An assessment for the eastern Bering Sea snow crab fishery

Cody Szuwalski and Jack Turnock

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Table 1: Historical status and catch specifications for snow crab (1,000t).

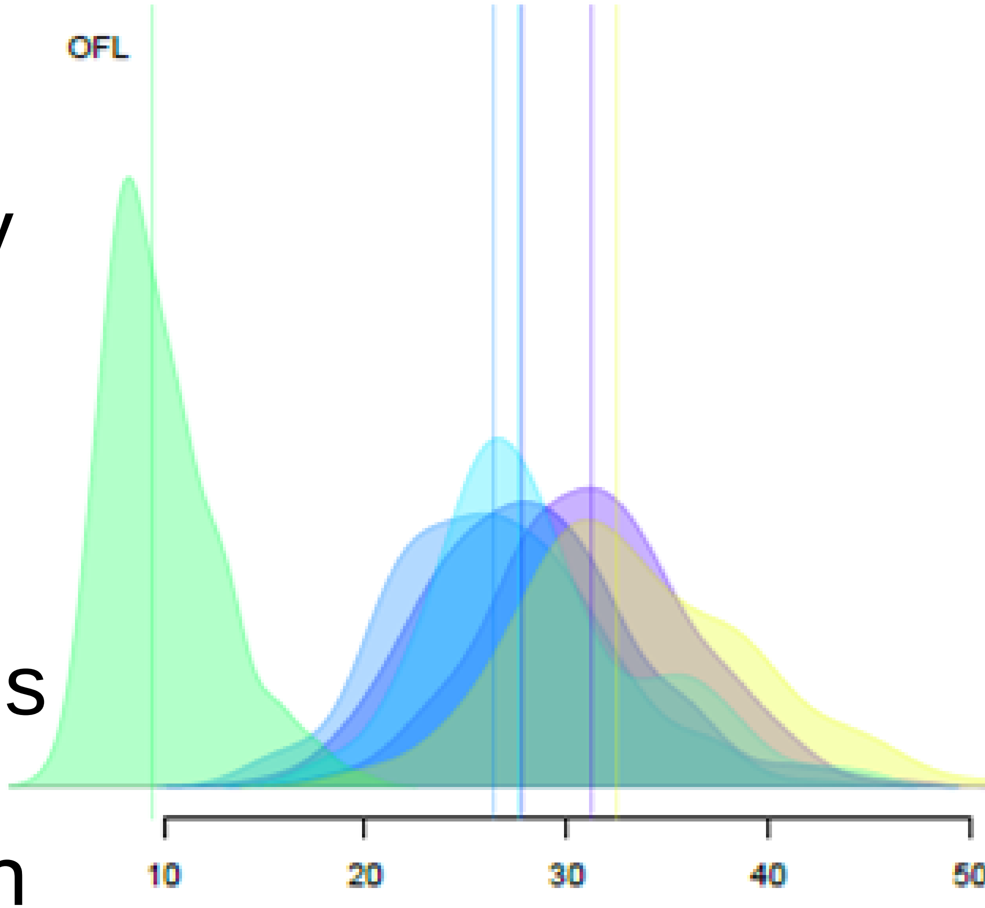
Year	MSST	Biomass (MMB)	TAC	Retained catch	Total catch	OFL	ABC
2011/2012	77.3	165.2	40.3	40.5	42	73.5	66.2
2012/2013	77.1	170.1	30.1	30.1	32.4	67.8	61
2013/2014	71.5	126.5	24.5	24.5	27.7	78.1	69.3
2014/2015	73.2	129.3	30.8	30.8	34.3	69	62.1
2015/2016	73.2	123.5	13.4	13.4	16.4	61.5	55.4
2016/2017	77.5	109.4				32.4	29.2

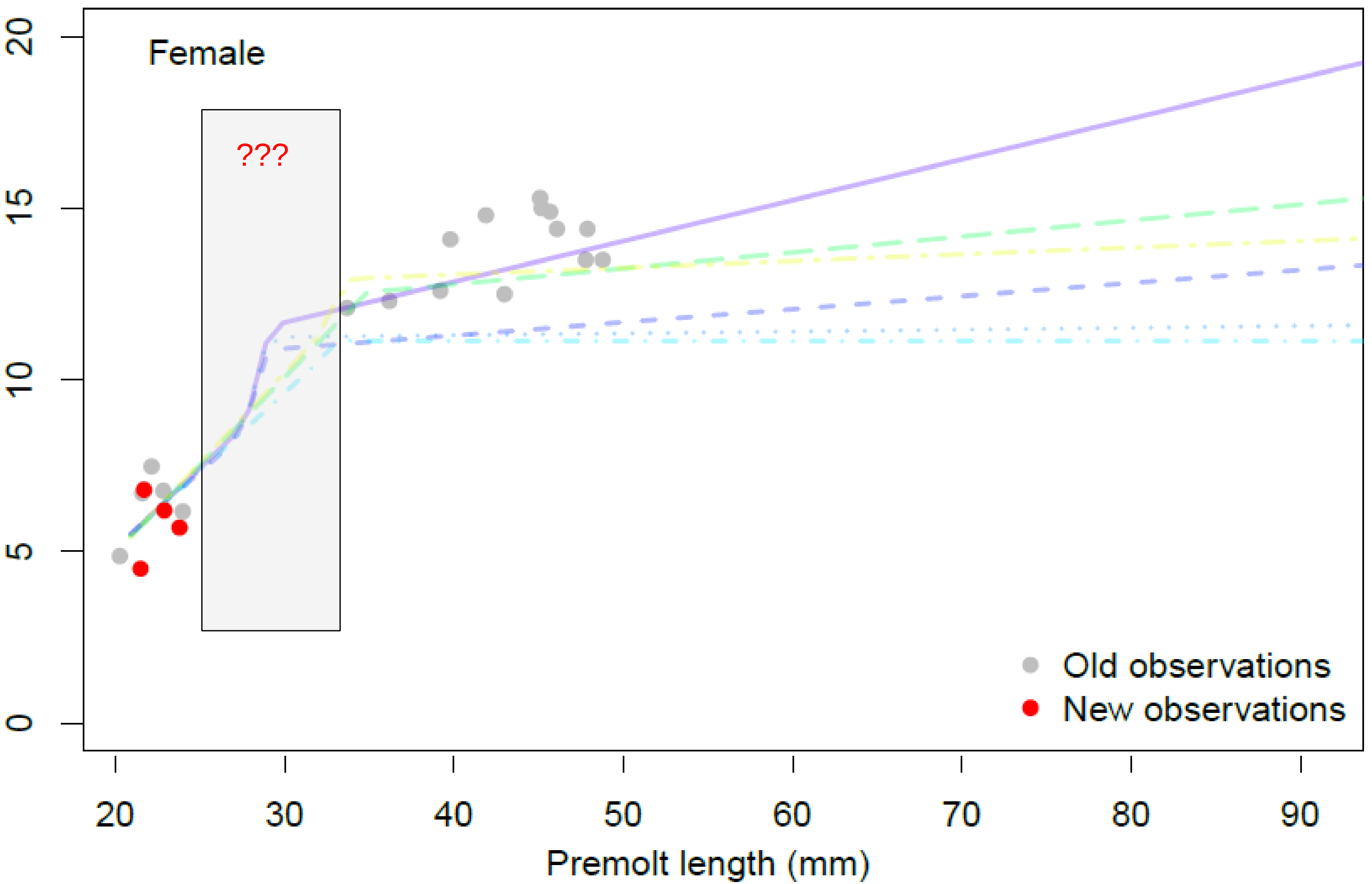
Summary of major changes

1. New data:
    1. 5 growth data points
    2. Added catch data from all sources
    3. Added survey data
    4. Weight at length data
2. Model structure did not change
3. Recommended OFL is based on Bayesian methods
    1. MLE approaches are also presented, but are not much different than the Bayesian methods.

