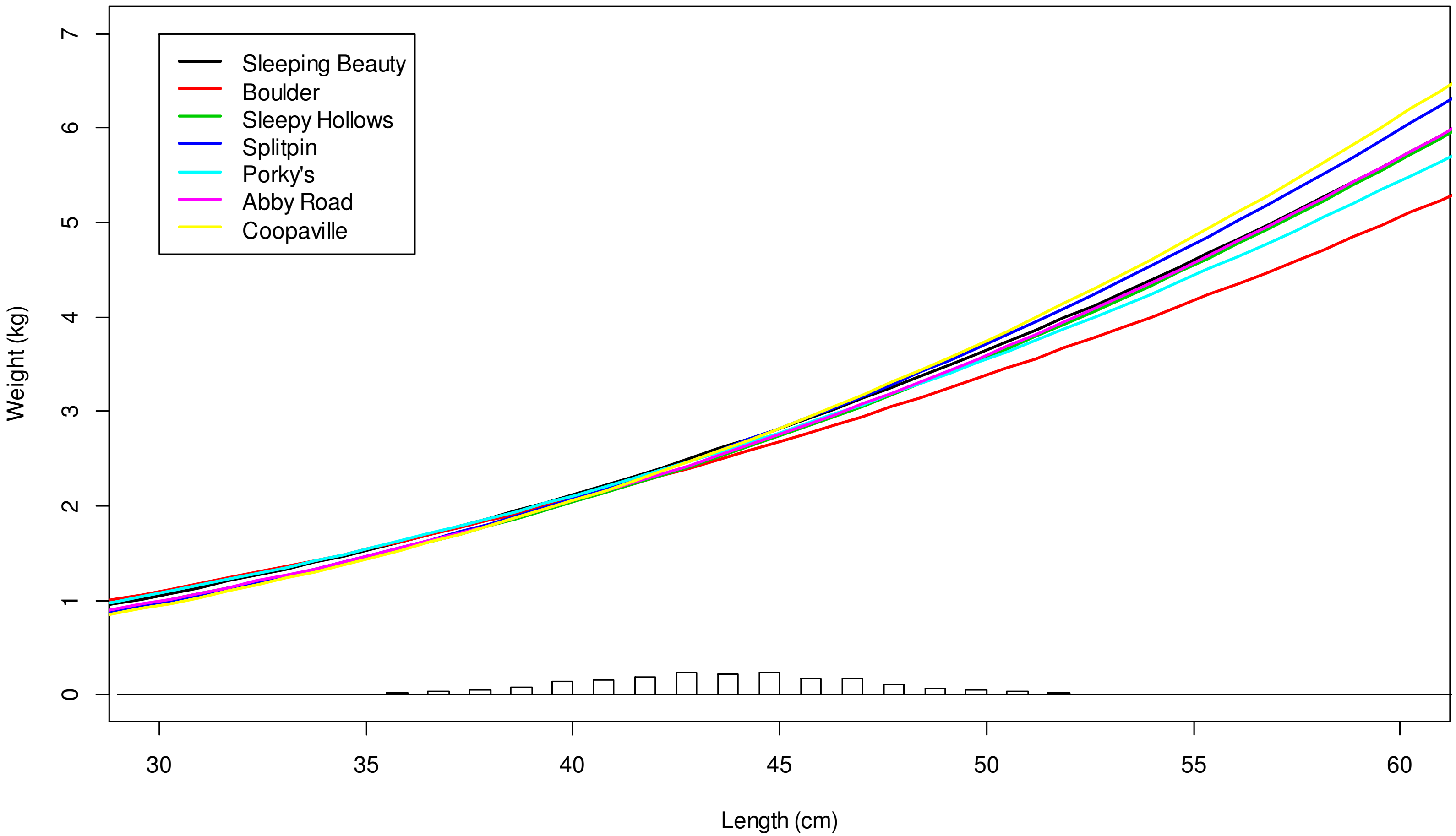
Data: biological parameters

- A single sex model is used which requires:
  - Growth parameters (von Bertalanffy is normally used)
  - Length-weight parameters
  - Natural mortality (M)
  - Stock-recruitment relationship (Beverton-Holt, h=0.75 unless some reliable information is available)
  - Maturation parameters (normally estimated within the model)

Biological parameters: length-weight

- Length-weight parameters estimated by log-log regression: $\ln(\text{weight}) = \ln(a) + b\ln(L)$
- Estimated separately for males and females then an average relationship calculated (assuming males and females 50/50 at length)
- A steeper relationship is obtained if unsexed data are fitted instead (males dominate at small lengths because data are from spawning plumes)
- Stock assessment results, for age-structured models, are not sensitive to the length-weight parameters

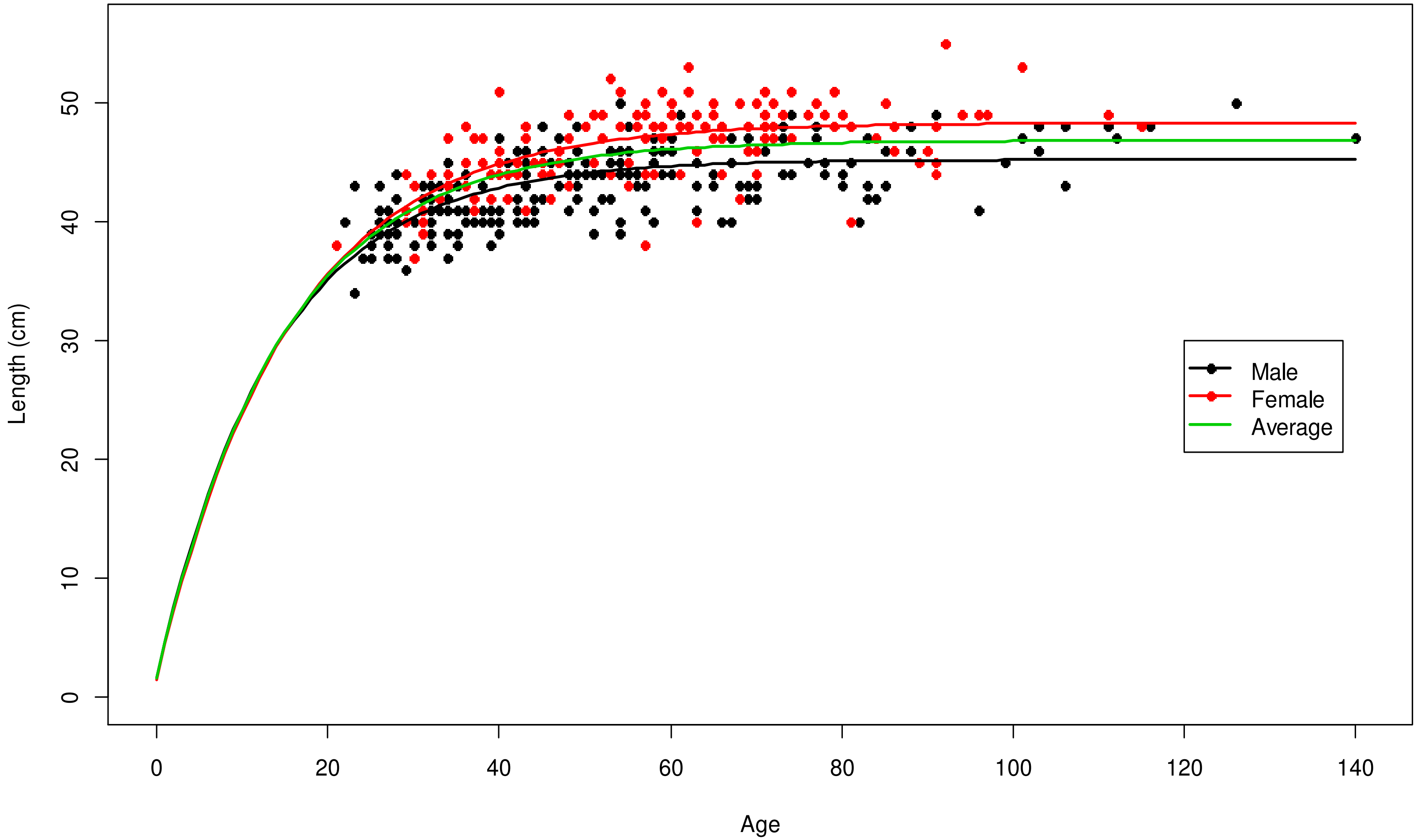
Biological parameters: length-weight (av.)



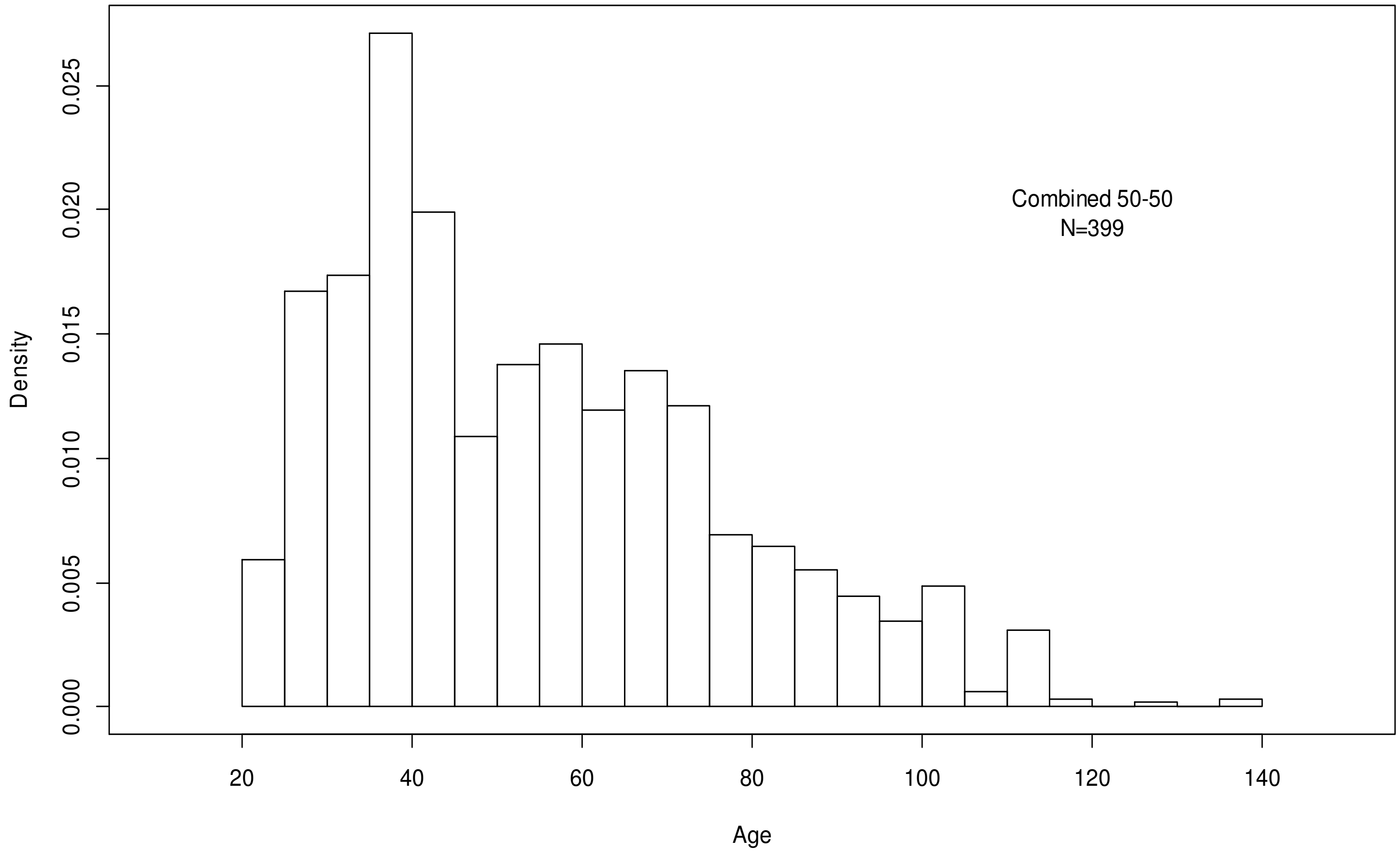
Biological parameters: growth

- Estimated von Bertalanffy k and L_{inf} by least squares with t_0 = -0.5 (borrowed from NZ orange roughy)
- Estimated separately for males and females then an average relationship calculated (assuming males and females 50/50 at age)
- Stock assessment results, for age-structured models, are not sensitive to the growth parameters (unless length frequencies are being fitted)

Biological parameters: growth



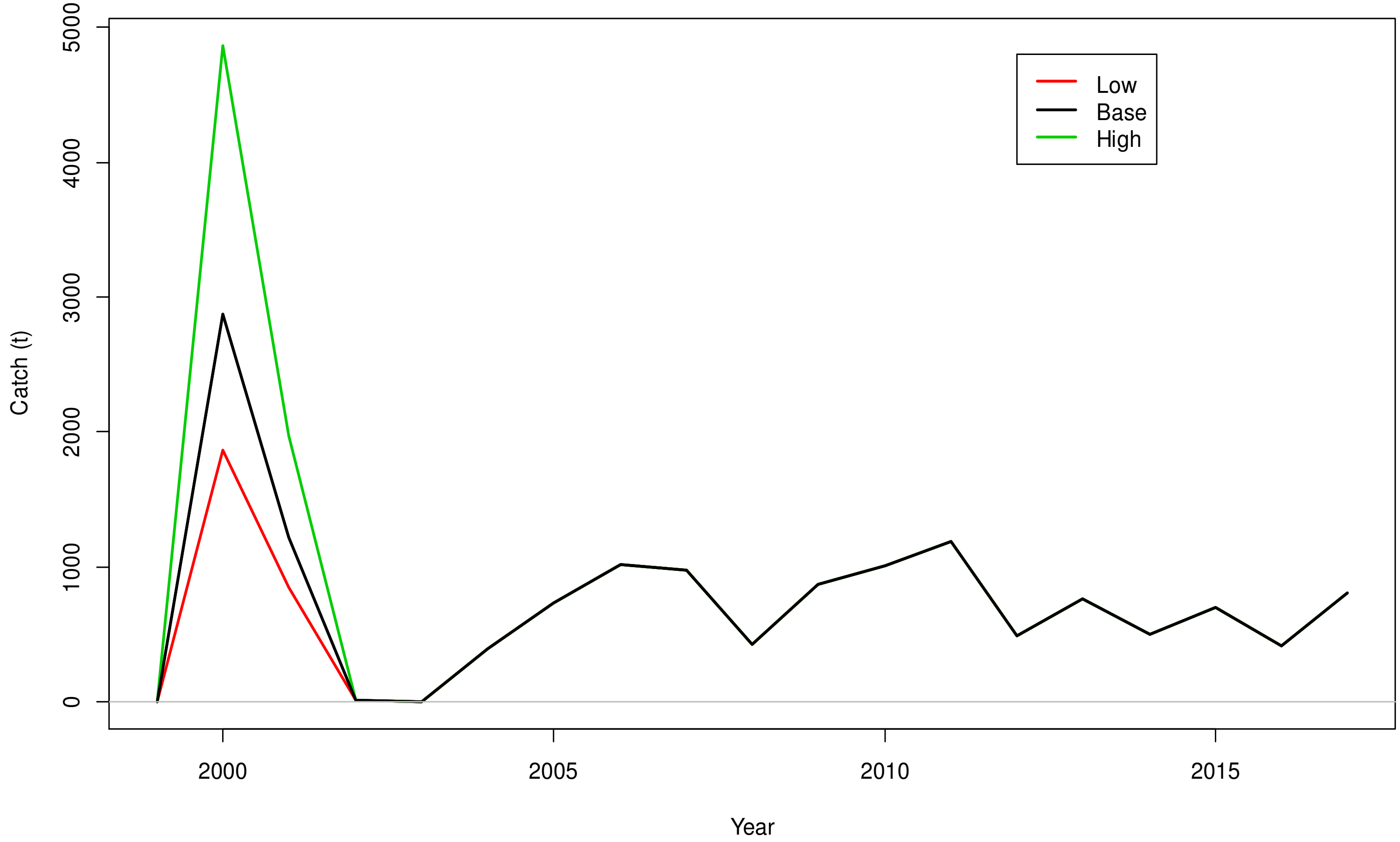
Data: age frequency



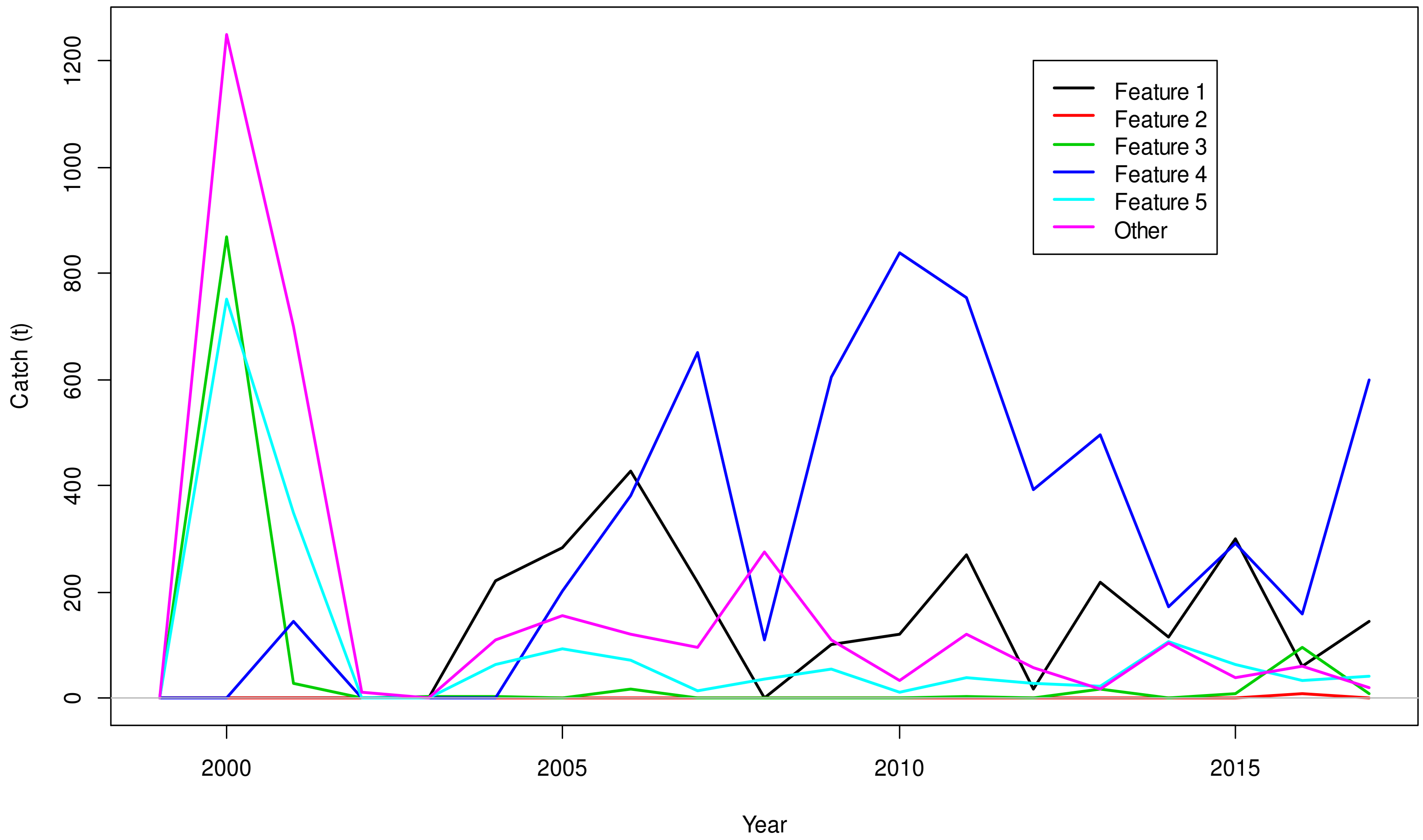
Data: catch history

- Catch history well defined from 2002 onwards with a requirement to report catches
- In 2000 and 2001 there were a lot of vessels fishing in SIOFA areas and some catch was from the WSR
- Reported catches from NZ, Australia, and Japan combined with Sealord information (Graham Patchell)
- In 2000 a guesstimate of 2000 t was added to reported catches
- In 2001 a guesstimate of 750 t was added to reported catches
- Sensitivity runs done at half and double the guesstimates