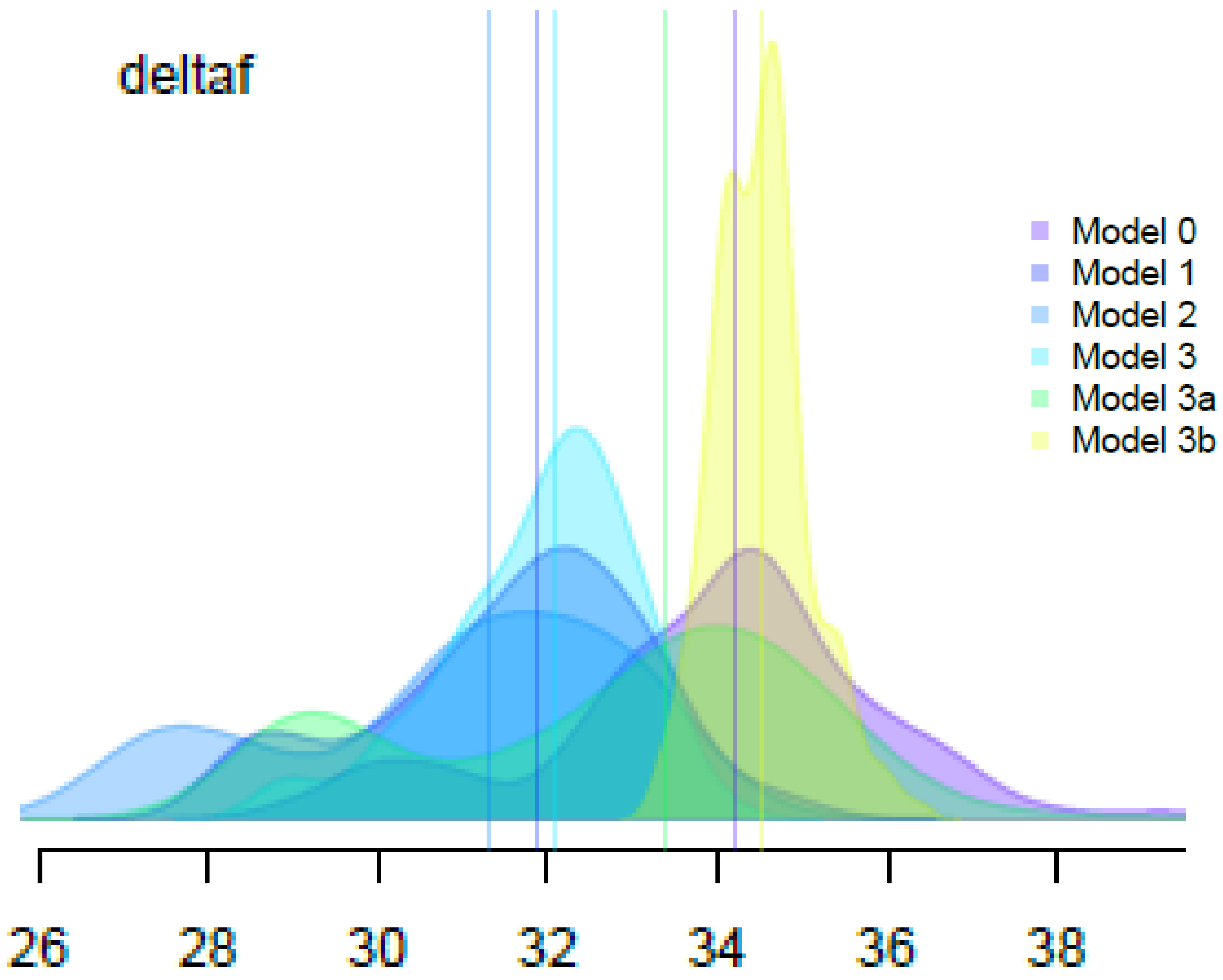
Why Bayesian?

- Think ‘distributions’
- Incorporates all uncertainty
- Provides intuitive distributions of quantities important in management
- Imposes fewer assumptions on the data and allows them to ‘speak’ (even when the answer is ‘I don’t know’)





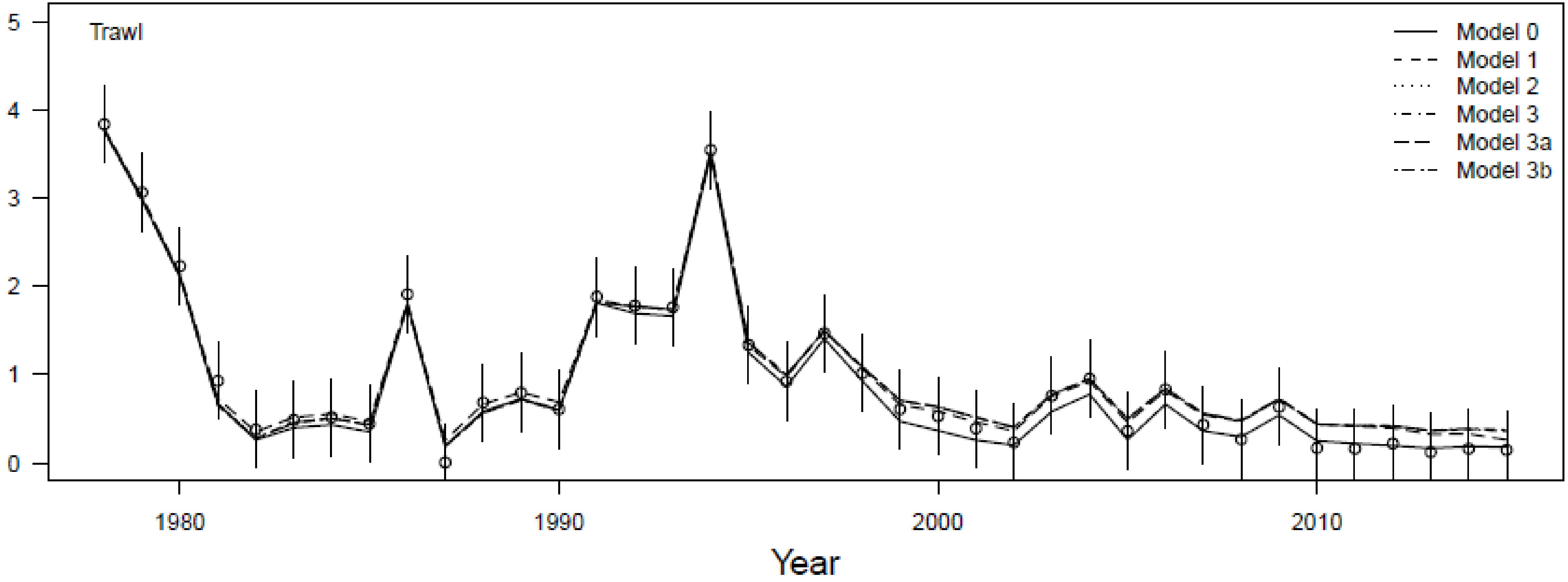
Female
???
Old observations
New observations
Premolt length (mm)
20
30
40
50
60
70
80
90
0
5
10
15
20


deltaf
Model 0
Model 1
Model 2
Model 3
Model 3a
Model 3b
26
28
30
32
34
36
38

- Model 0:
  - Only small structural changes from above were implemented to provide a comparison to last year's model (described below)
- Model 1:
  - All changes in model 0
  - Estimate average F for the groundfish trawl, rather than specifying it
  - Remove penalties on F from 1992 to present
  - Estimate a separate vector of F_devs for 1978-90 and 1991-present
  - Estimate a constant of proportionality between fishing effort in the pot fishery and F for the females in the pot fishery
- Model 2:
  - All changes in model 1
  - Remove priors on probabillity of maturing for males and females
- Model 3:
  - Increase the weight on the smoothness penalty for the probability of maturity
  - Estimate the 50% selectivity parameter for female discard
- Model 3a:
  - All changes in model 3
  - Decrease the effective sample sizes for survey size composition data by applying Francis' weighting methodology
- Model 3b:
  - All changes in model 3
  - Increase weighting on female growth likelihood
  - Decrease the variance for the prior on natural mortality

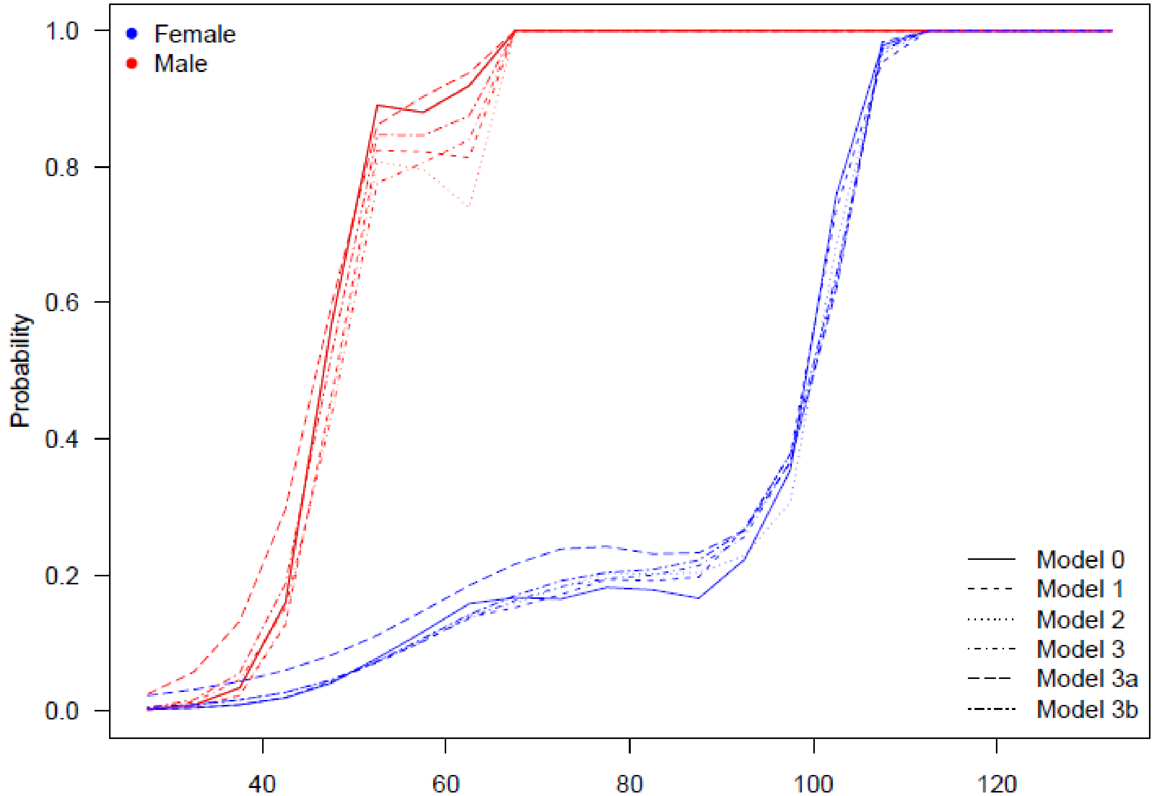
Motivation for model changes

- **Model 1** was directed at 'fixing' the model fits to the trawl.
  - Not terribly successful—size comps have influence.



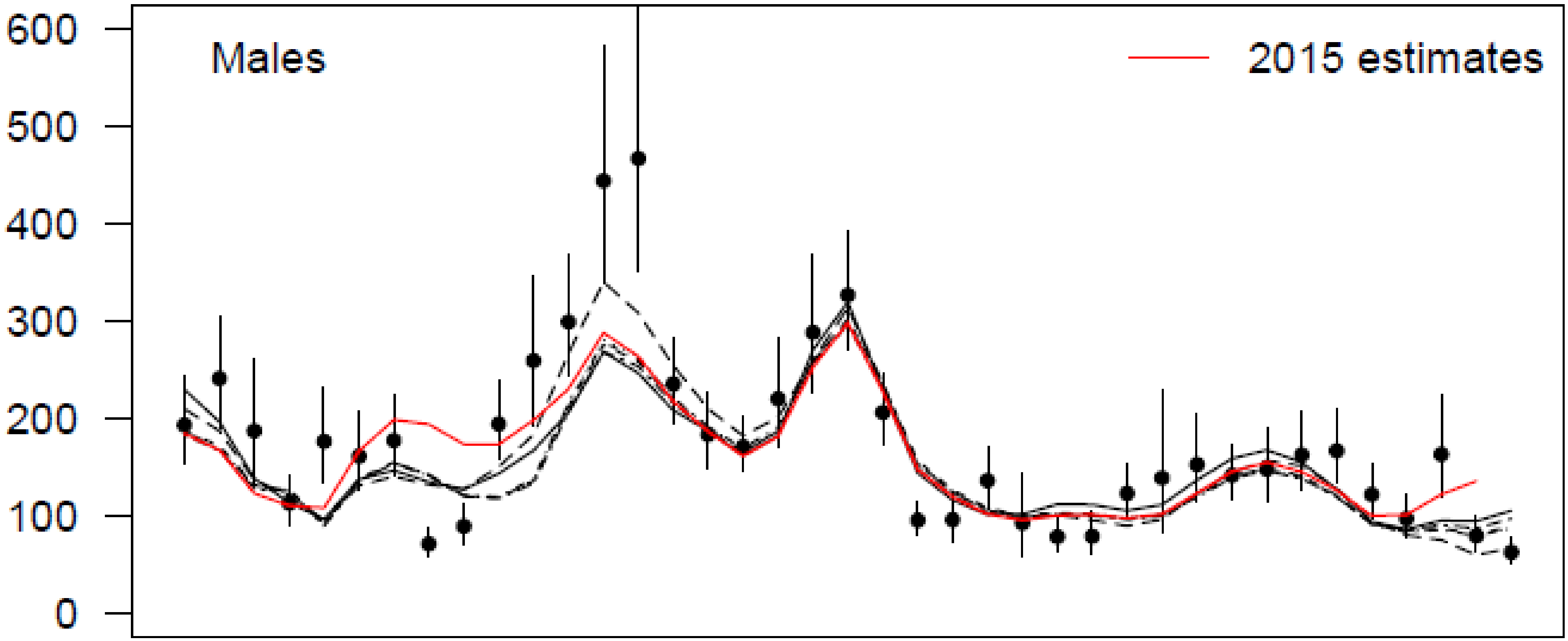
Motivation for model changes

- **Model 1** was directed at ‘fixing’ the model fits to the trawl.
  - Not terribly successful—size comps have influence.
- **Model 2 and 3** were directed at limiting the assumptions placed on maturity and female discards.
  - ‘Worked’ but maturity can change a lot when weightings are changed.