Data: total catch history



Catch history by individual feature and "Other"



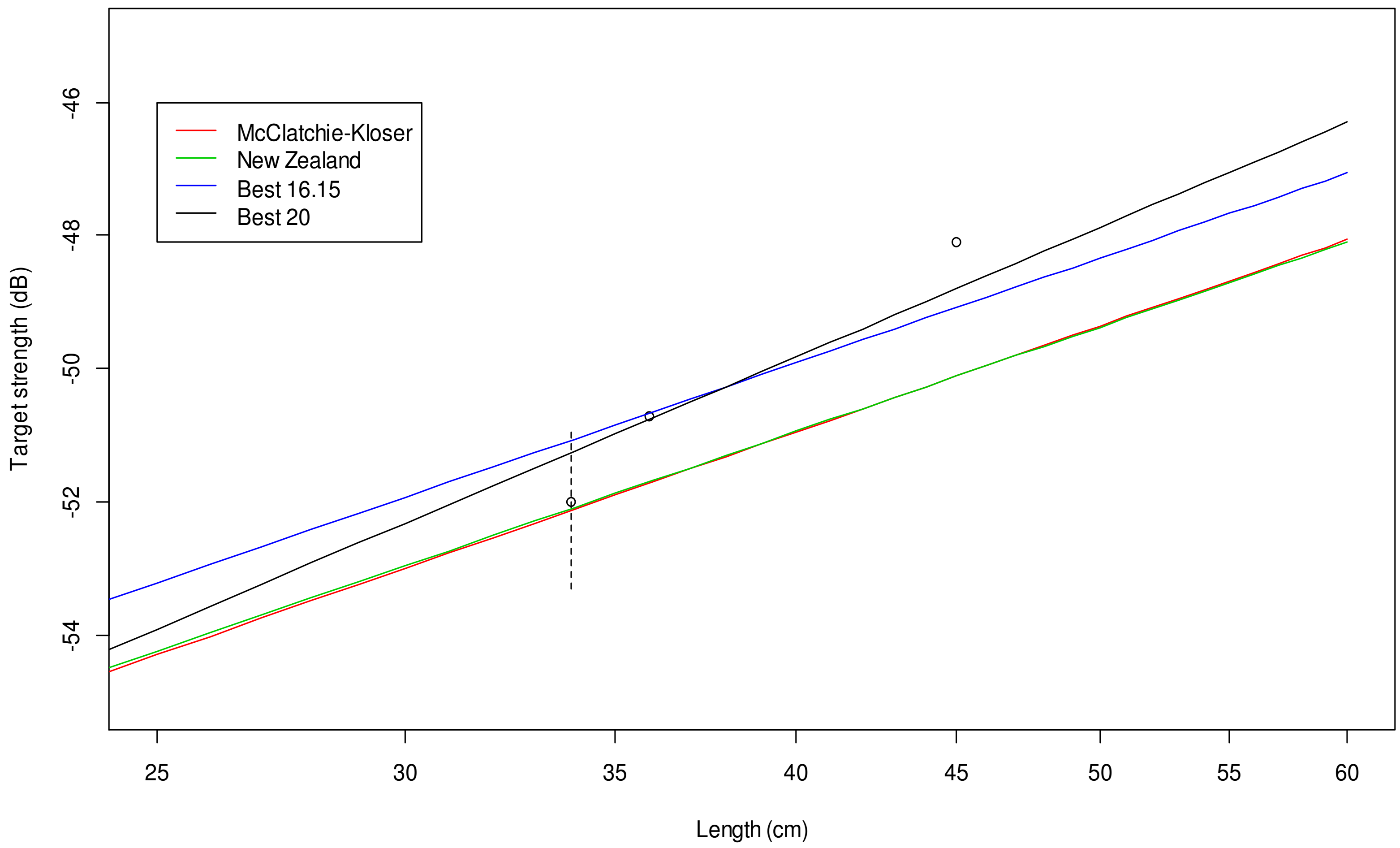
Data: acoustic estimates (1)

- Eight acoustic survey biomass estimates available that have been reviewed and refined
- From five different features in years from 2007 to 2015 at peak spawning
- A much larger set of acoustic estimates also available (but not reviewed and refined) – used in a sensitivity run
- Potential biases from three factors: target strength, absorption coefficient; analysis method (double counting and species mix not an issue for the reviewed surveys)

Data: acoustic estimates (2)

- Three different treatments of the acoustic estimates:
  - Low: uses the option for each factor that reduces the biomass estimates the most (observed TS estimate; Doonan absorption; geostatistical analysis): 63% of the original biomass estimates
  - Base/Middle: two adjustments that cancel out so that original estimates are used (lower TS but design based analysis instead of geostatistical)
  - High: uses the option for each factor that increases the biomass estimates the most (ignore new TS data; design based analysis; Francois and Garrison absorption): 165% of the original biomass estimates

Orange roughy target strength



Revised acoustic biomass estimates

Feature	Year	Low estimate (t)	Middle estimate (t)	High estimate (t)	CV (%)
1	2007	1829	**2902**	4790	11
	2015	2386	**3788**	6250	32
2	2015	1993	**3164**	5221	12
3	2015	2381	**3779**	6235	20
4	2007	4991	**7923**	13 073	10
	2009	6689	**10 618**	17 520	30
5	2009	1138	**1806**	2980	21
	2011	1094	**1737**	2866	43

Model structure (1)

- Single-sex, with fish categorised by age (1-120^{+}) and maturity (immature or mature)
- Seven areas: Home, Other, and the five numbered features
- Home only has immature fish, they migrate as soon as they mature (different constant migration proportions to the other areas)
- Fishing is at the end of year on Other and the numbered features (only mature fish, equally vulnerable by age)

Model structure (2)

- Model is initialised at virgin spawning biomass (B_0) with equilibrium age structure and constant recruitment (R_0)
- Natural mortality (M) constant across ages
- Model starts in 1885 so that lots of Year Class Strengths (YCS) can be estimated (the cohort strengths: multipliers of the recruitment off the stock-recruitment curve)

Model structure (3)

- Free parameters in the model (those estimated):
  - B_0: virgin spawning biomass
  - YCS (1987-1992): the cohort strengths
  - M: natural mortality (with an informed prior)
  - Maturation: two parameters of a logistic curve (a_{50} = age at 50% maturity, a_{to95} = number of years after 50% maturity that 95% maturity occurs for the population)
  - Five migration parameters (informed prior for proportion migrating to Other)
  - The acoustic q: the proportionality constant for the acoustic estimates: $E(X) = qB$

Estimation approach (1)

- Bayesian estimation:
  - Philosophy:
    - Treat the estimated parameters as random variables and use conditional probability to update the probability distributions (using Bayes' theorem)
    - Include ancillary information in *prior* distributions for the free parameters (describing the initial belief about the parameters)
    - The *joint posterior* distribution of the free parameters updates the prior distributions given the data that were observed (the updated belief about each parameter being found in its *marginal* posterior distribution)
    - Can also construct marginal posterior distributions for derived parameters (e.g., current stock status)

Estimation approach (2)

- Bayesian estimation:
  - Two steps:
    - Find the Mode of the joint Posterior Distribution (MPD) – just a minimization exercise (finds the point that maximizes the objective function: likelihoods + prior + penalty functions)
    - Obtain samples from the joint posterior distribution – requires Markov chain Monte Carlo (MCMC) – can take days to get enough samples so that the estimates (medians and 95% CIs) are precise enough.

Informed priors (1)

- We have information about the acoustic q:
  - If all fish were pluming at the same time and TS was correct then q=1
  - However, not all fish would have been surveyed and the TS is unlikely to be correct
  - The prior on the acoustic q accounts for potential *bias* in the estimates
  - Prior developed for NZ assessments: LN(mean=0.8, CV=19%)
  - Prior used here: LN(mean=0.8, CV=25%)
  - Note, the largest potential biases in the assessment are captured by having three different treatments of the acoustic estimates.

Informed priors (2)

- We have information on M from New Zealand orange roughy:
  - Two estimates from lightly fished stocks
  - Consistent with N(mean=0.045, CV=15%)
  - Used in NZ orange roughy stock assessments when M is estimated (which it normally is not, instead M=0.045 is assumed)
  - Only one AF to help with estimation but M was estimated so that some uncertainty with regard to M was captured.

Informed priors (3)

- An informed prior was used for the migration proportion to Other:
  - Five numbered features with “average” acoustic biomass estimate totaling 21 330 t
  - Six un-numbered (spawning) features with average acoustic biomass estimate (probably under-estimates) per feature of 753 t
  - A rough estimate of the proportion covered by the six un-numbered features is 6 × 753 / (6 × 753 + 21330) = 17%.
  - Used N(mean=20%, CV=10%) for migration proportion to Other for the base model (10% for Low and 30% for High)

Informed priors (4)

- In initial model runs the maturity parameters were getting a bit big (too large to be credible in the right hand tails of the posteriors)
- Informed prior used for a_{50} (in particular) based on New Zealand orange roughy estimates: N(mean=37 years, CV=25%)
- Weakly informed prior on a_{to95}: N(12 years, CV=90%) (truncated, range: 2.5-50 years)
- Sensitivity model with uniform priors

Model runs in addition to Base/Middle

- **Low**:
  - The low treatment of the acoustic biomass estimates with only 10% of mature fish instead of 20% assumed to migrate to Other.
- **High**:
  - The high treatment of the acoustic biomass estimates with 30% of mature fish assumed to migrate to Other.
- **Uniform**:
  - A uniform prior on both maturation parameters.
- **AF80**:
  - Double the effective sample size on the age frequency (80 instead of 40).
- **Low catch**:
  - The amount of catch added on to reported catch for 2000 and 2001 is half that assumed in the base model.
- **High catch**:
  - The amount of catch added on to reported catch for 2000 and 2001 is double that assumed in the base model.
- **Low, low *M***:
  - The low treatment of the acoustic data, 10% to Other, and a fixed $M = 0.036$ (20% less than the mean of the prior in the base model).
- **More acoustics**:
  - This uses a more extensive set of acoustic biomass estimates (that have not been revised/refined).

Methods: projections

- 5 year stochastic projections
- New YCS sampled at random from all estimated YCS
- For Base model and Low model:
  - Constant catch equal to current catches (with current distribution across features)
- For Base model:
  - Constant exploitation rate equal to maximum allowed under the NZ HCR (5.625%)
  - Not practical, but gives an idea of the maximum catches that could be taken from the stock in the short term under the HCR

Deterministic B_{MSY}: Beverton Holt

Maturity: a_{50}= 37 years, a_{to95}= 12 years

		Steepness (h)		
M	0.65	**0.75**	0.90	0.95
0.036	28	23	16	11
0.045	28	**24**	15	11
0.054	28	23	15	11

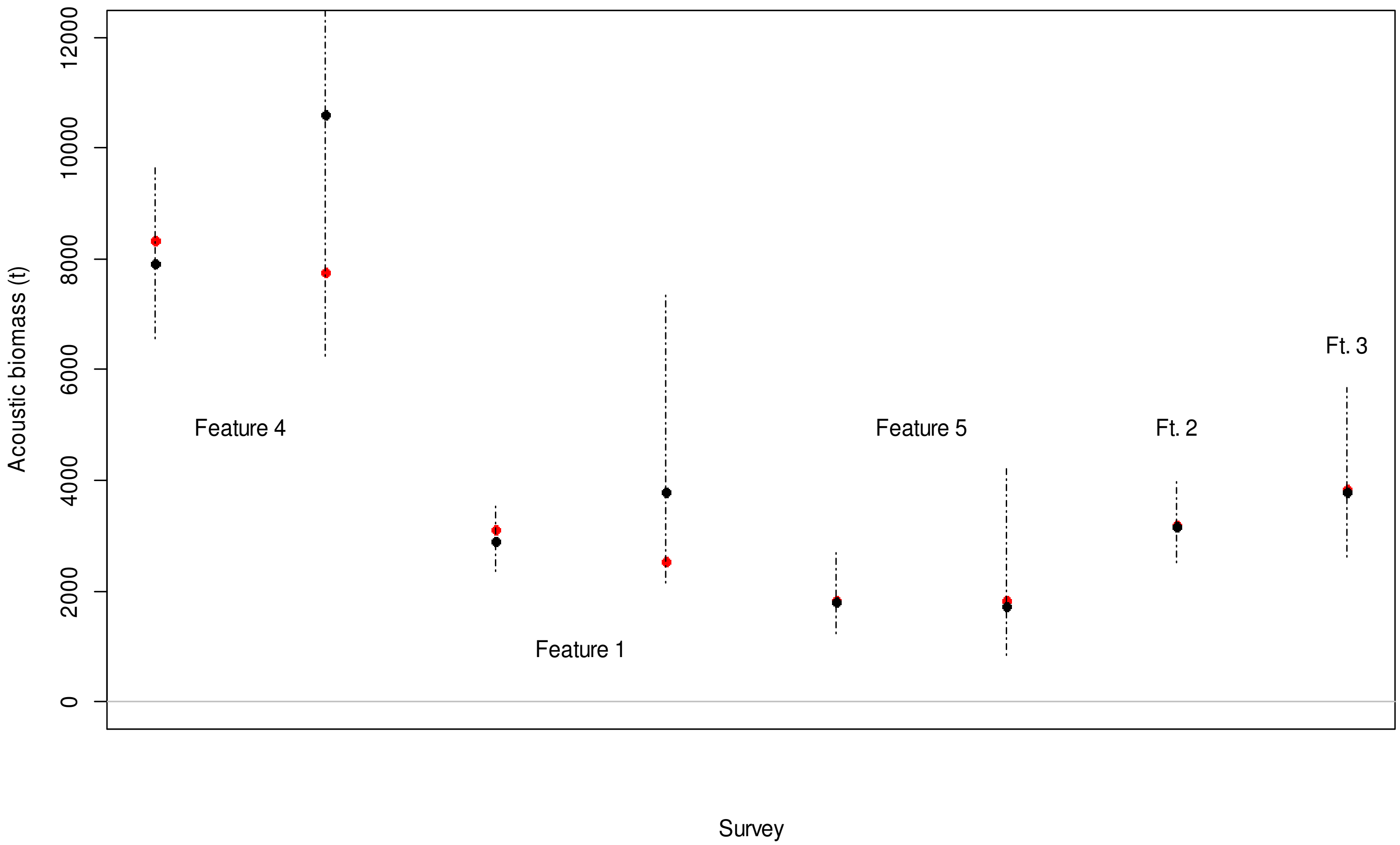
Sensitivity to maturity (M = 0.045, h = 0.75)

Maturity (a_{50}, a_{to95})	B_{MSY} (%B_0)	MSY (%B_0)	U_{MSY}
30 years, 10 years	23.9	2.14	0.086
37 years, 12 years	23.6	2.25	0.091
45 years, 20 years	23.3	2.27	0.093

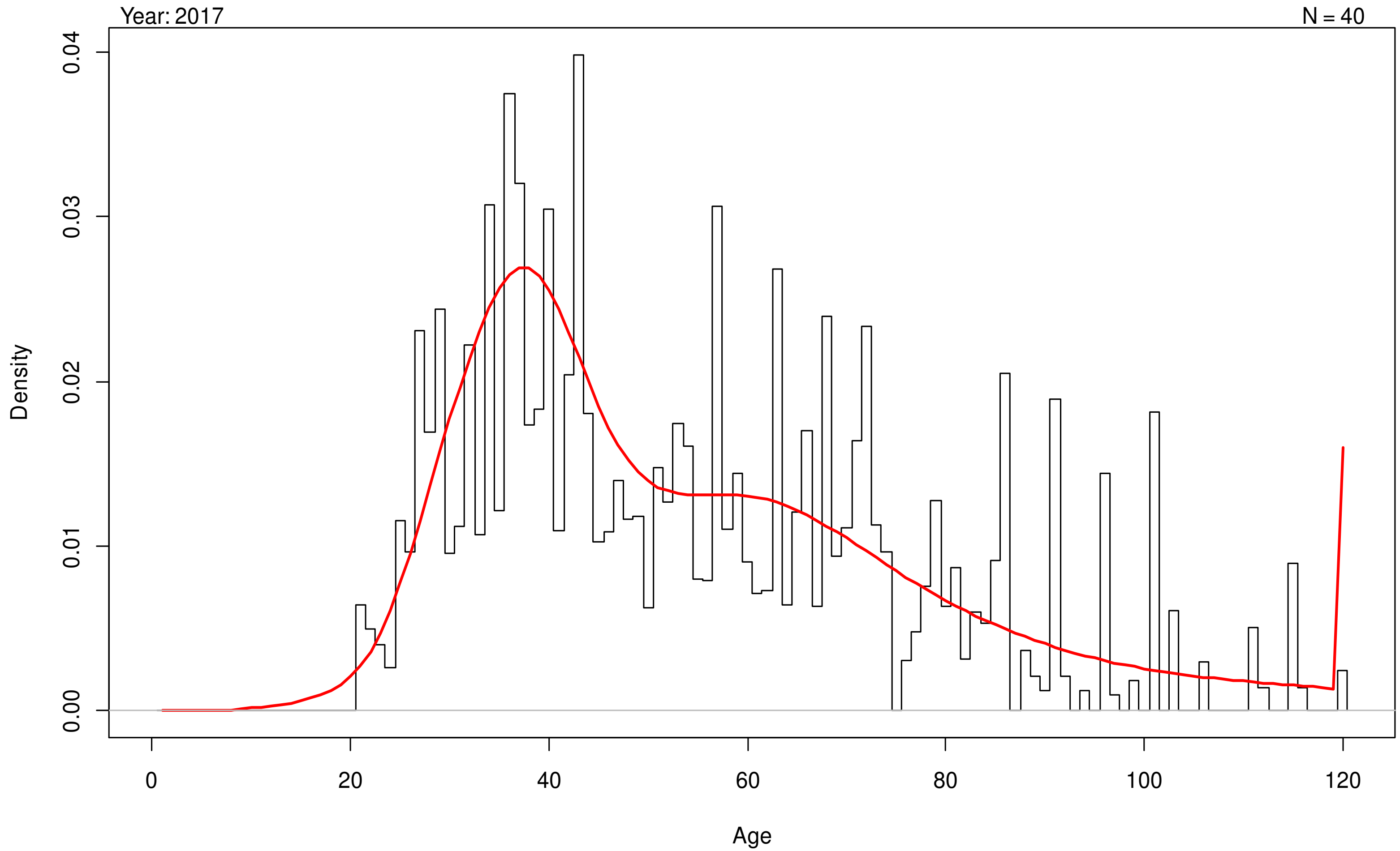
Results: MPD fits

- Useful to look at the best fits because if they are very poor then there is something wrong with the model:
  - Might suggest a structural problem
  - Perhaps an inappropriate statistical distribution
  - Perhaps a prior which is inconsistent with the data
  - Might indicate a problem with data weighting