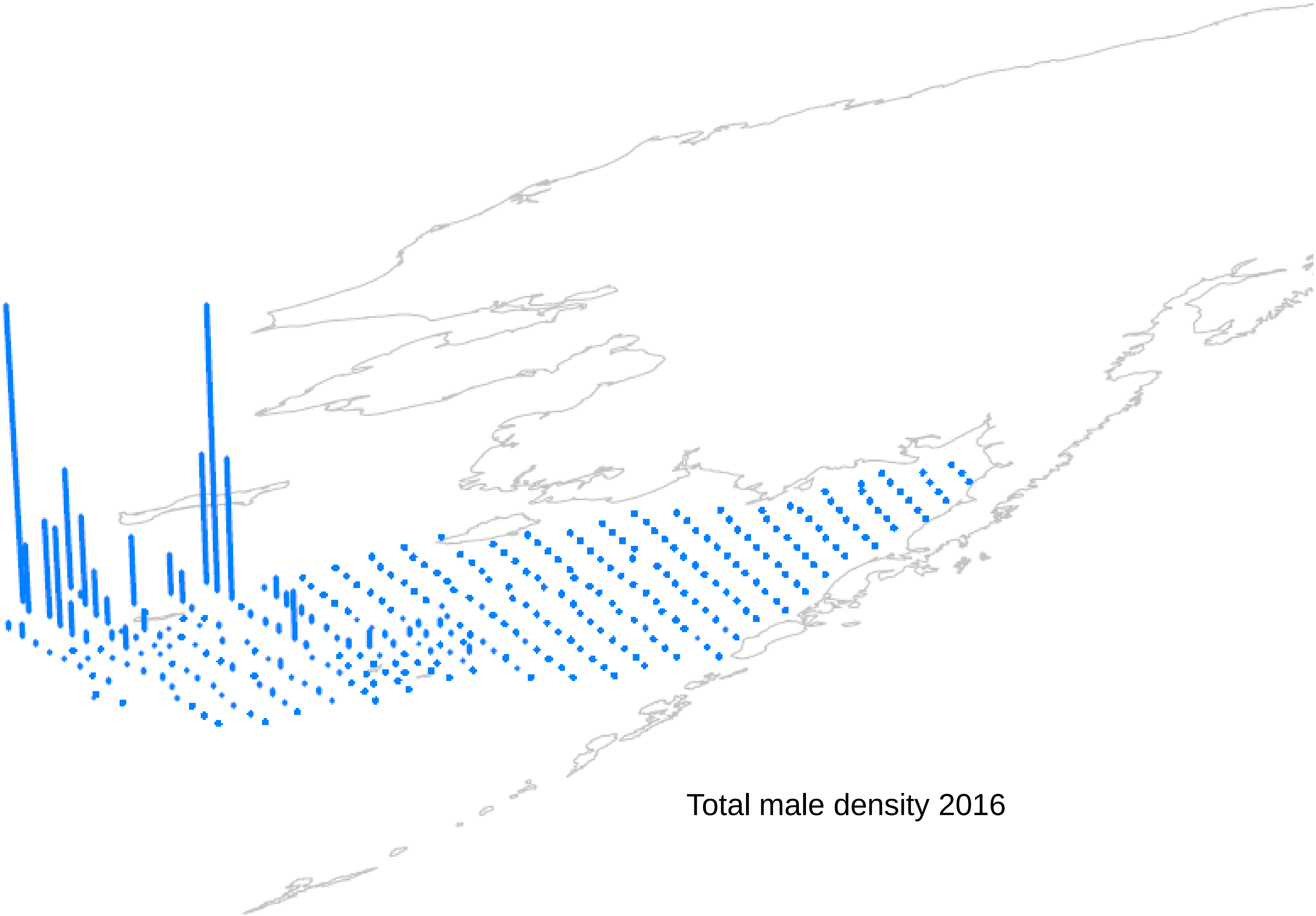
Motivation for model changes

- **Model 3a** was aimed at exploring the ability of the model to fit the survey biomass by down-weighting size composition data.
  - Changes model estimates and management quantities a lot—survey catchability and maturity change.

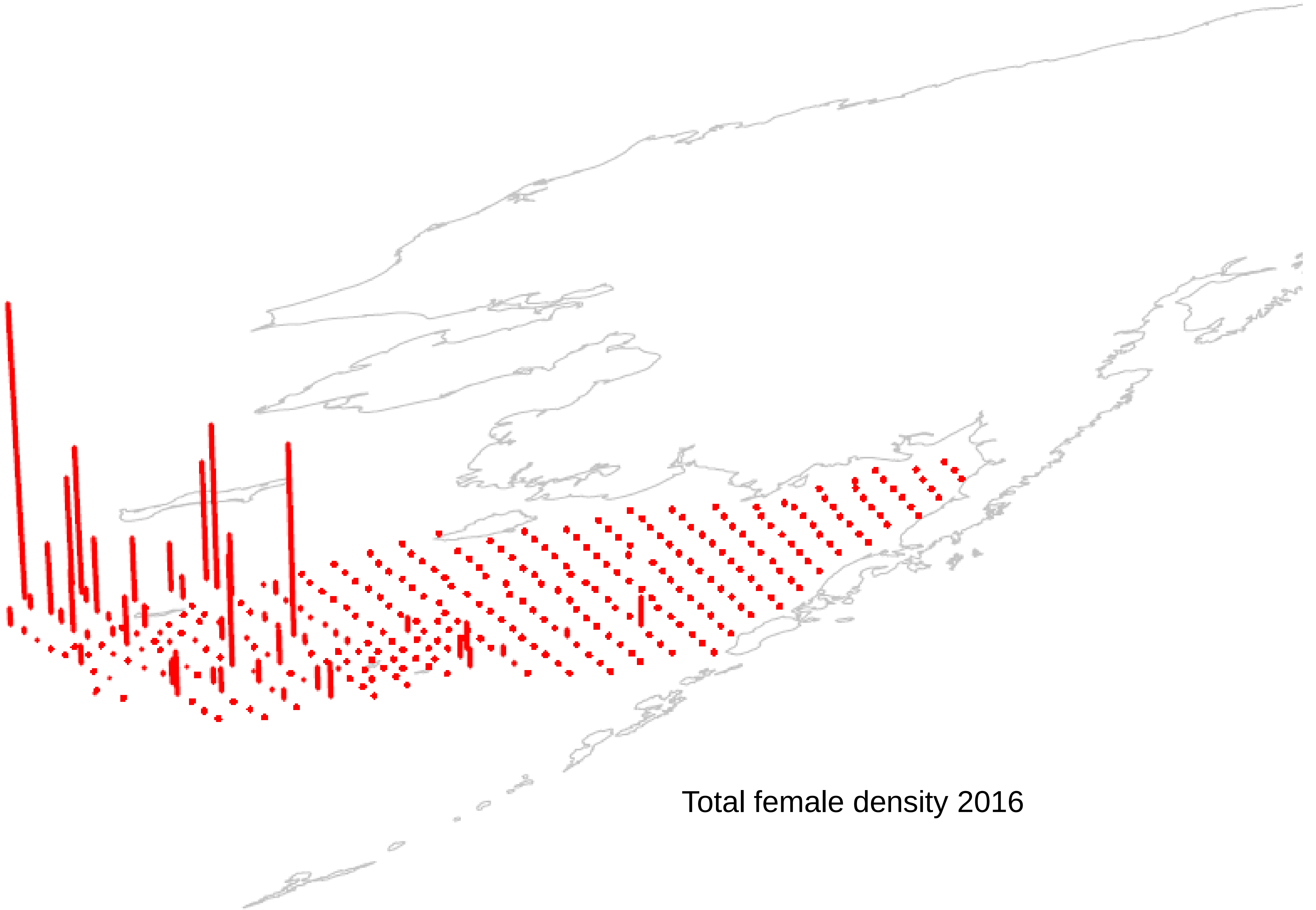


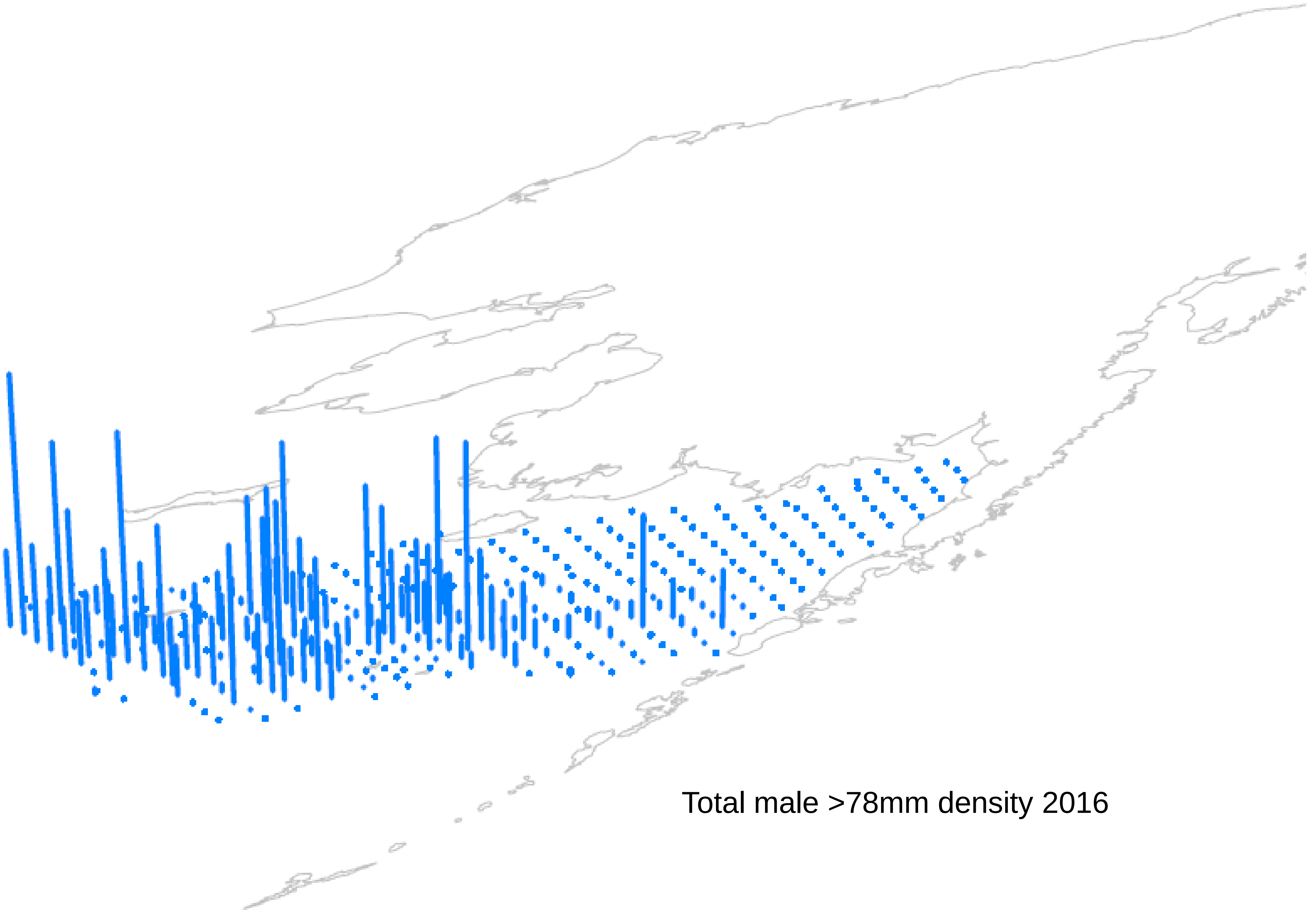
Motivation for model changes

- **Model 1** was directed at 'fixing' the model fits to the trawl.
    - Not terribly successful—size comps have influence.
- **Model 2 and 3** were directed at limiting the assumptions placed on maturity and female discards.
    - 'Worked' but maturity can change a lot when weightings are changed.
- **Model 3a** was aimed at exploring the ability of the model to fit the survey biomass by downweighting size composition data.
    - Changes model estimates and management quantities a lot—survey catchability and maturity change.
- **Model 3b** was a model I added that attempted to fit female growth and pull natural mortality away from its bounds