Results: MPD fit to biomass indices



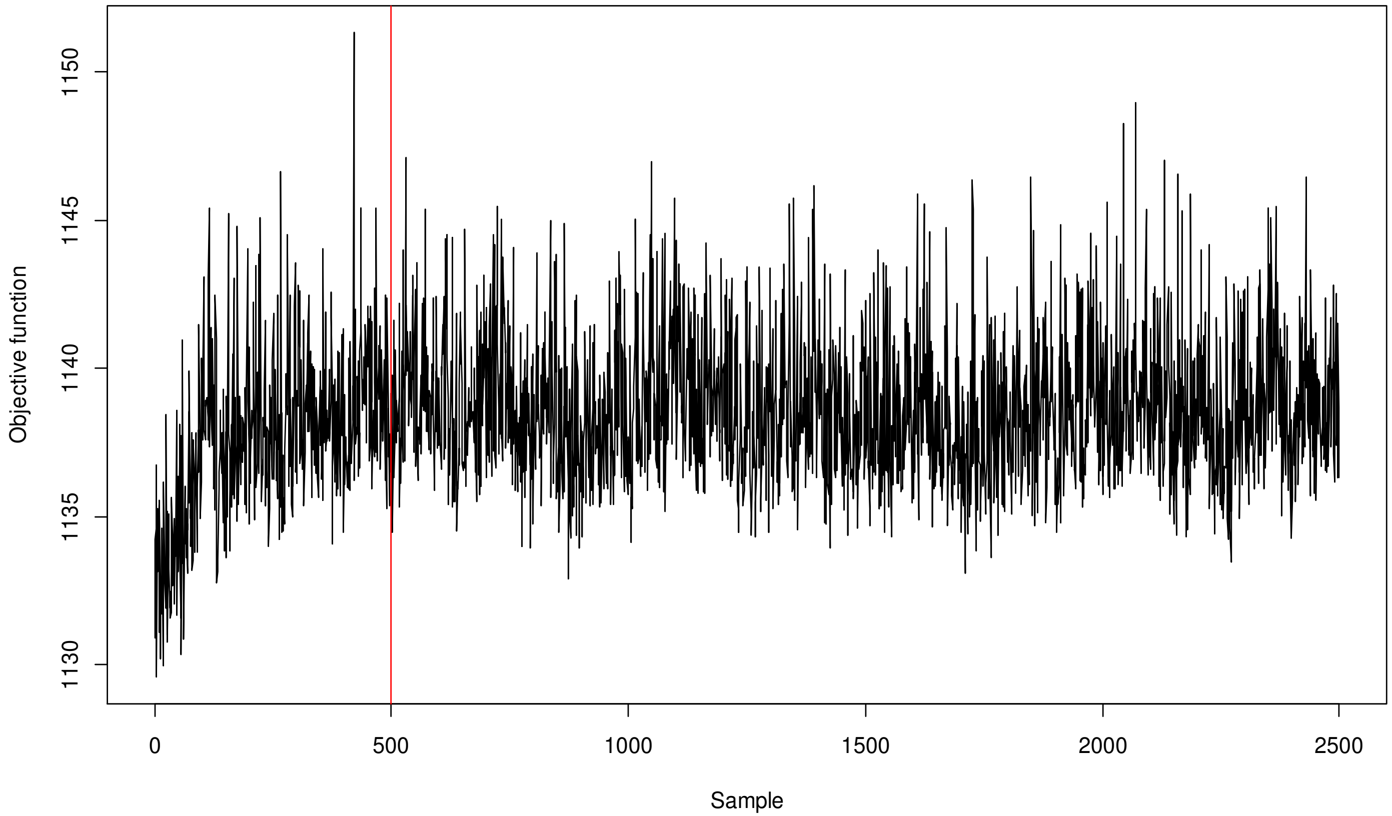
Results: MPD fit to AF



MCMC chain diagnostics (1)

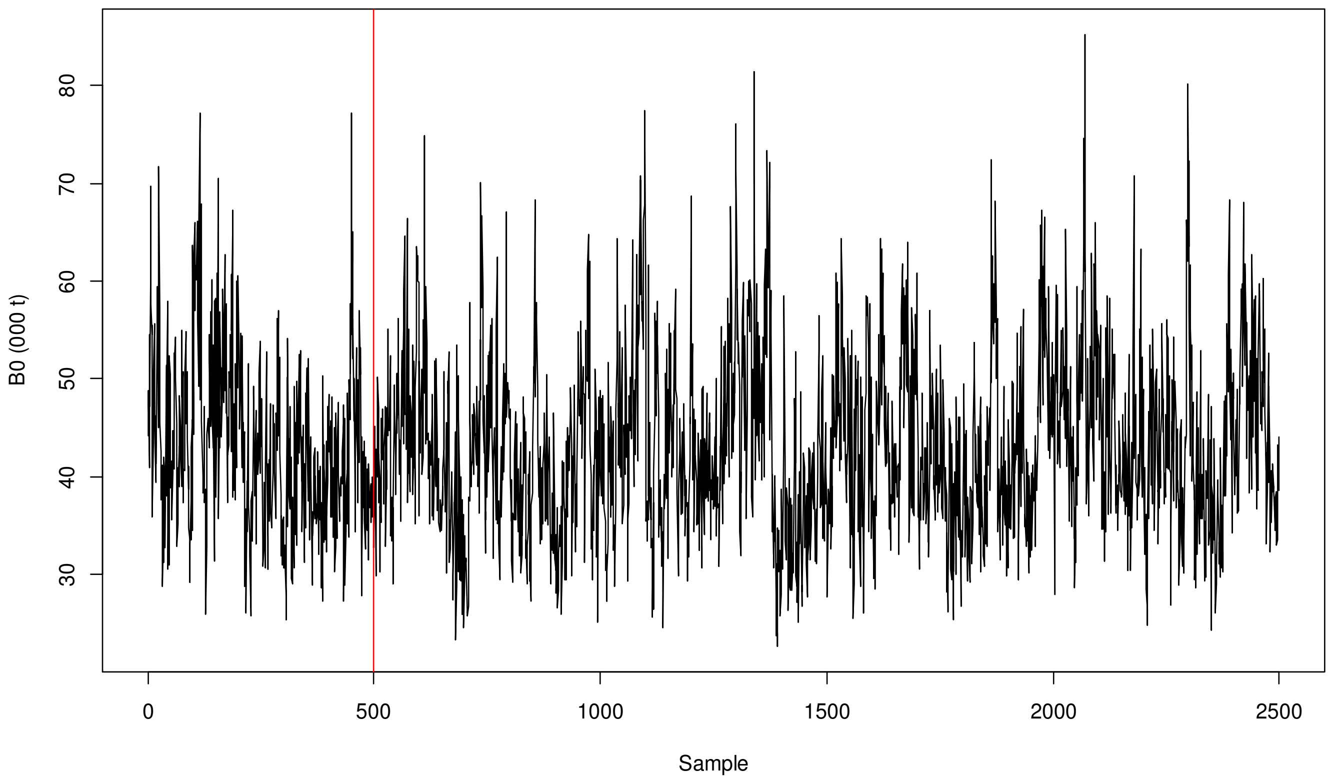
- Because there are 120 age classes, a large number of years, and migrations the model is "slow"
- Normally would run 3 long chains (say 8 million for each chain)
- Instead ran 5 short chains:
  - Each chain 2.5 million with 1 in every 1000 samples retained
  - First 500 samples discarded as a burn-in.

MCMC chain diagnostics: burn-in



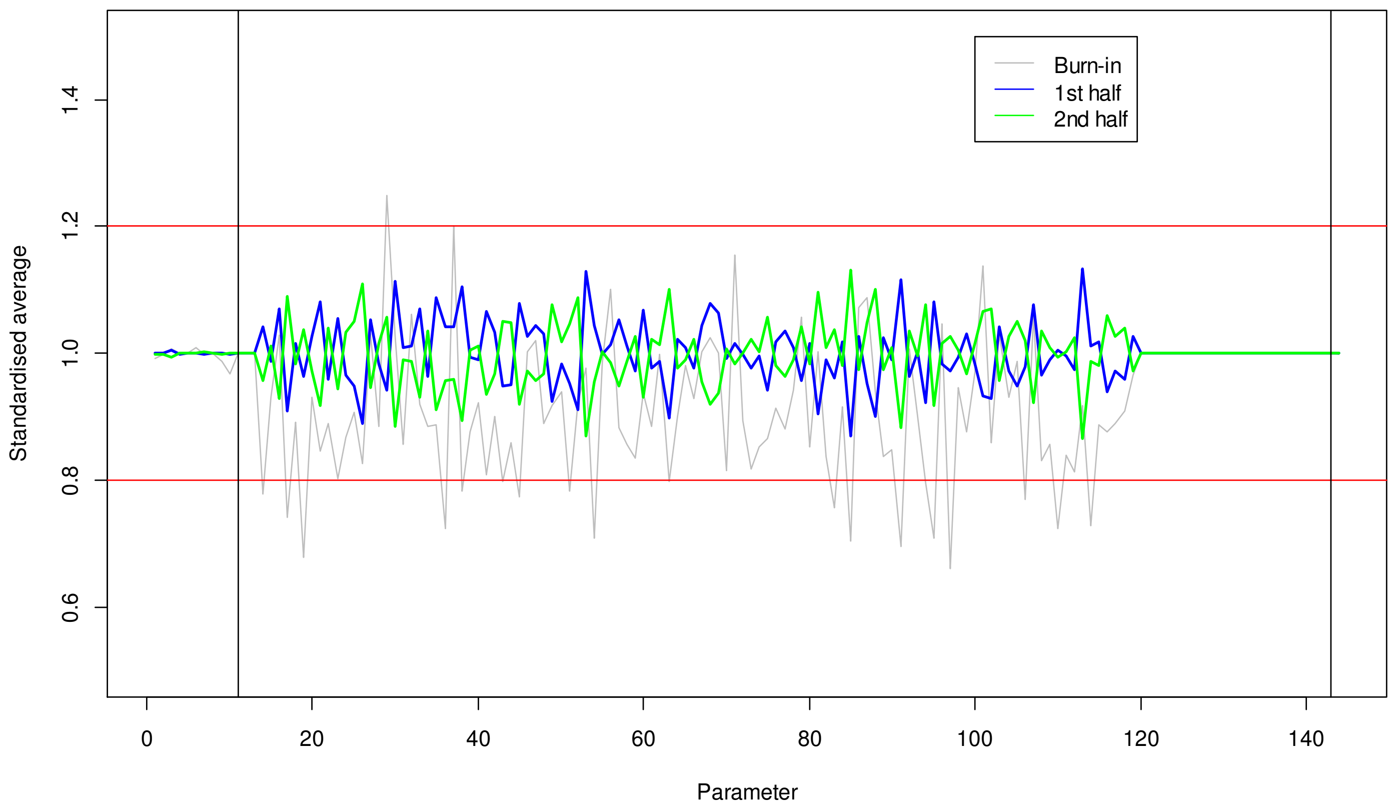
Each chain starts at a random jump from the MPD (where the objective function is minimized)

MCMC chain diagnostics: example chain for B_0



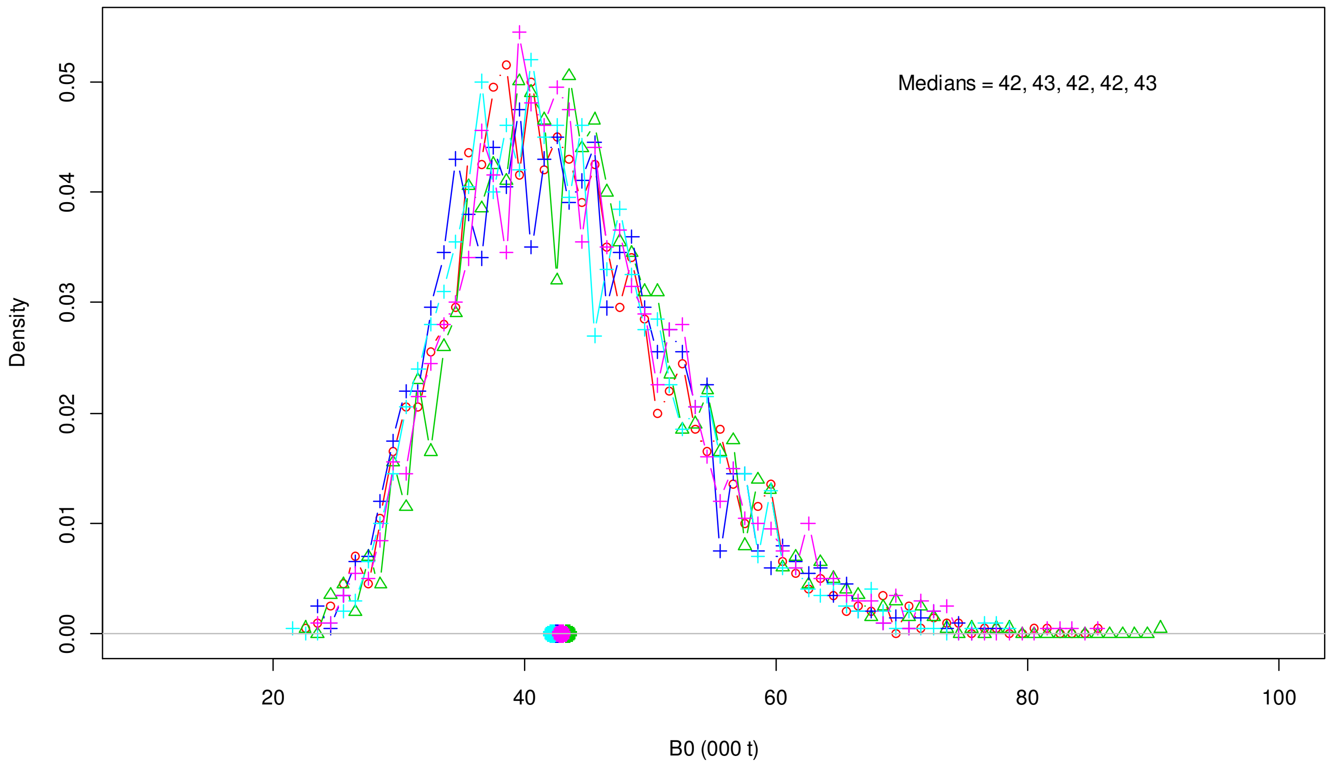
Highly correlated samples (as expected) but the chain is mixing well (a relatively high frequency – going from low to high values and back again)

MCMC chain diagnostics: check for drift



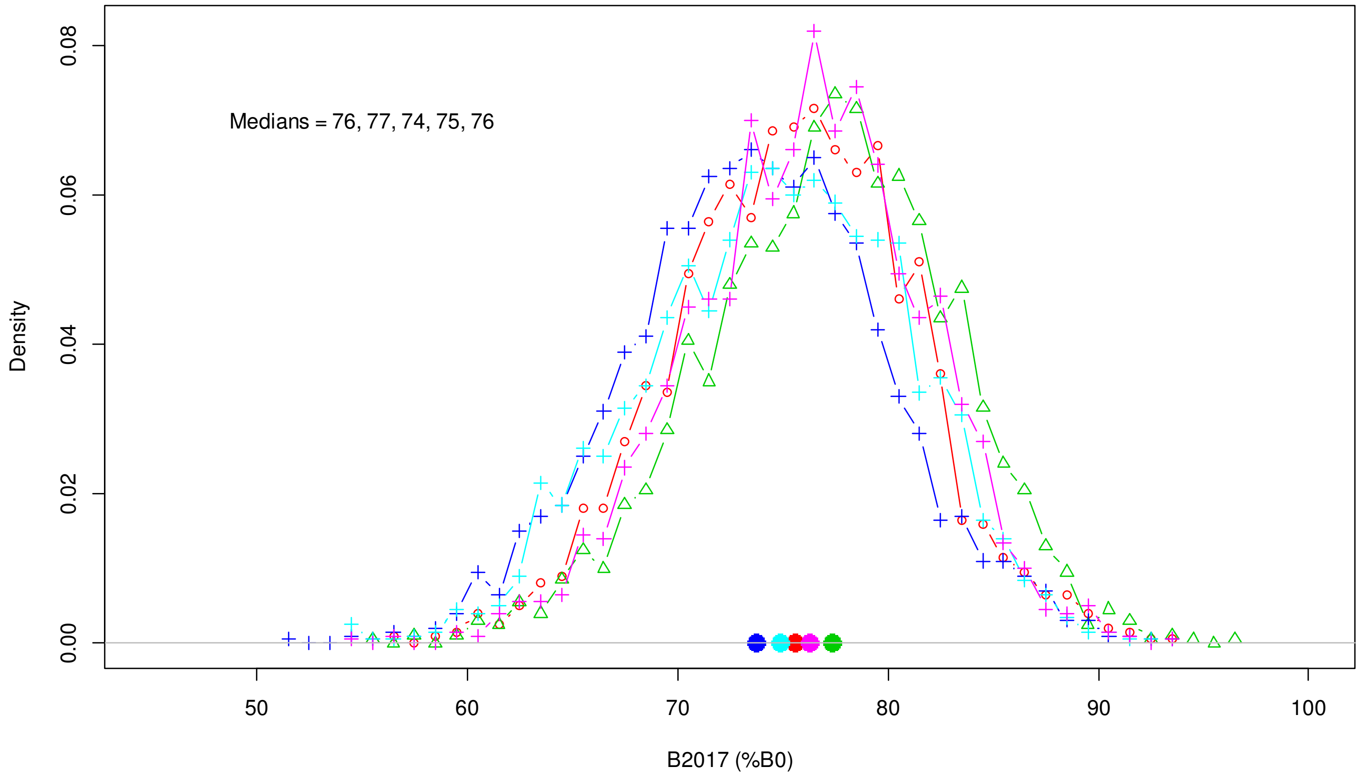
Almost no difference between the mean parameter values for the 1st half of the chains and the 2nd half of the chains except for YCS parameters (between vertical lines)