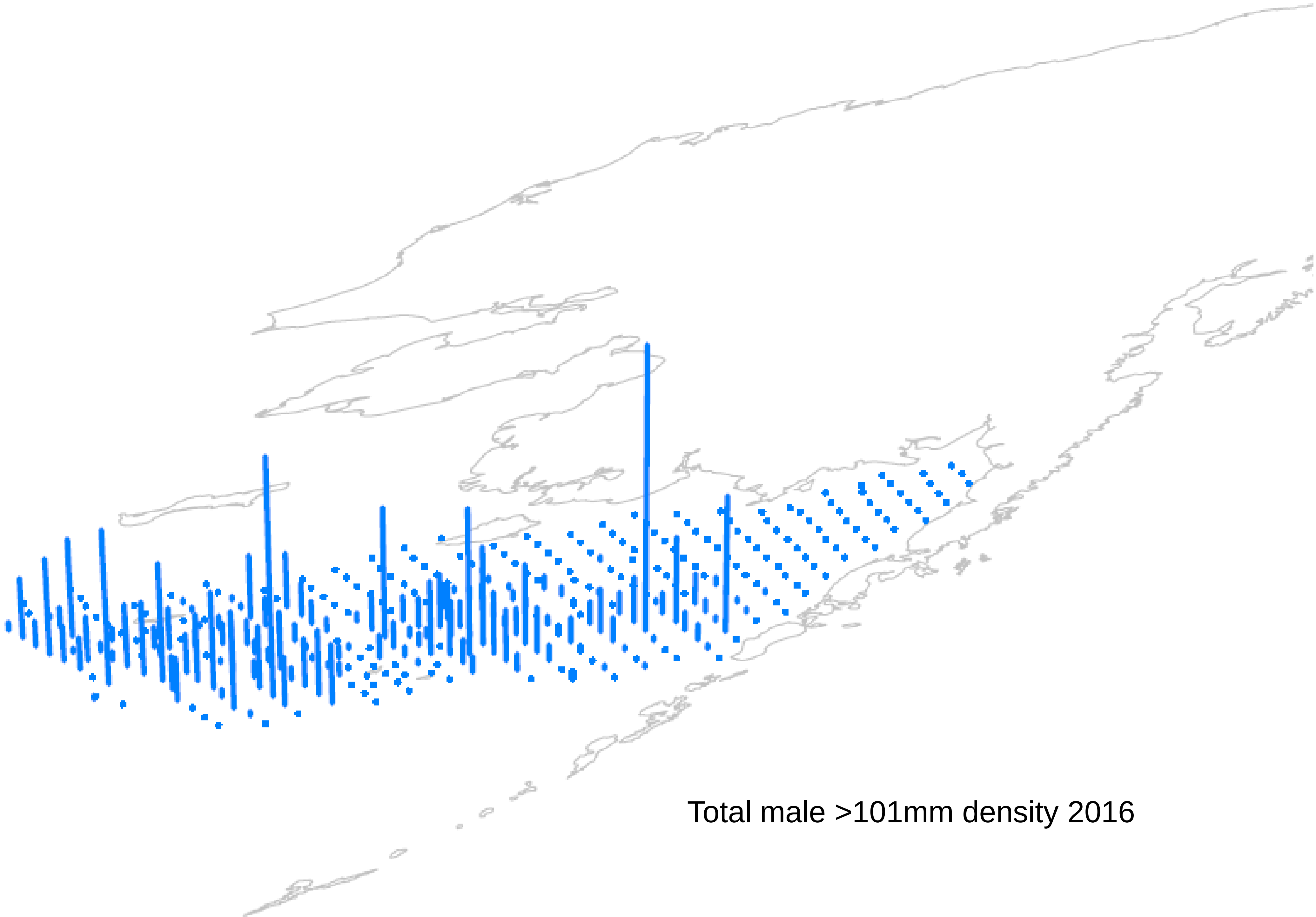


Total male density 2016

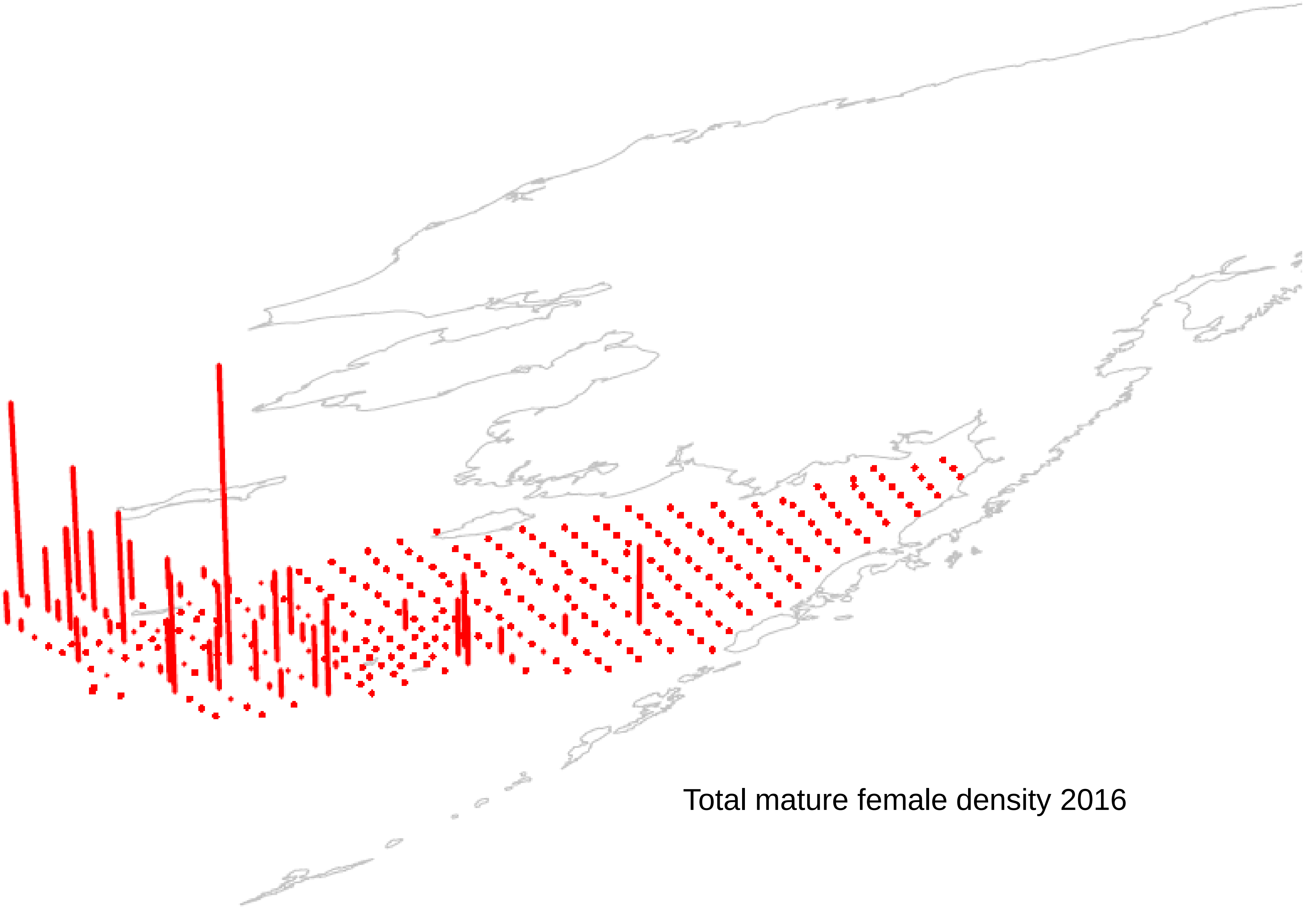

Total female density 2016



Total male >78mm density 2016