MCMC chain diagnostics: histogram check



Each individual chain giving a similar result (estimates use all 5 chains)

MCMC chain diagnostics: histogram check

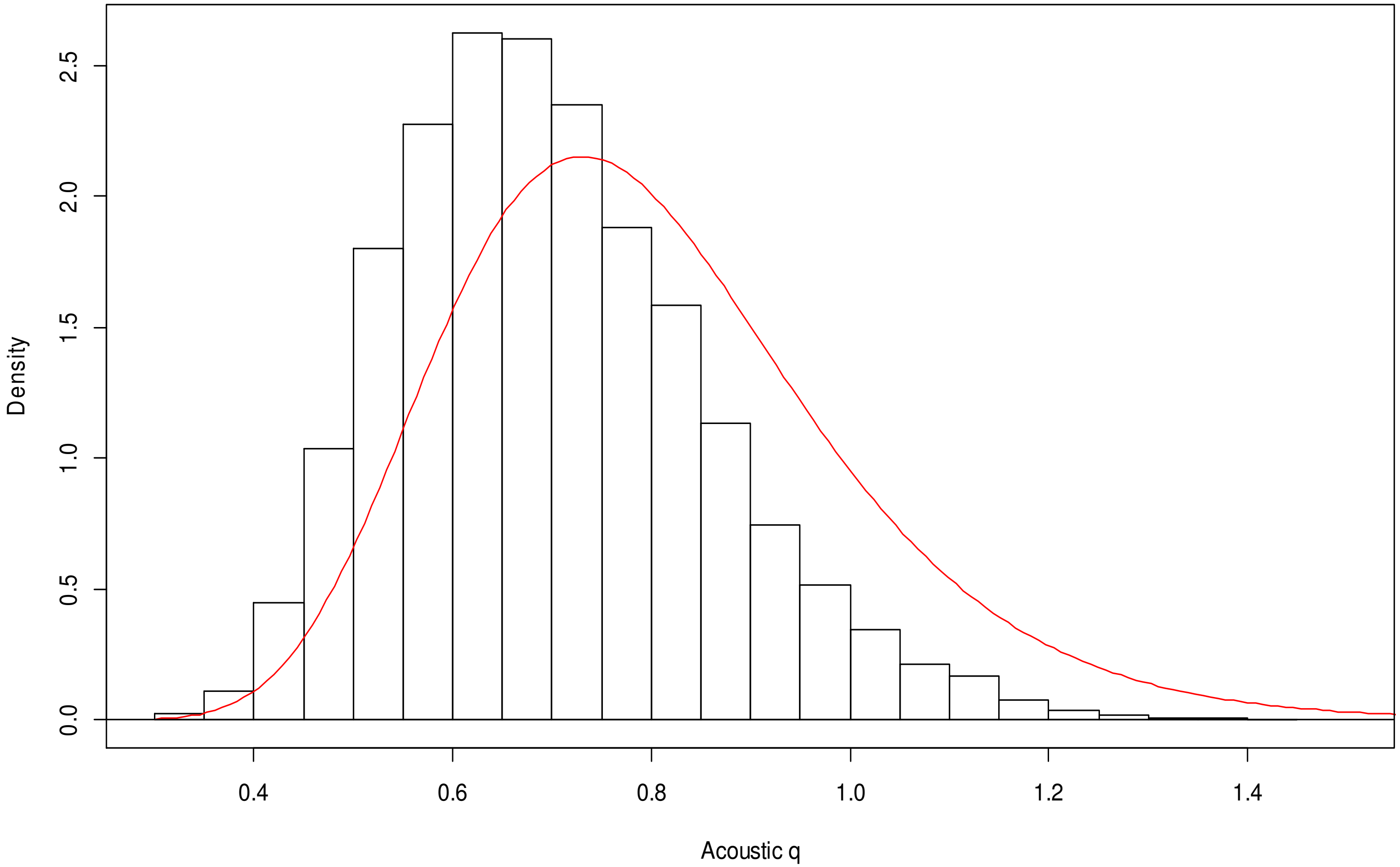


Each individual chain giving a similar result (estimates use all 5 chains)

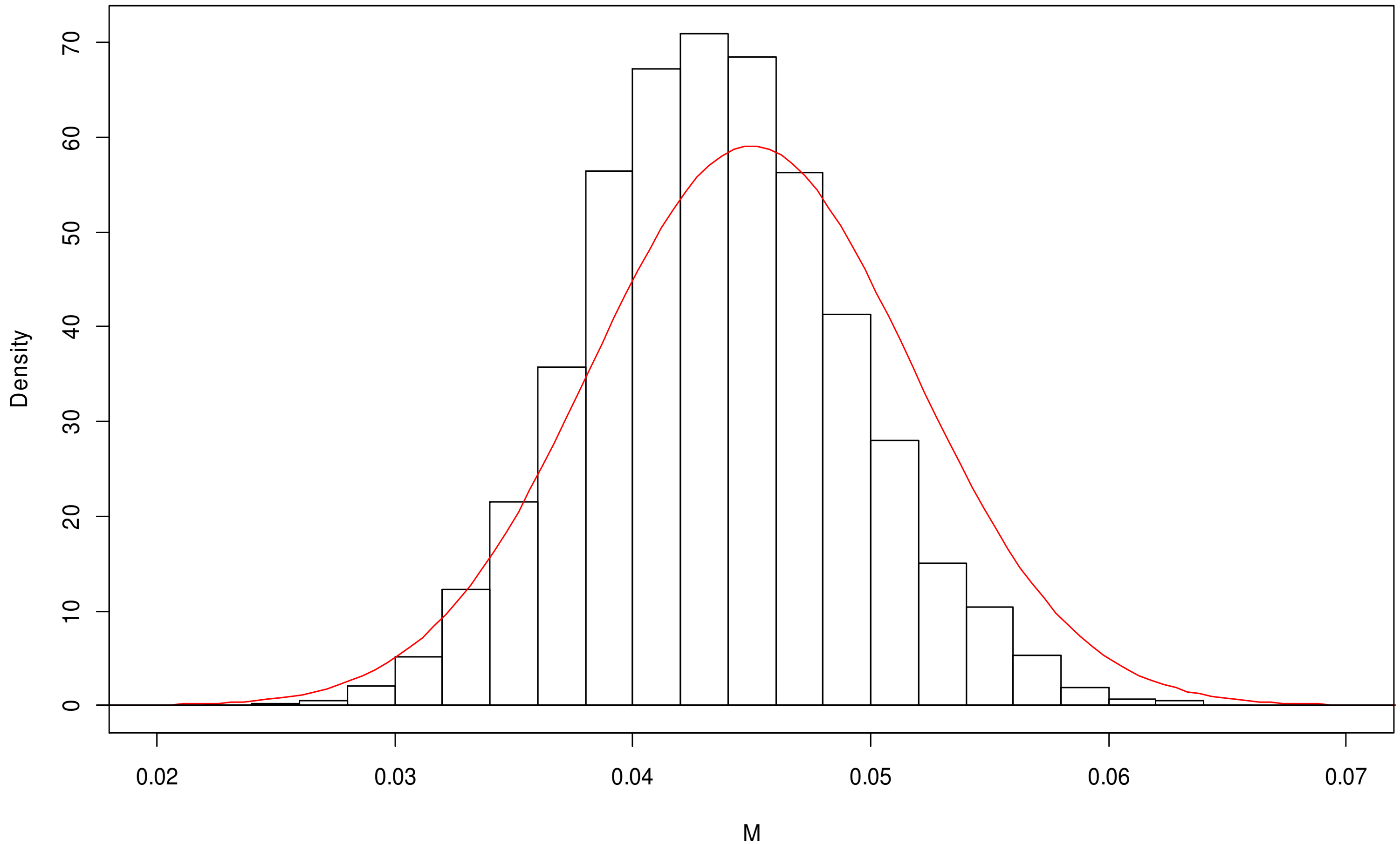
Base model MCMC results

- Check that the informed priors have been sensibly updated
- Check the MCMC fits and residuals
- Look at the estimates:
  - B_0
  - M
  - YCS
  - Migration parameters
  - Maturity
  - SSB trajectory

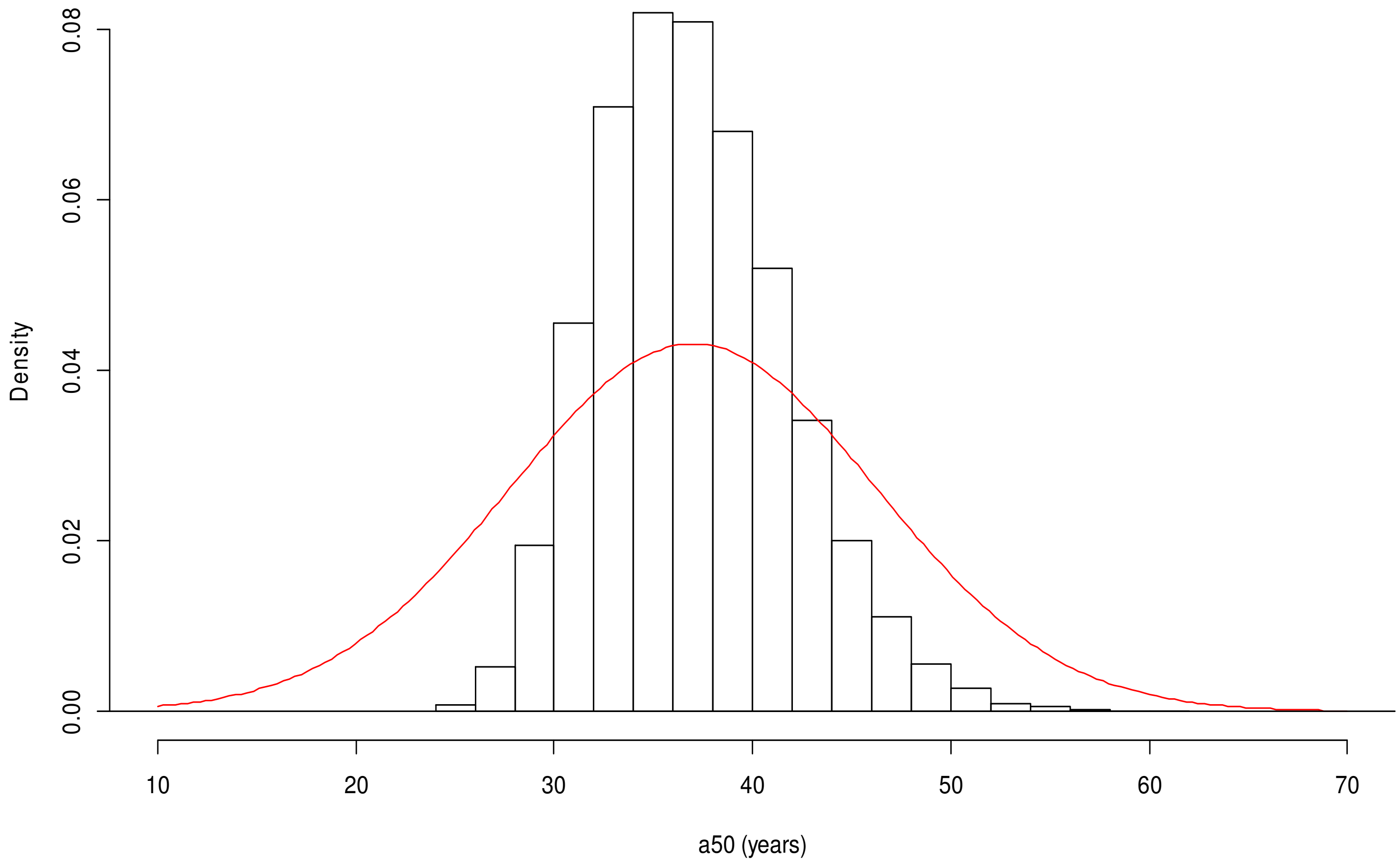
Marginal posterior distribution (histogram) and prior for acoustic q



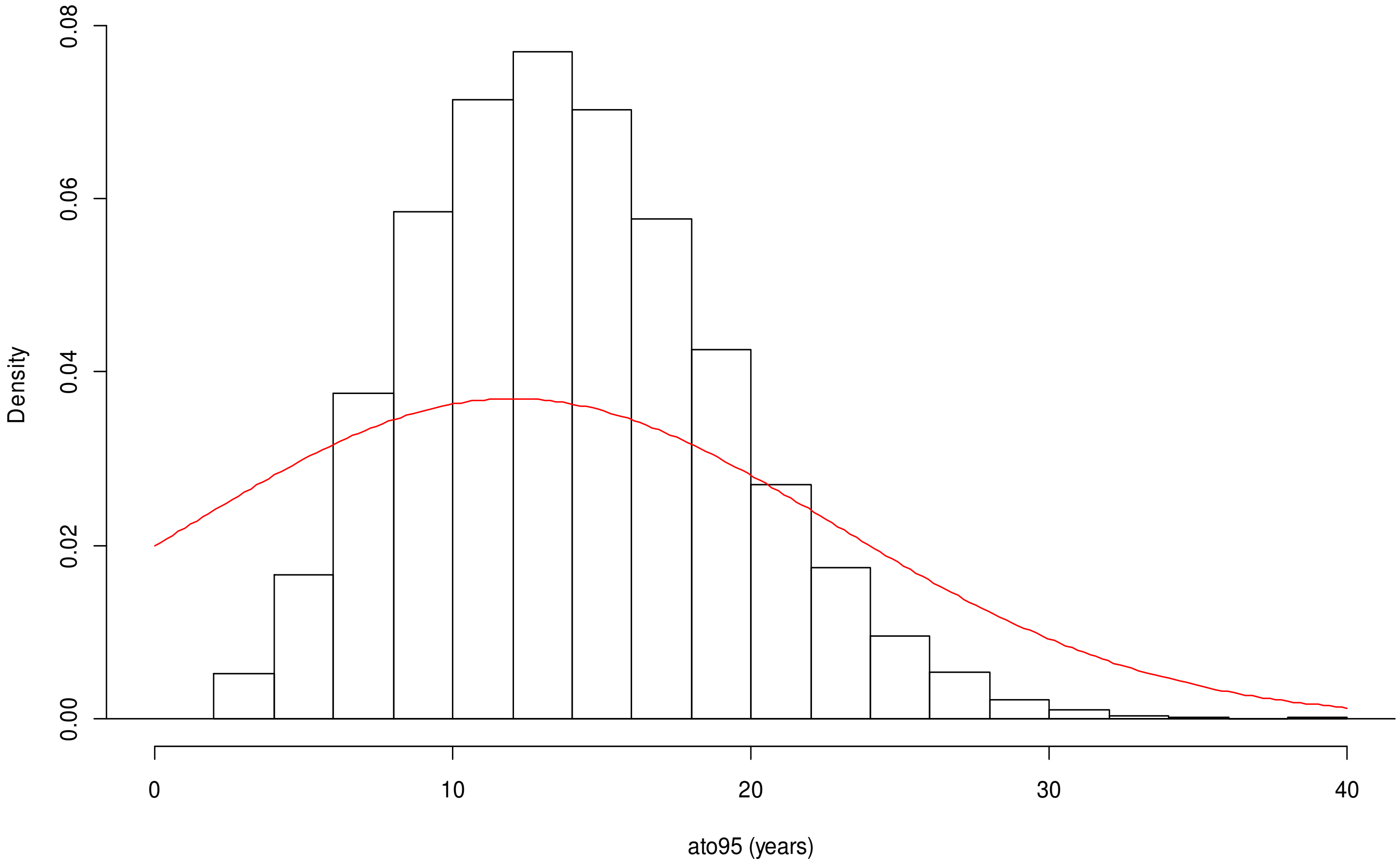
Marginal posterior distribution (histogram) and prior for M



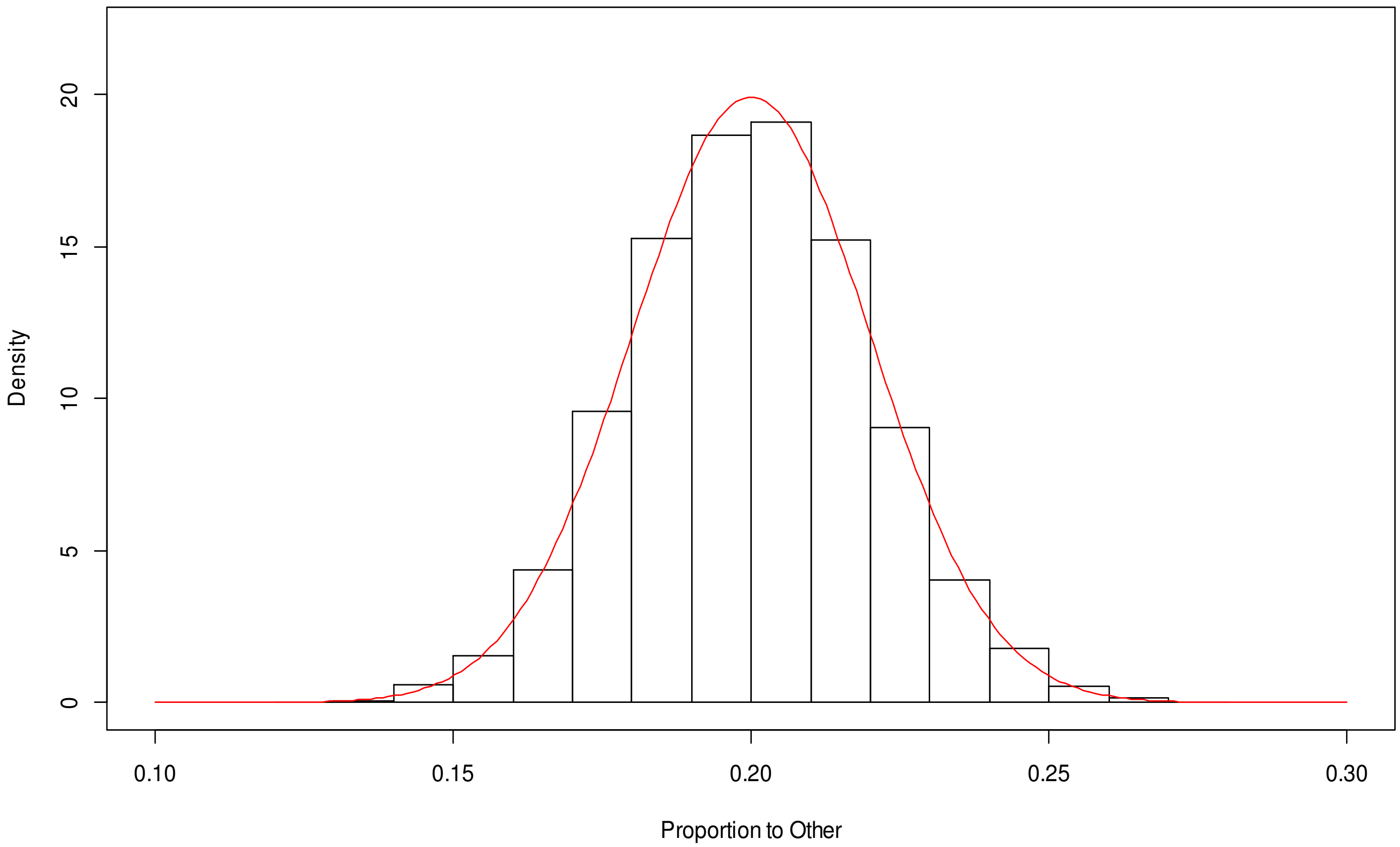
Marginal posterior distribution (histogram) and prior for a_{50}



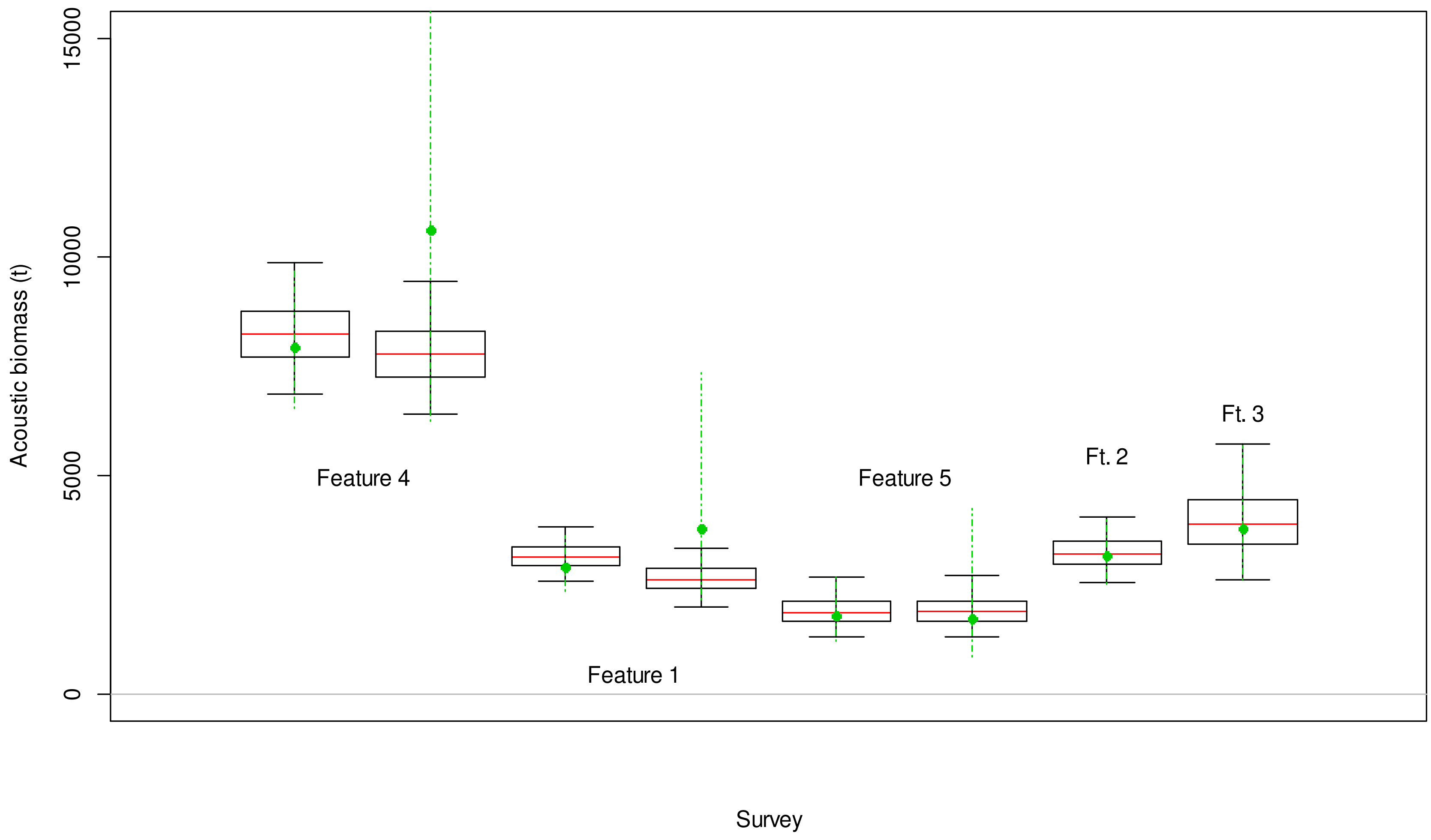
Marginal posterior distribution (histogram) and prior for a_{to95}



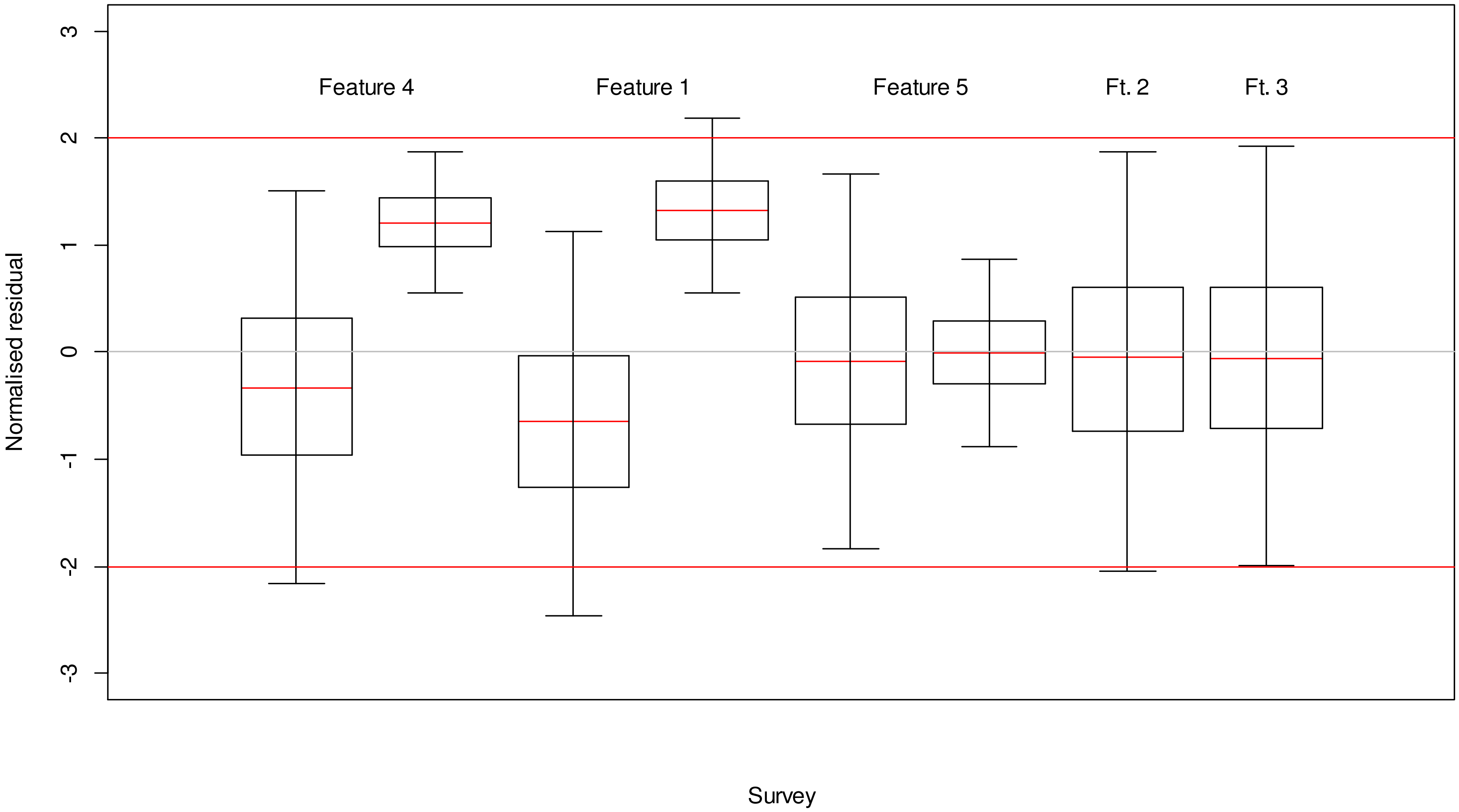
Marginal posterior distribution (histogram) and prior for proportion migrating to Other



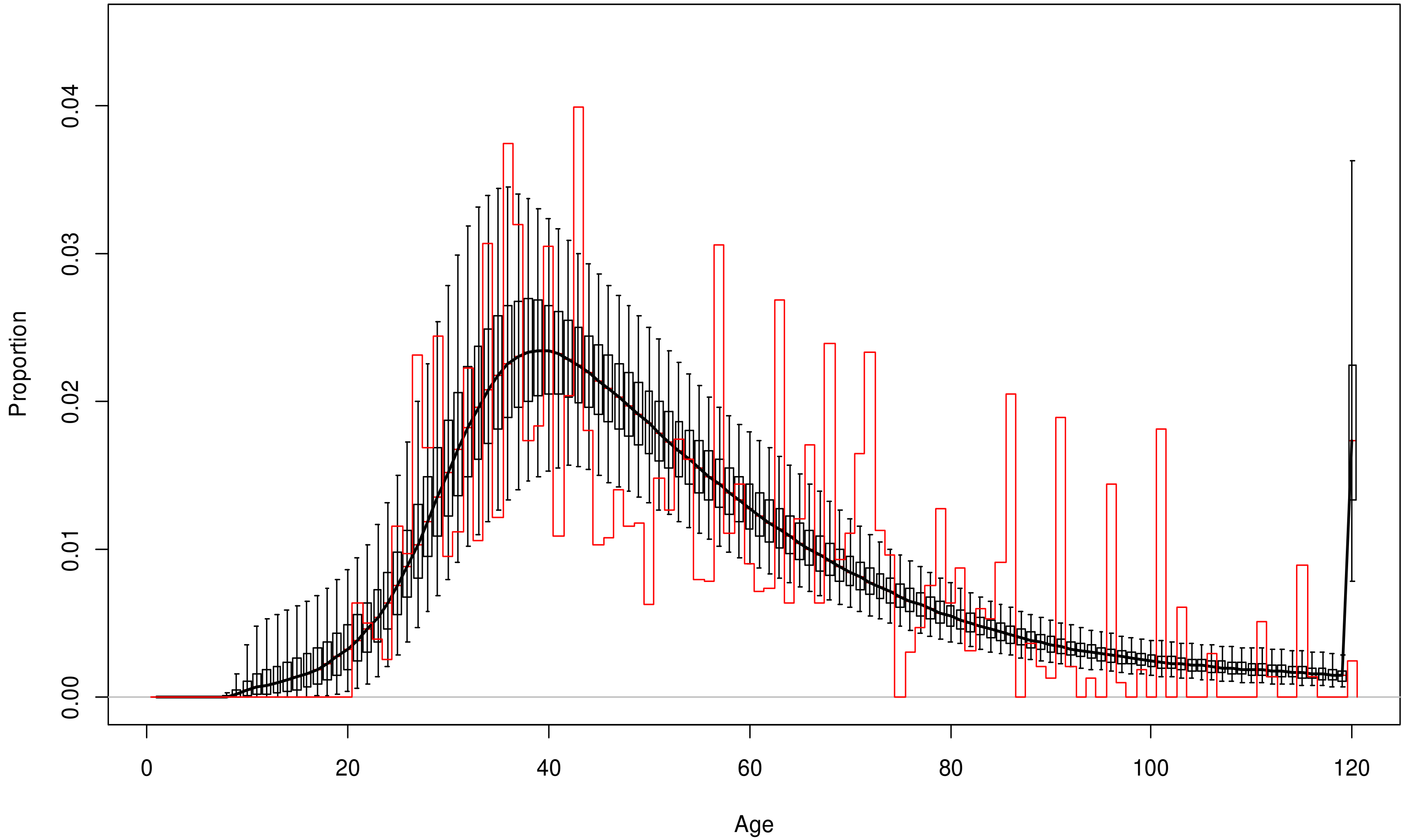
MCMC fit to acoustic biomass indices



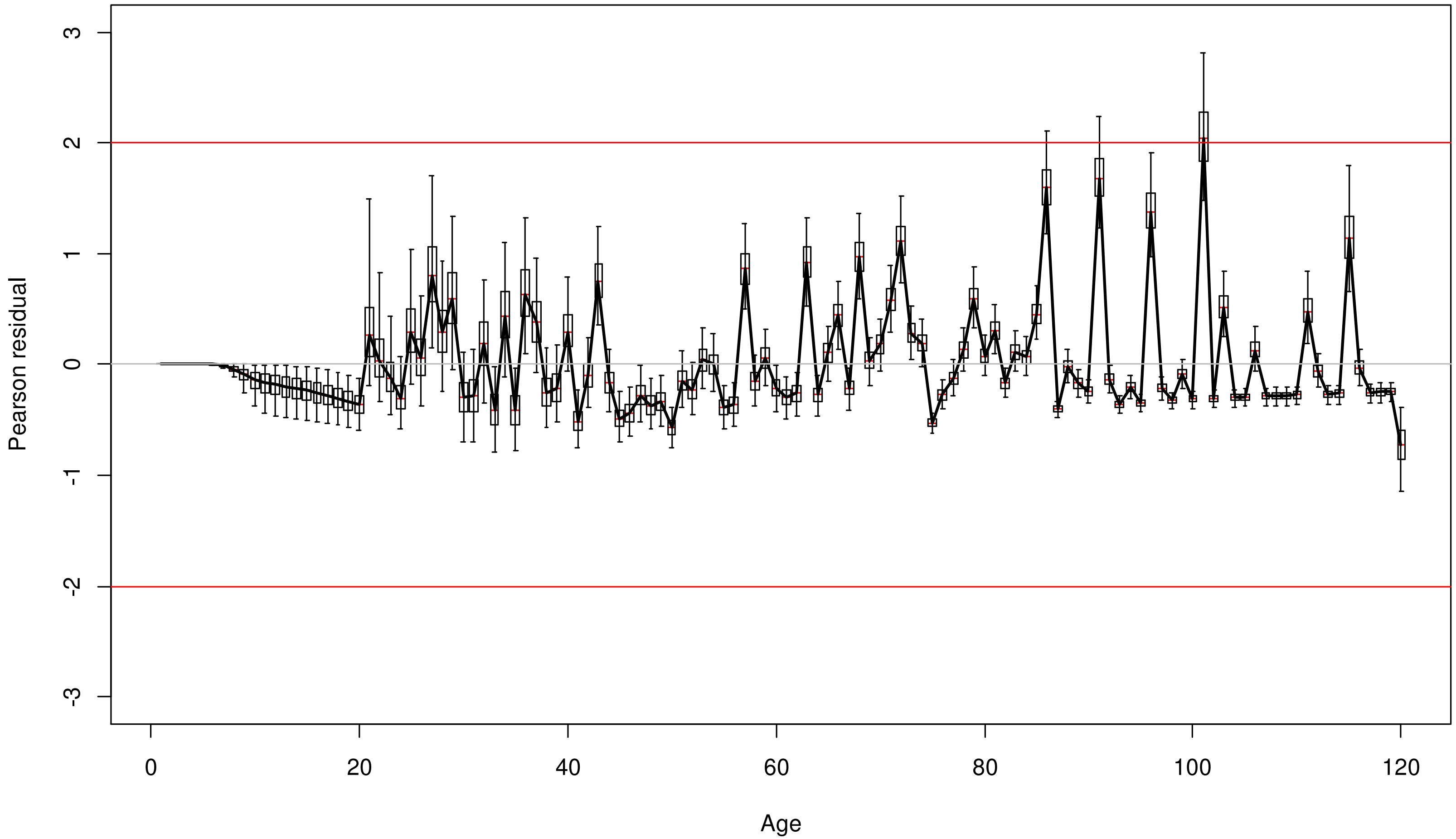
MCMC normalized residuals for acoustic biomass indices