Total male >101mm density 2016



Total mature female density 2016

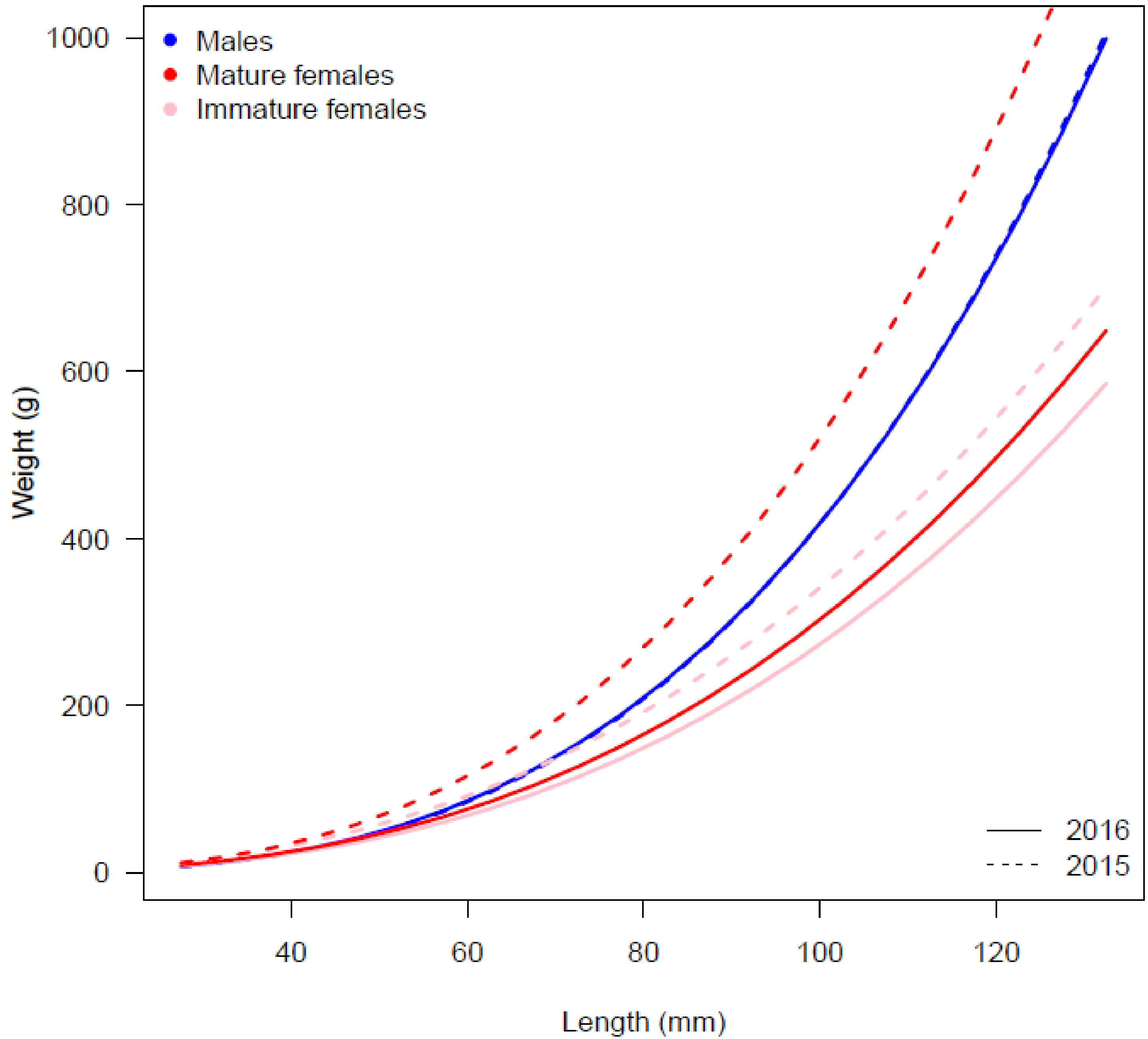


Figure 6: Changes in weight at length from 2015 to 2016 assessment