MCMC fit to AF



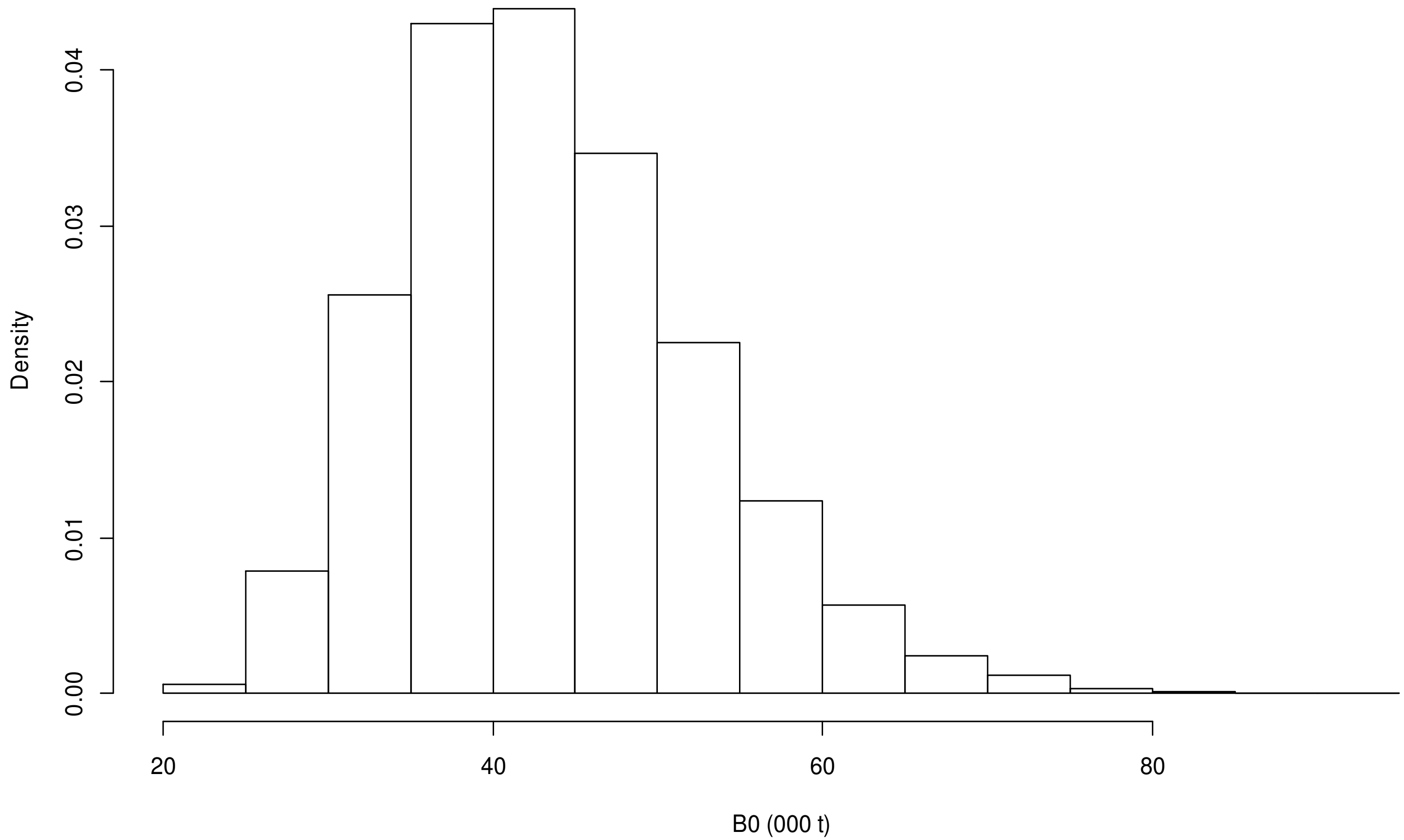
MCMC Pearson residuals for AF



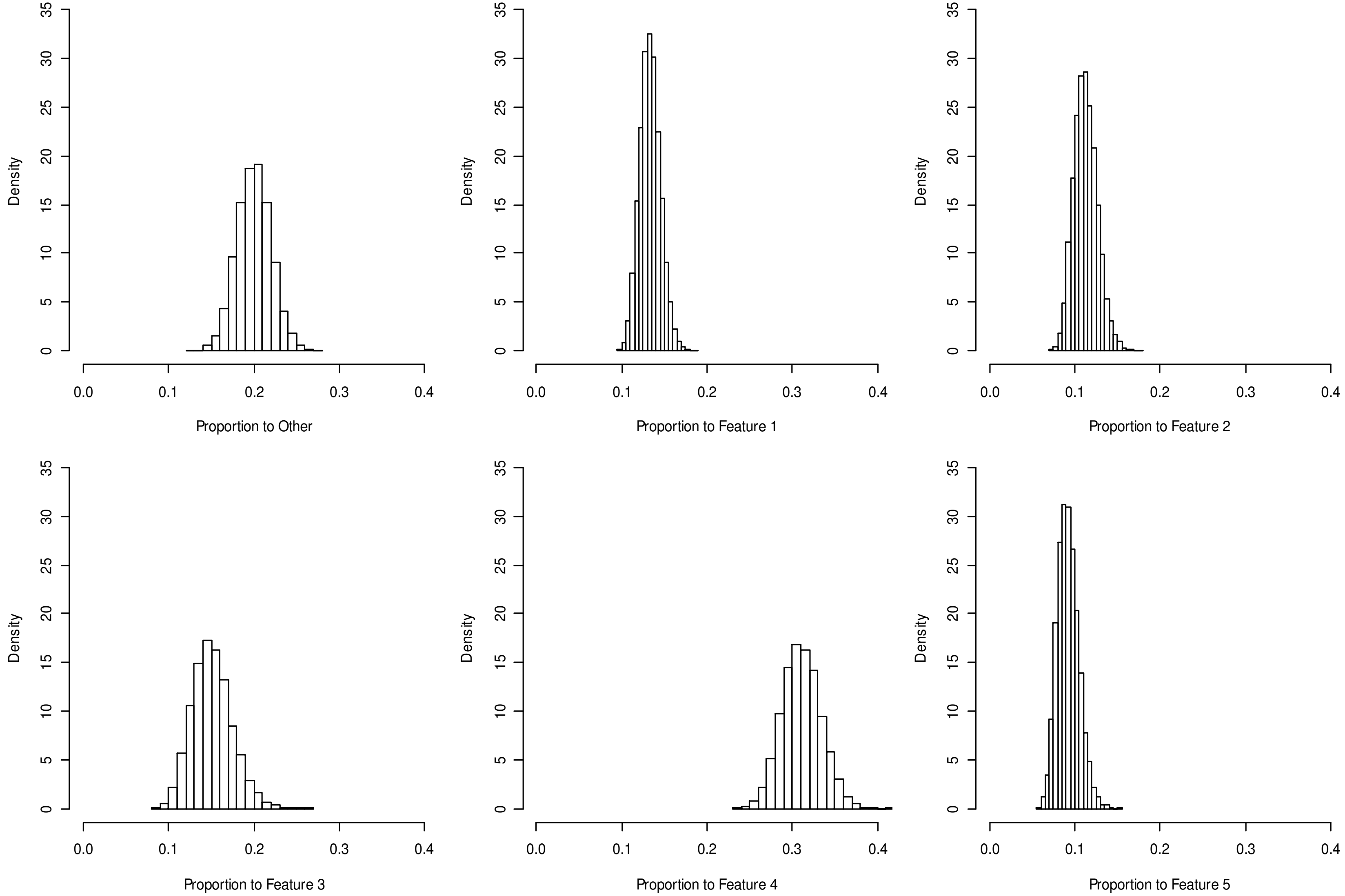
Base model MCMC estimates (median) and 95% Credibility Intervals (CIs)

B_0 (000 t)	Acoustic q	M (%)	a_{50} (years)	a_{to95} (years)	
43 29-64	0.68 0.44-1.05	4.3 3.3-5.5	37 29-47	14 5-25	
Migration proportions					
Other	Feature 1	Feature 2	Feature 3	Feature 4	Feature 5
20 16-24	13 11-16	11 9-14	15 11-20	31 27-36	9 7-12

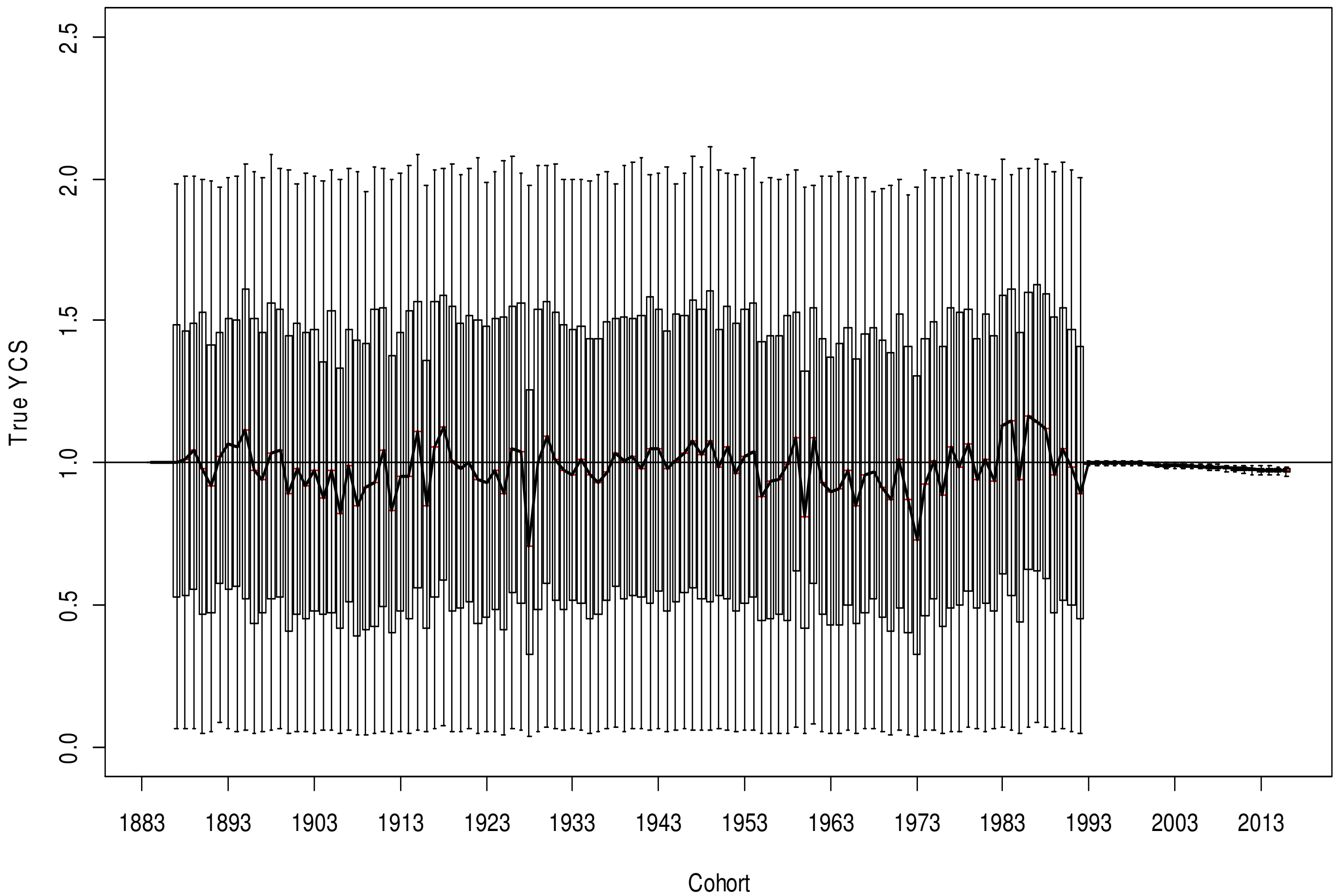
Marginal posterior distribution for B_0



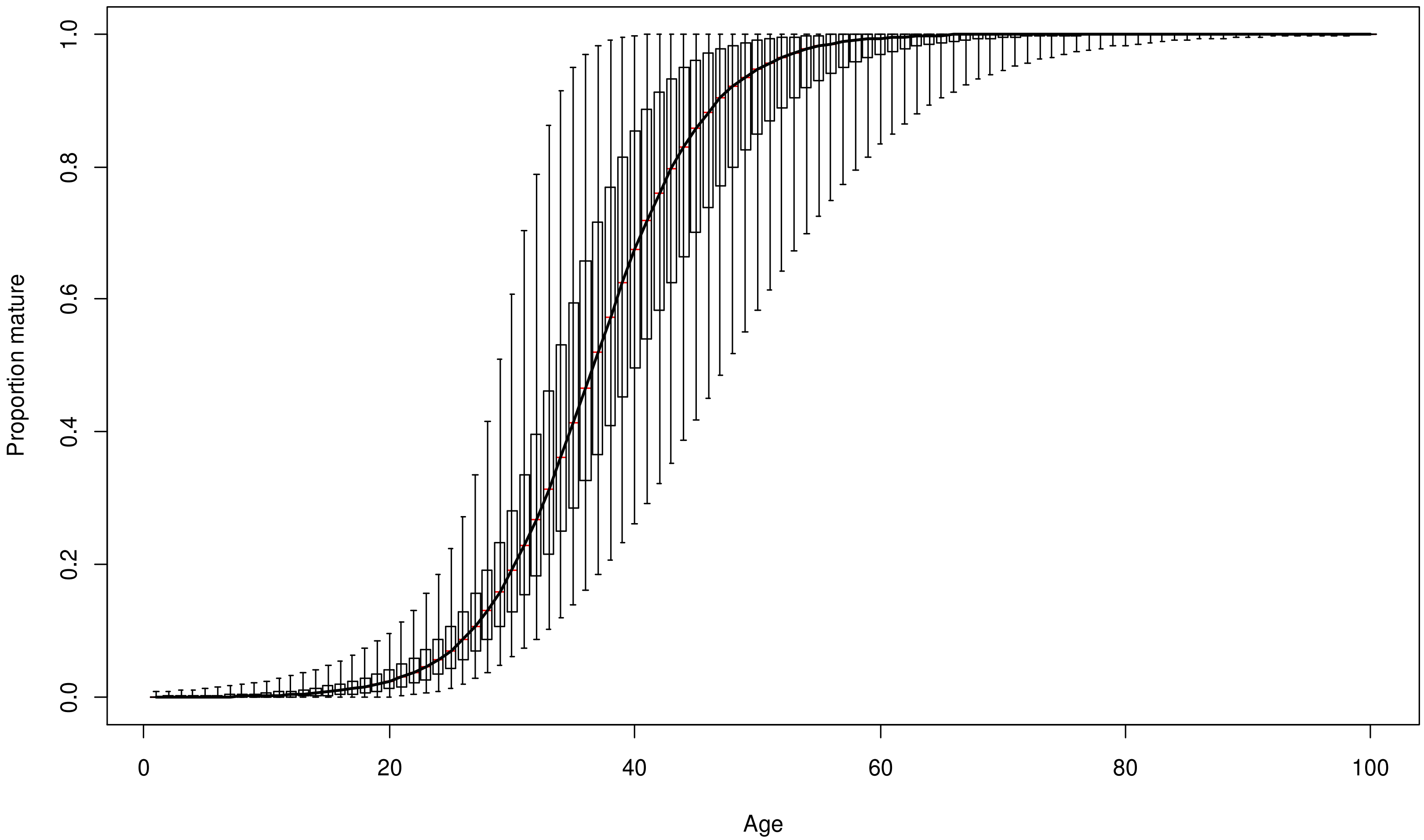
Marginal posterior distributions for the migration proportions



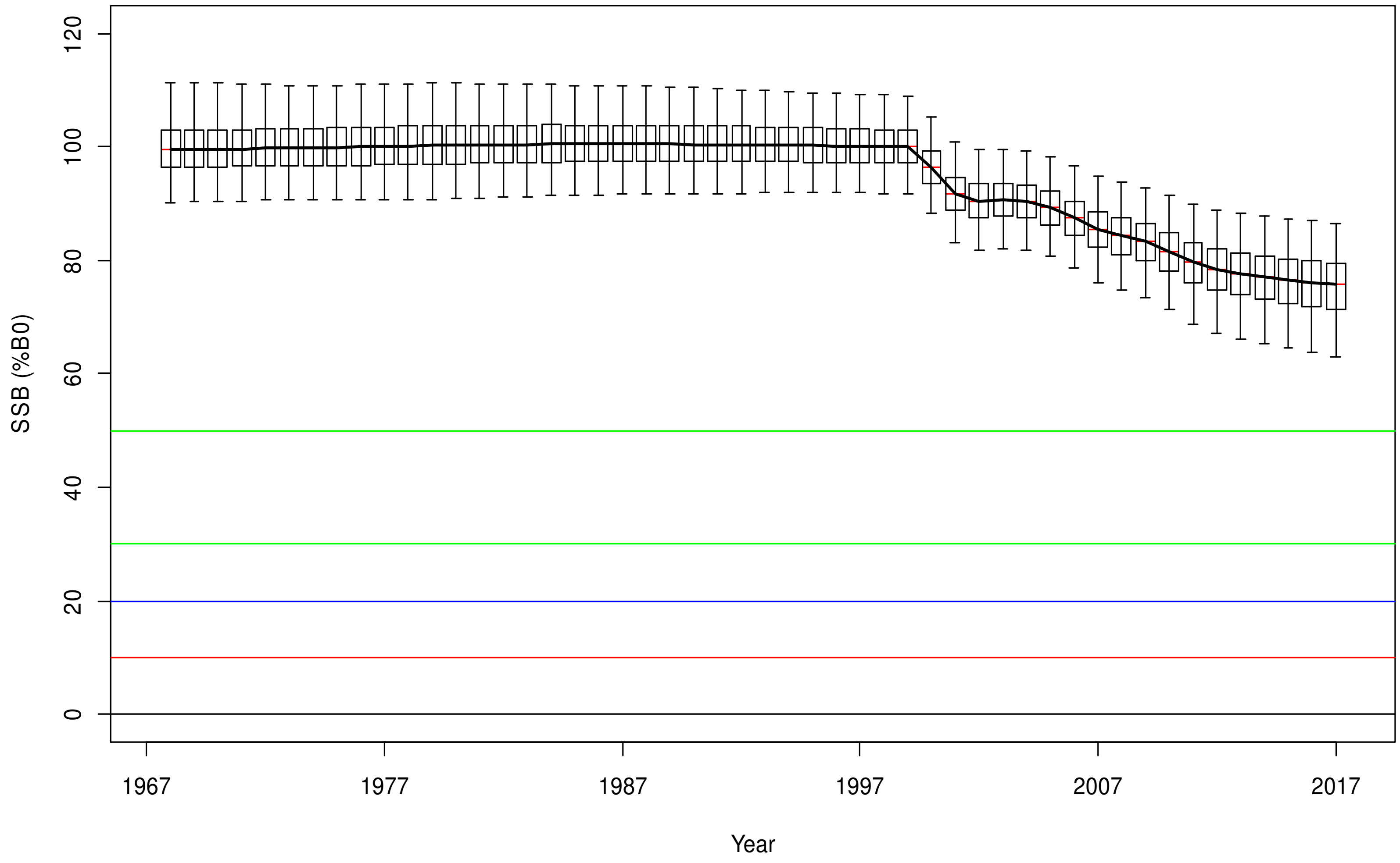
True YCS (R_i/R_0): box and whiskers



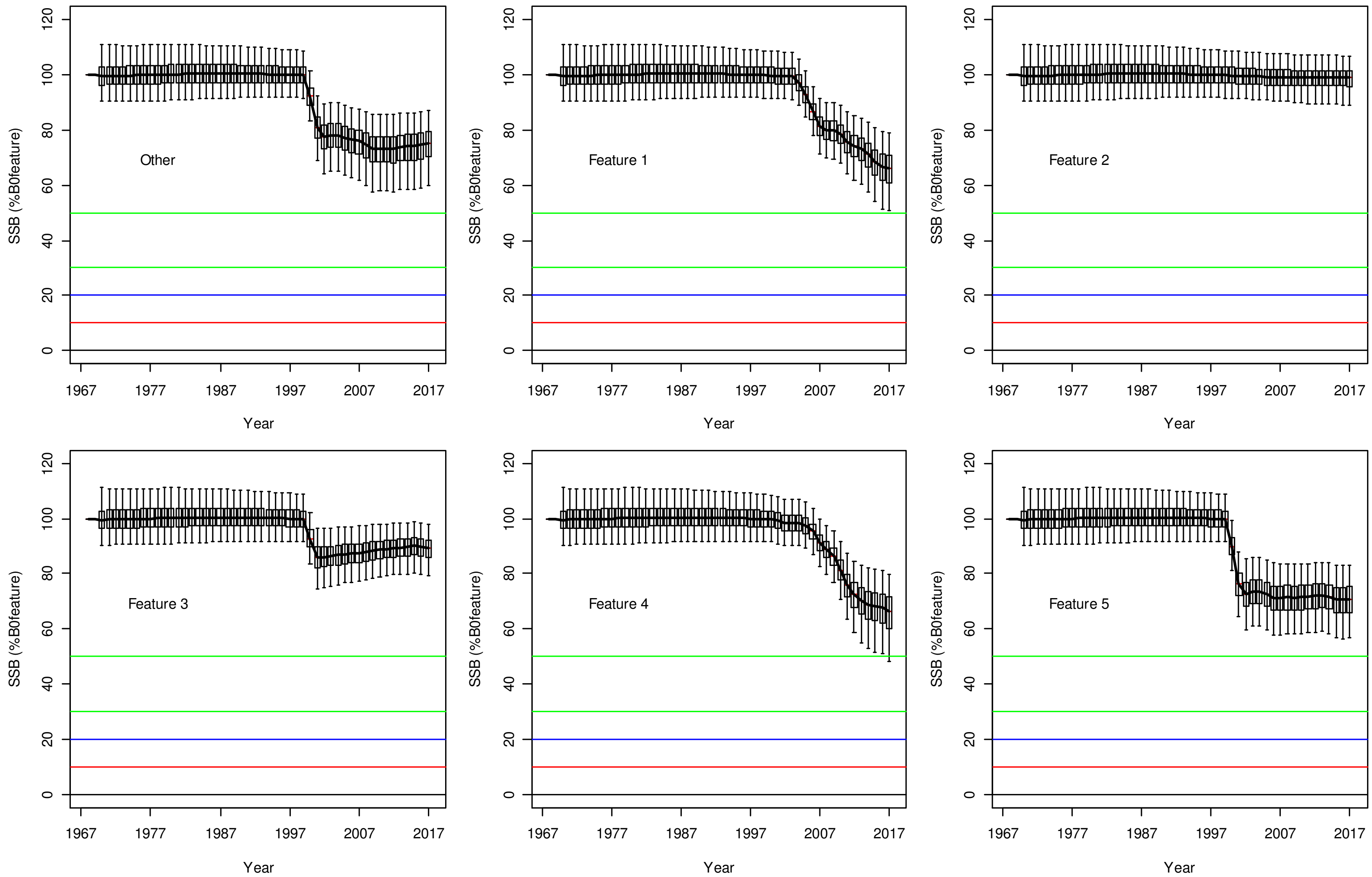
Proportion mature at age in the virgin population: box and whiskers



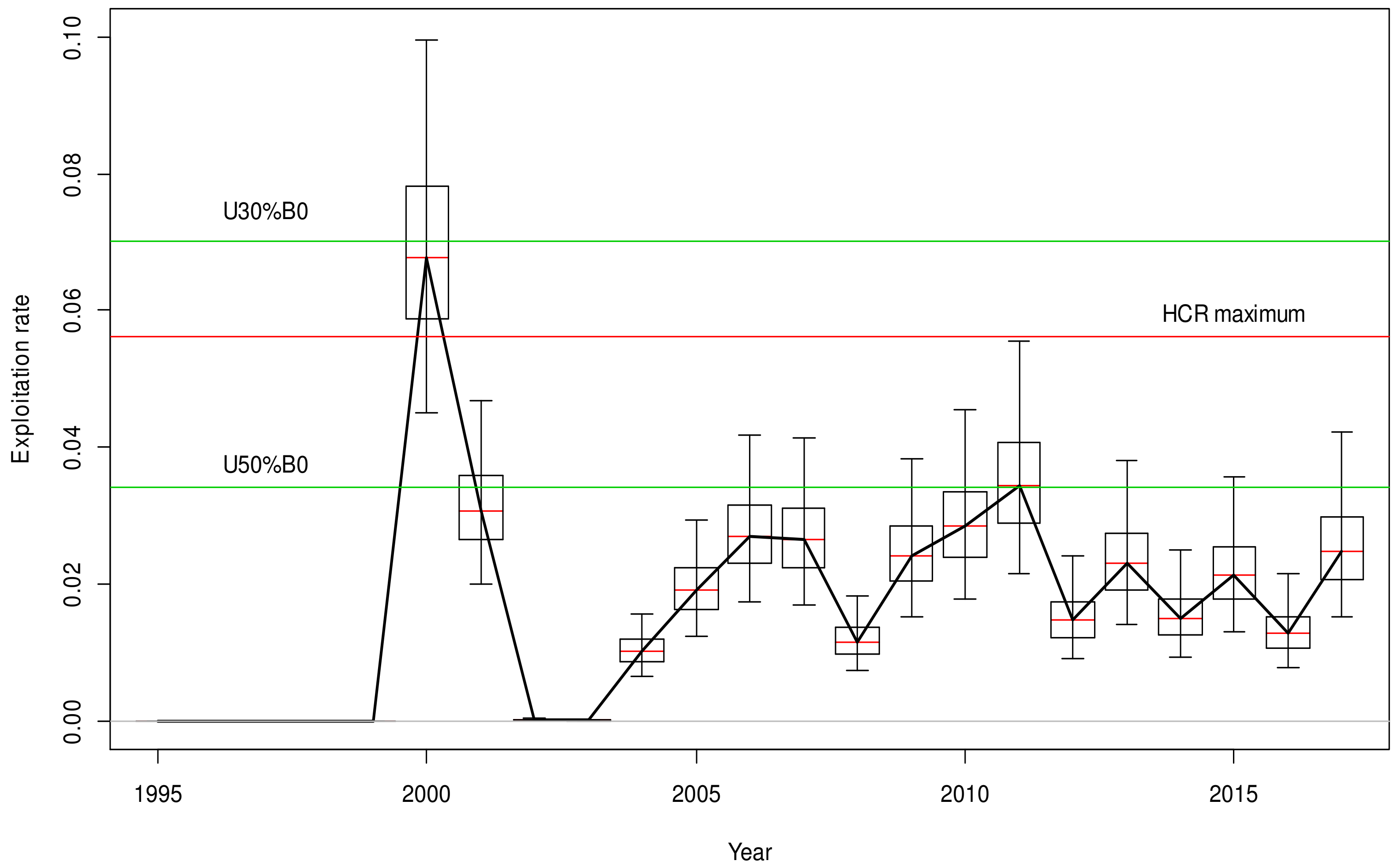
SSB trajectory: box and whiskers



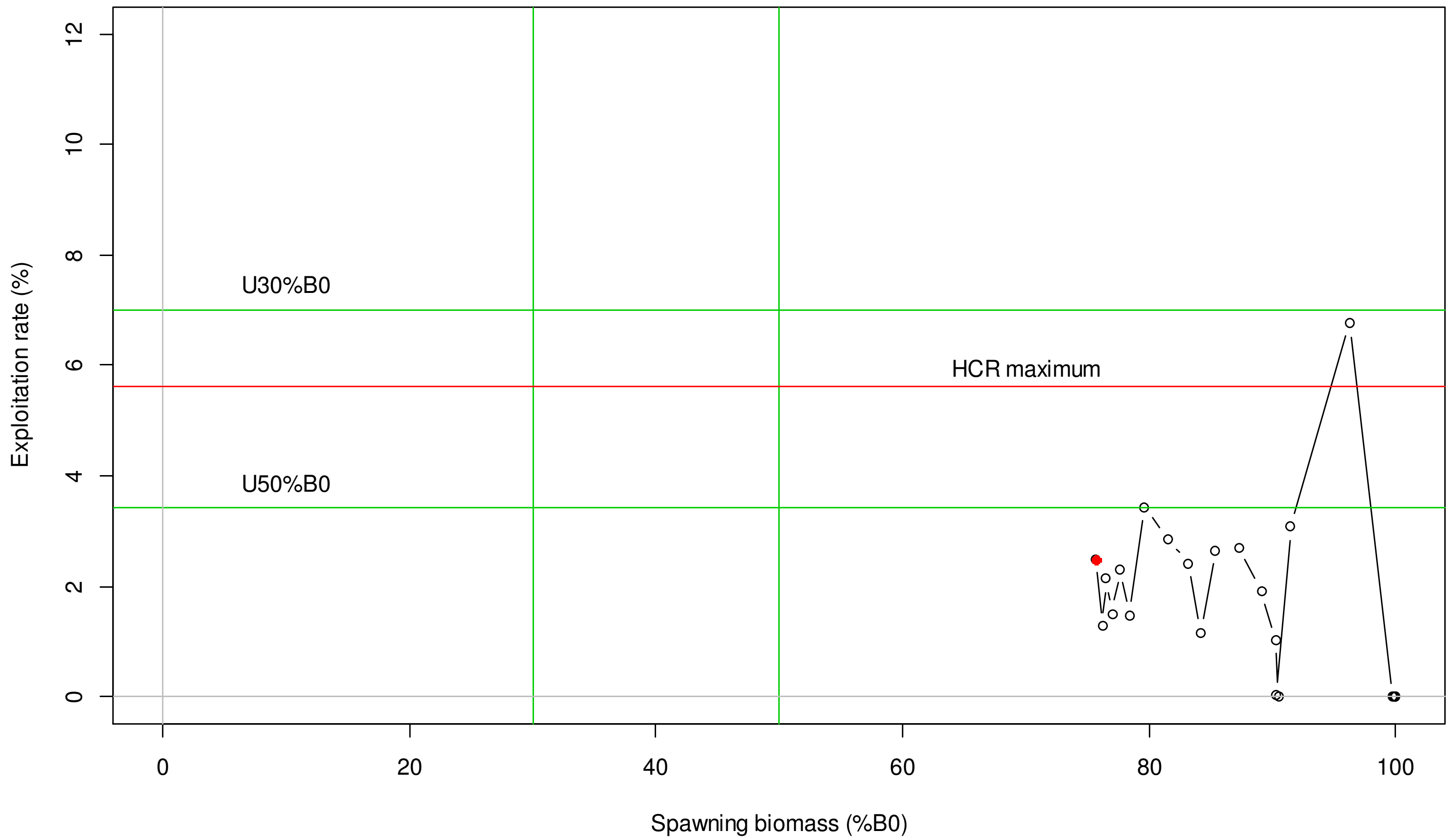
SSB trajectories by model area (relative to virgin biomass in the model area)



Annual exploitation rate: box and whiskers



"Snail trail": median annual exploitation rate (y axis) and median annual SSB (x axis)



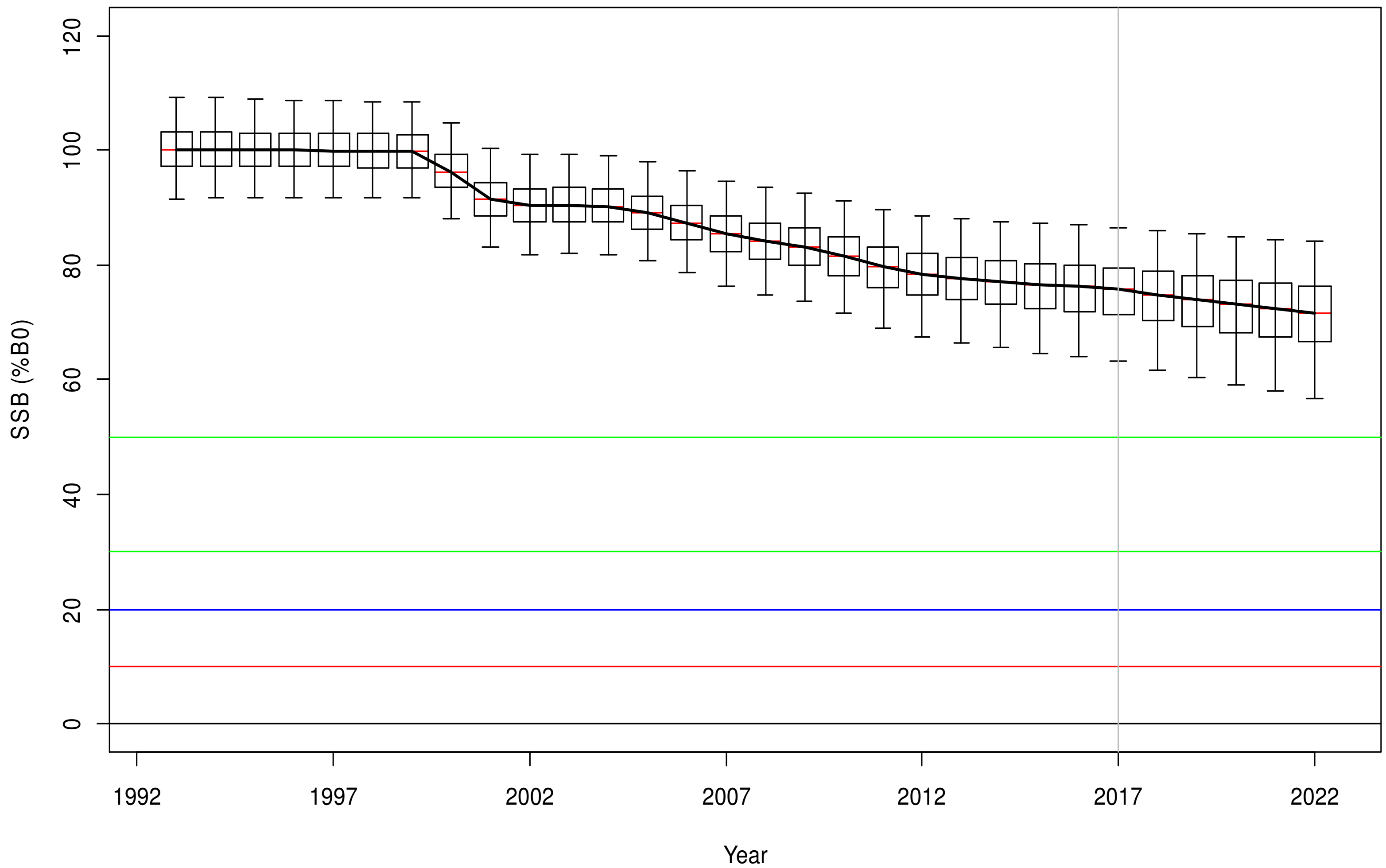
Results of the sensitivity analysis: whole stock

	B_0 (000 t)		B_{17} (000 t)		ss_{17} (%B_0)		P(B_{17} > 30%B_0)	P(B_{17} > 50%B_0)
Base	**43**	**29-64**	**32**	**19-53**	**76**	**63-87**	**100**	**100**
Low	29	22-42	19	12-31	65	53-77	100	100
High	71	46-97	61	37-86	85	76-94	100	100
Uniform	42	29-64	32	19-53	75	63-86	100	100
AF80	43	30-67	32	19-55	74	62-85	100	100
Low catch	42	28-65	32	18-55	77	65-88	100	100
High catch	43	29-66	32	18-53	73	60-84	100	100
Low and low M	29	23-42	19	12-31	63	53-75	100	99
More acoustics	44	30-69	34	20-58	76	64-87	100	100

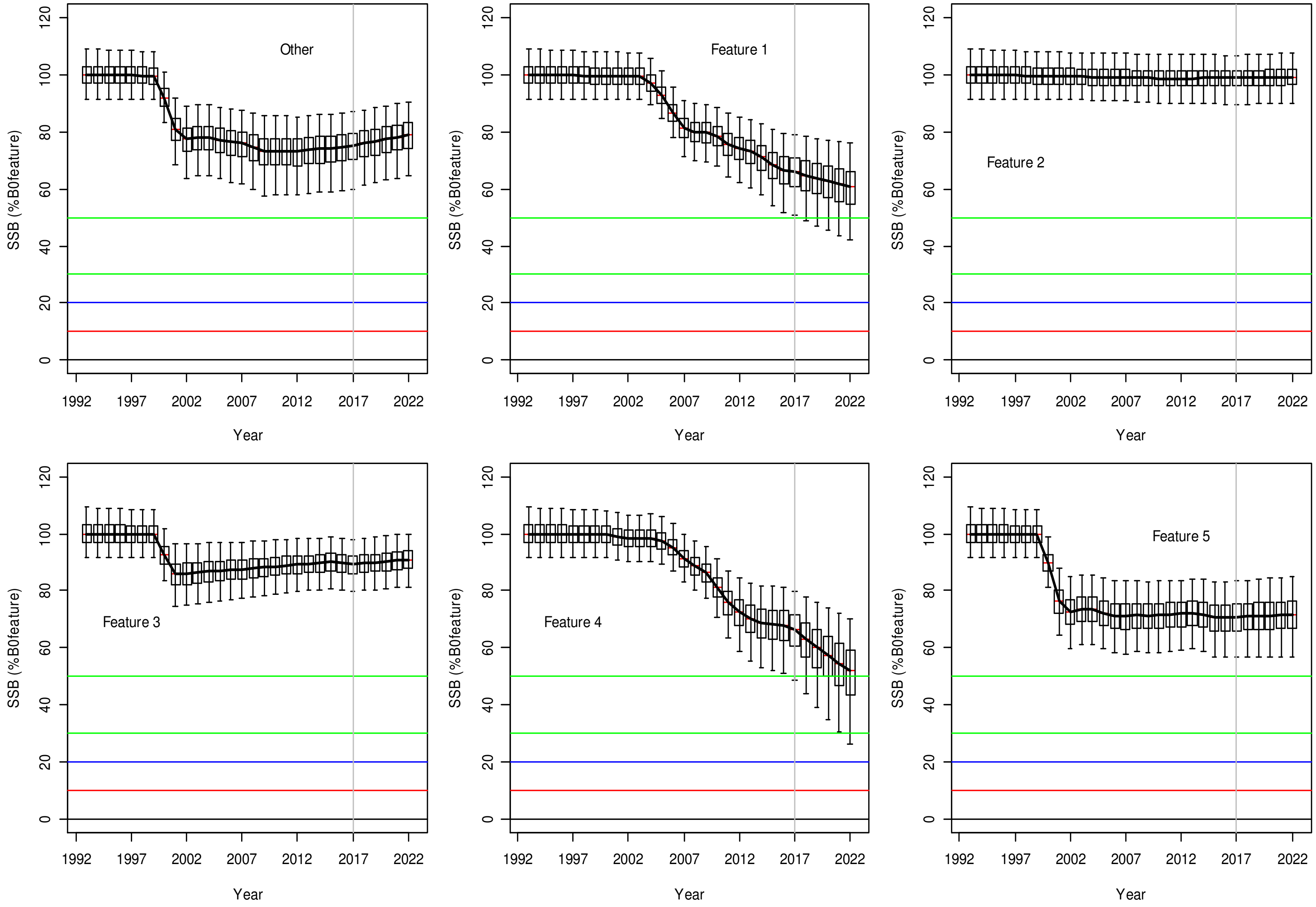
Results of the sensitivity analysis: local depletion by area (median and 95% CI)

	Other		Feature 1		Feature 2		Feature 3		Feature 4		Feature 5	
Base	**75**	**60-87**	**66**	**51-79**	**99**	**90-107**	**89**	**80-98**	**66**	**49-80**	**71**	**57-83**
Low	30	11-54	57	44-71	98	90-107	86	77-95	56	40-71	64	51-77
High	90	81-98	76	64-86	99	91-107	93	84-101	77	64-87	79	67-89
Uniform	74	59-85	65	50-78	97	88-105	88	78-96	65	48-79	70	56-82
AF80	74	59-85	65	50-78	97	88-105	88	78-96	65	48-79	70	56-82
Low catch	80	67-91	66	51-79	99	91-107	89	80-98	66	48-80	75	62-87
High catch	65	44-80	66	51-79	99	90-107	89	80-98	66	48-80	64	50-77
Low and low M	25	8-49	56	43-70	99	91-106	86	77-94	55	39-70	62	50-75
More acoustics	76	61-87	64	48-78	99	89-107	90	80-99	66	51-80	70	54-84

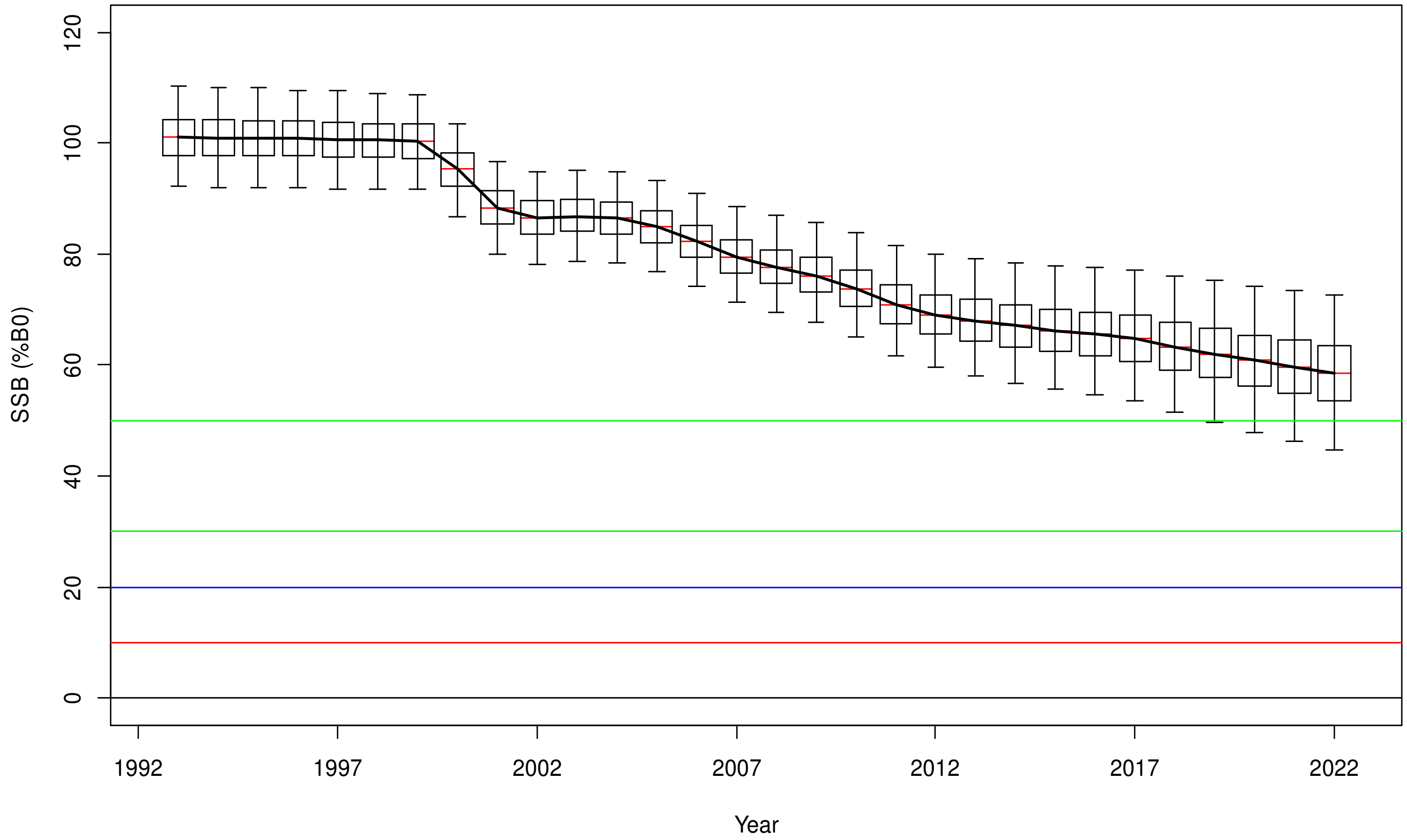
Base model projections at current catch



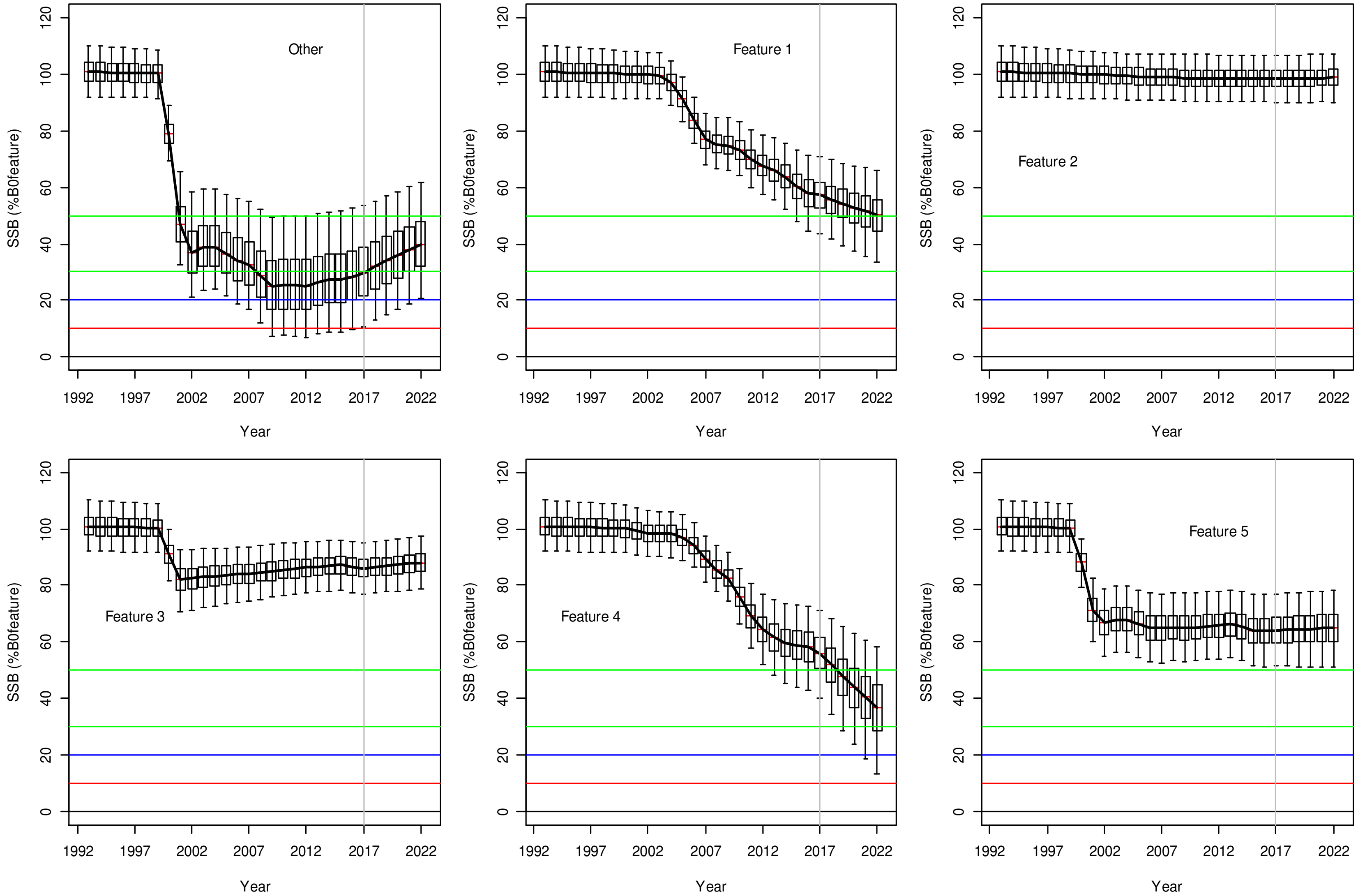
Base model projections at current catch



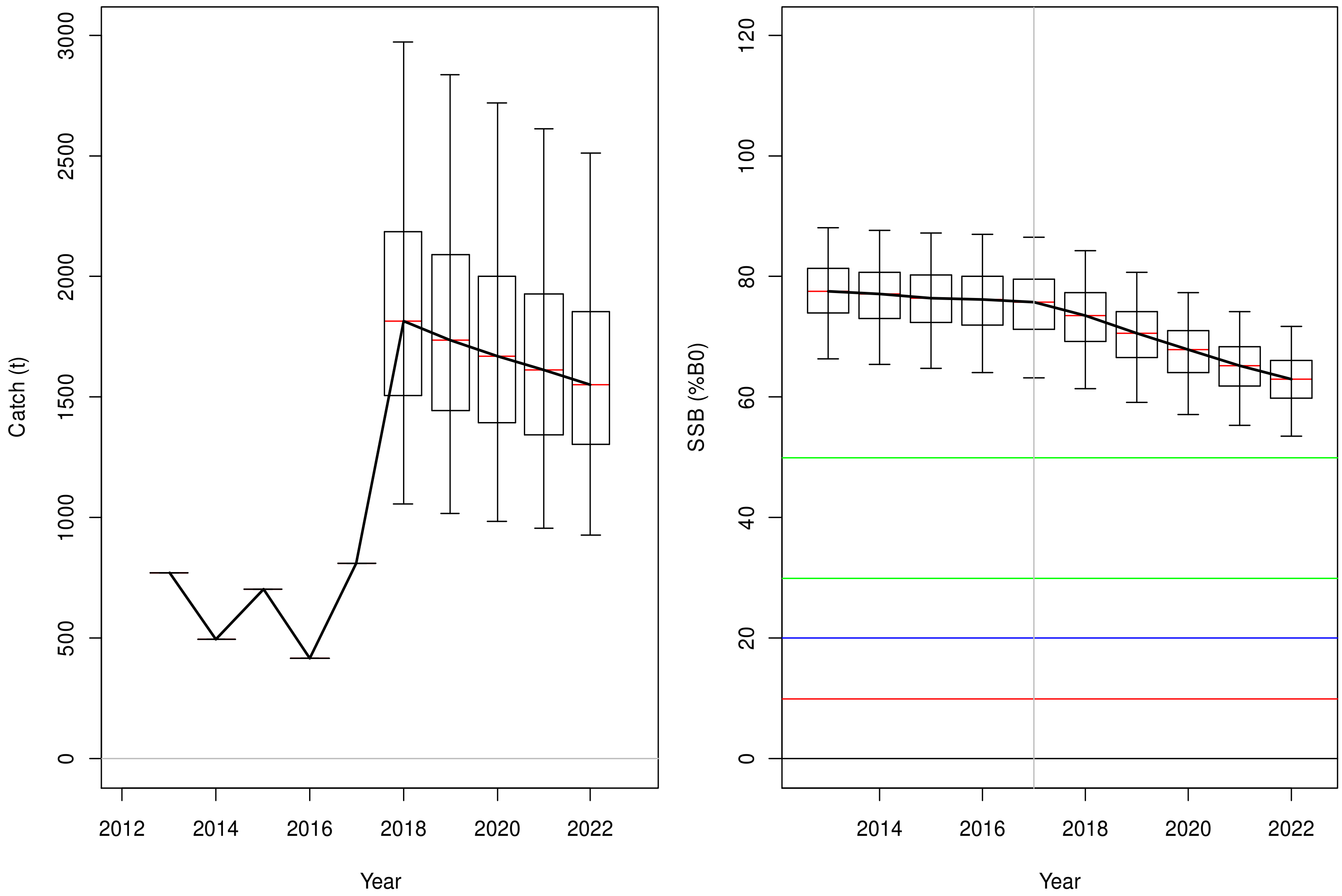
Low model projections at current catch



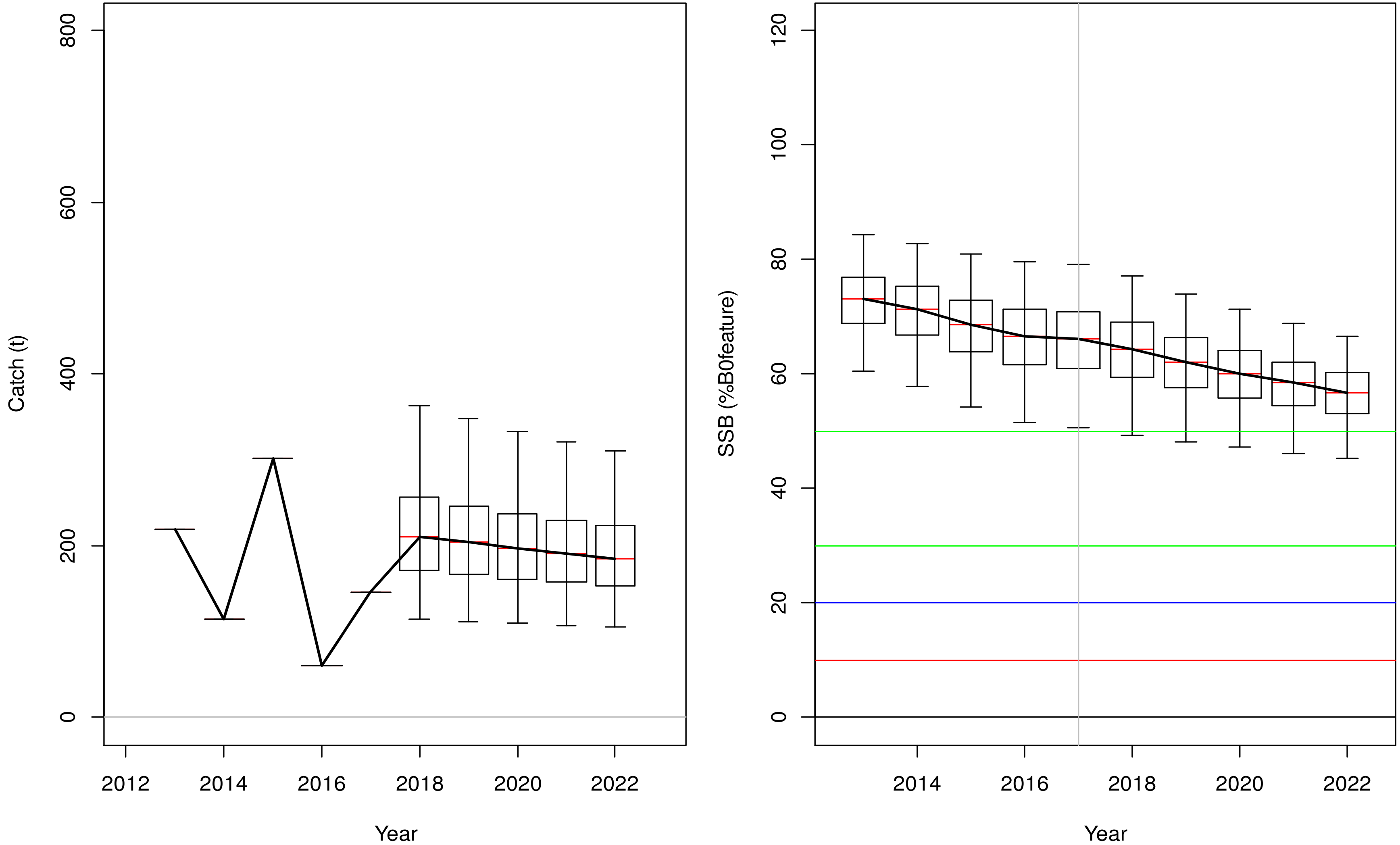
Low model projections at current catch



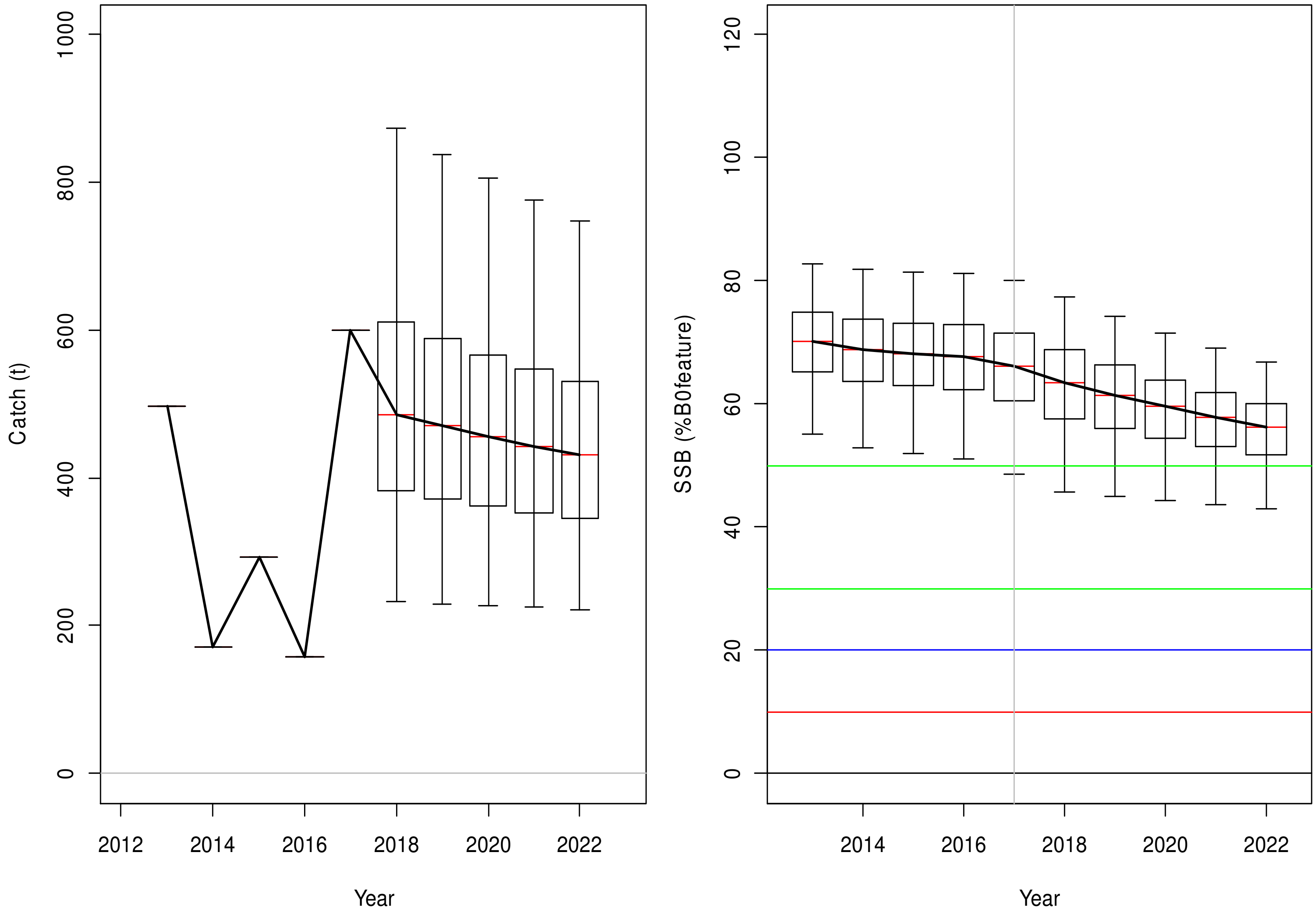
Whole stock:
Base model projections at U=5.625%



Feature 1:
Base model projections at U=5.625%



Feature 4:
Base model projections at U=5.625%



Conclusions

- Absolute scale of the WSR stock is very uncertain because the true scale of the acoustic biomass estimates is very uncertain
- Very probably B_0 is in the range: 25 000 – 90 000 t
- Stock status is certainly above 50% B_0
- Local depletion may be an issue for some un-numbered features if they were heavily fished in 2000/2001 and have not yet recovered
- Current catches with the current spatial distribution are fine (except perhaps for Feature 4)
- The challenge is to devise a practical management regime that maintains the stock at sustainable levels and avoids local depletion of any of the sub-stocks.