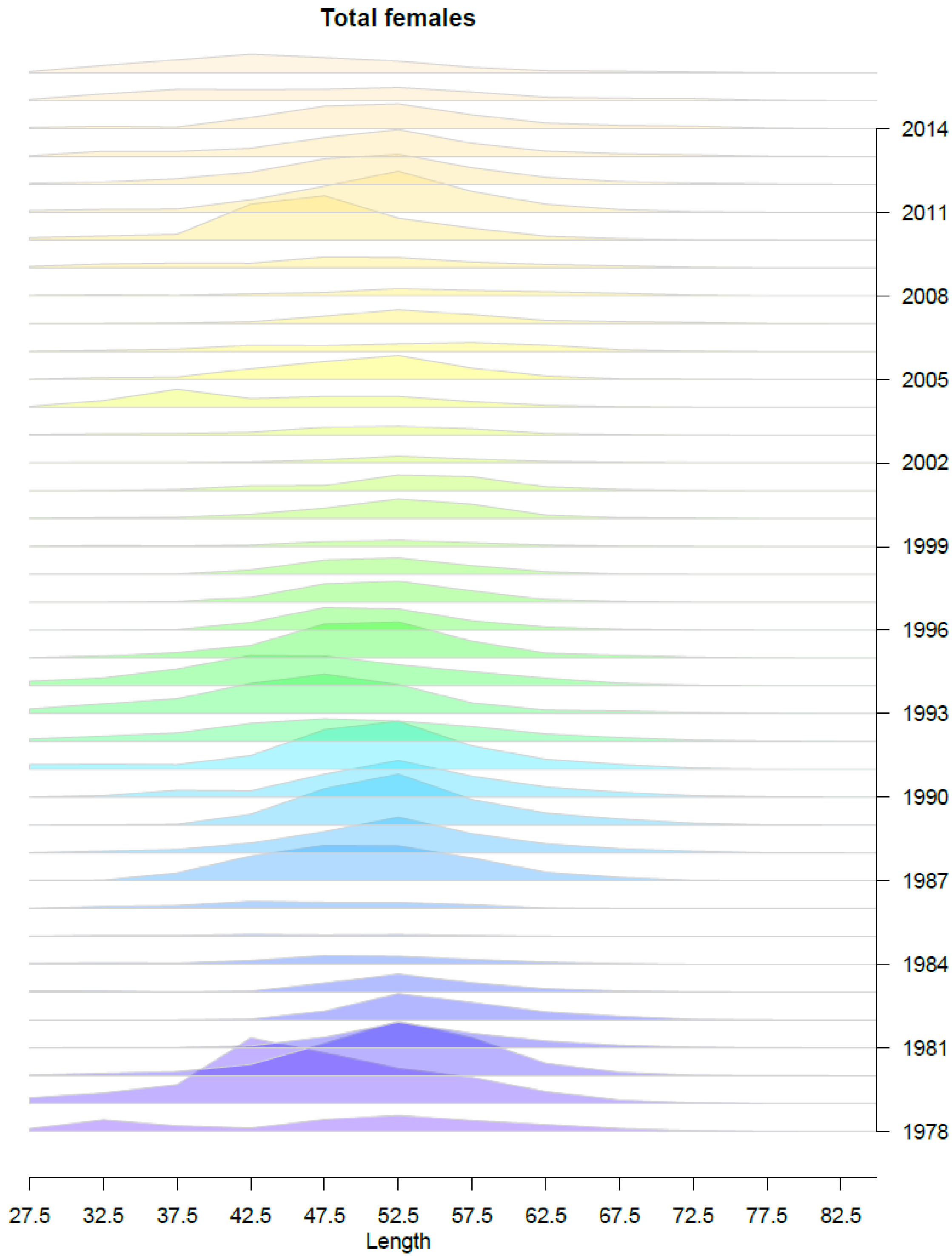


Figure 8: Observed relative numbers at length at the time of the survey

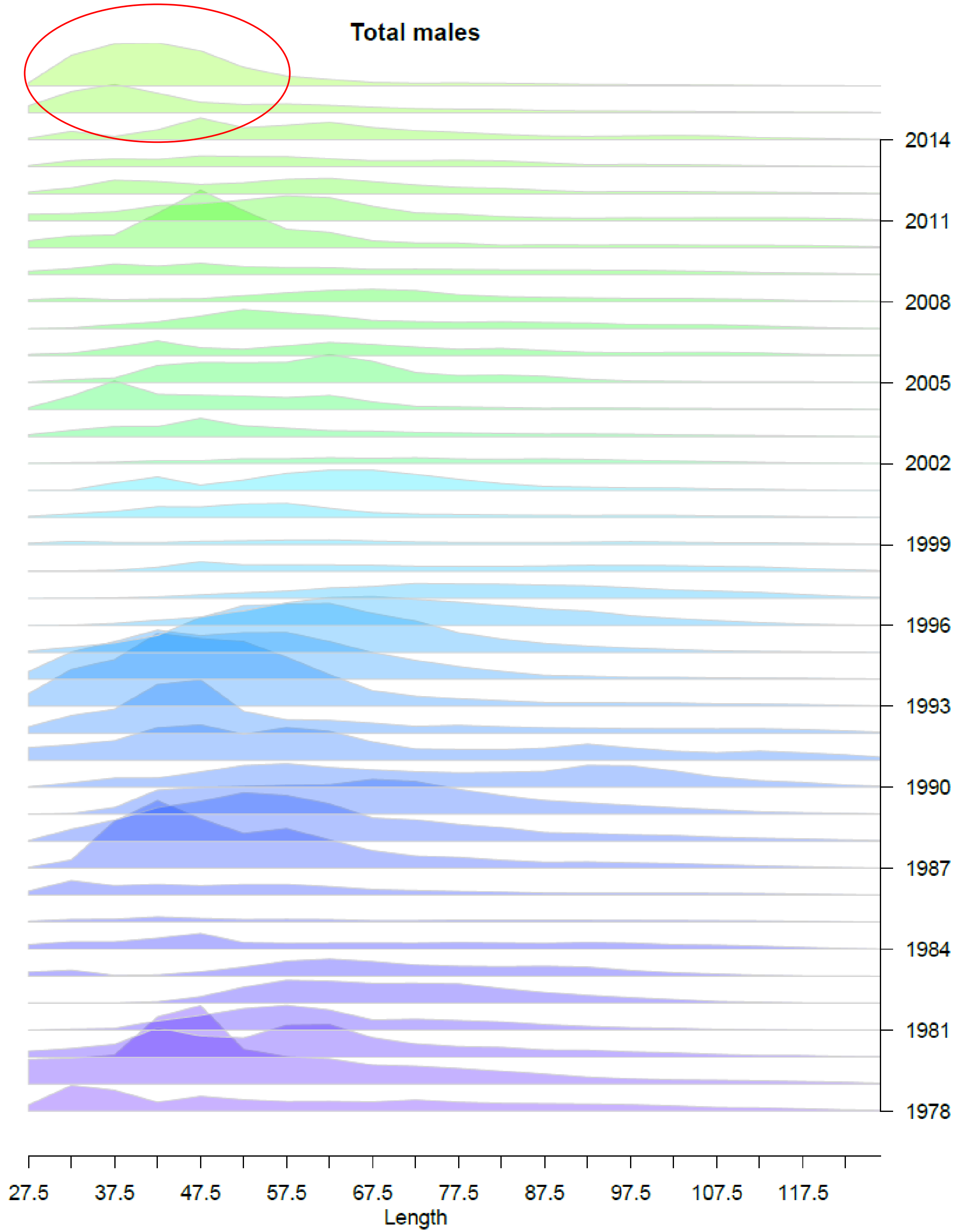
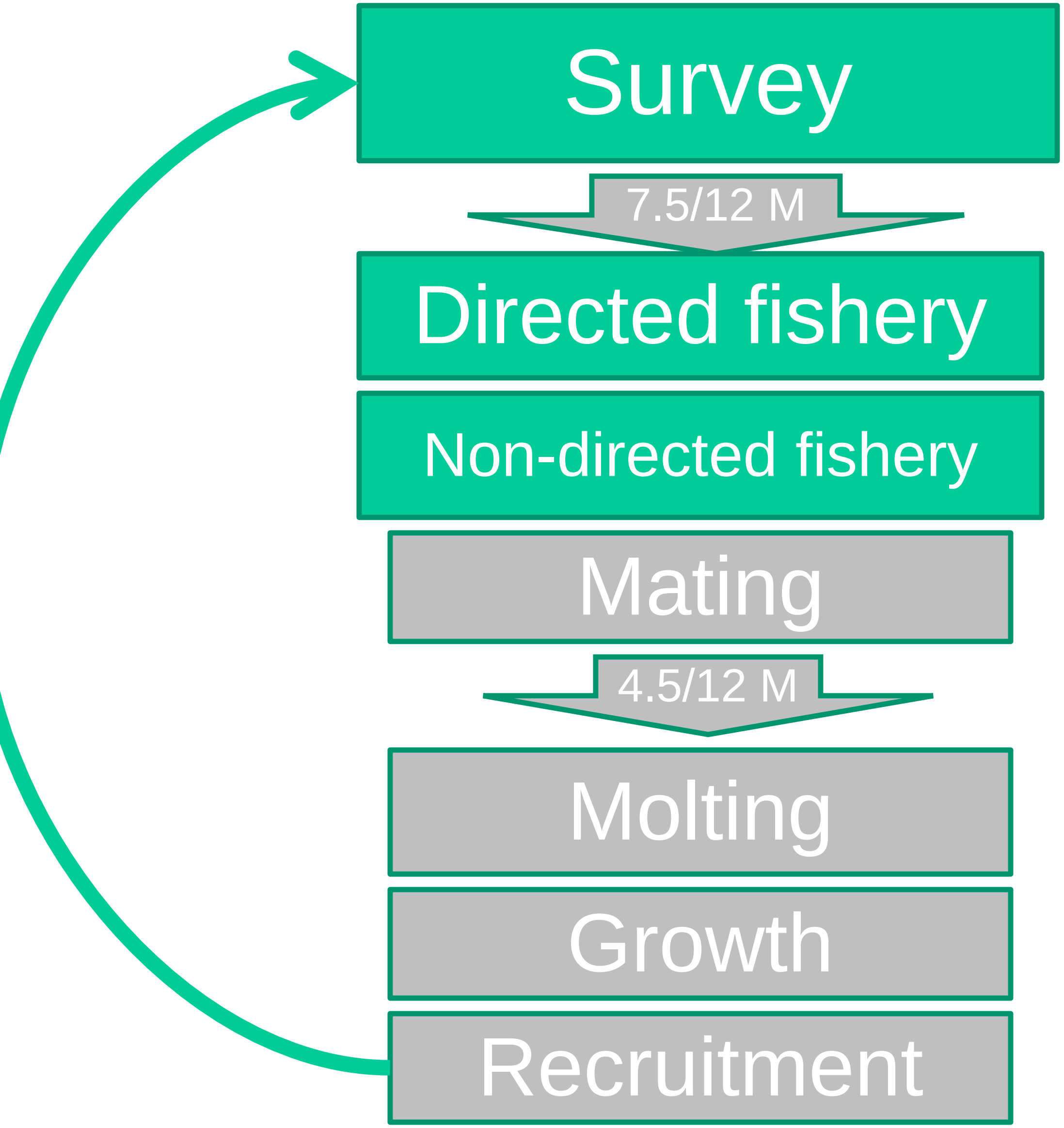


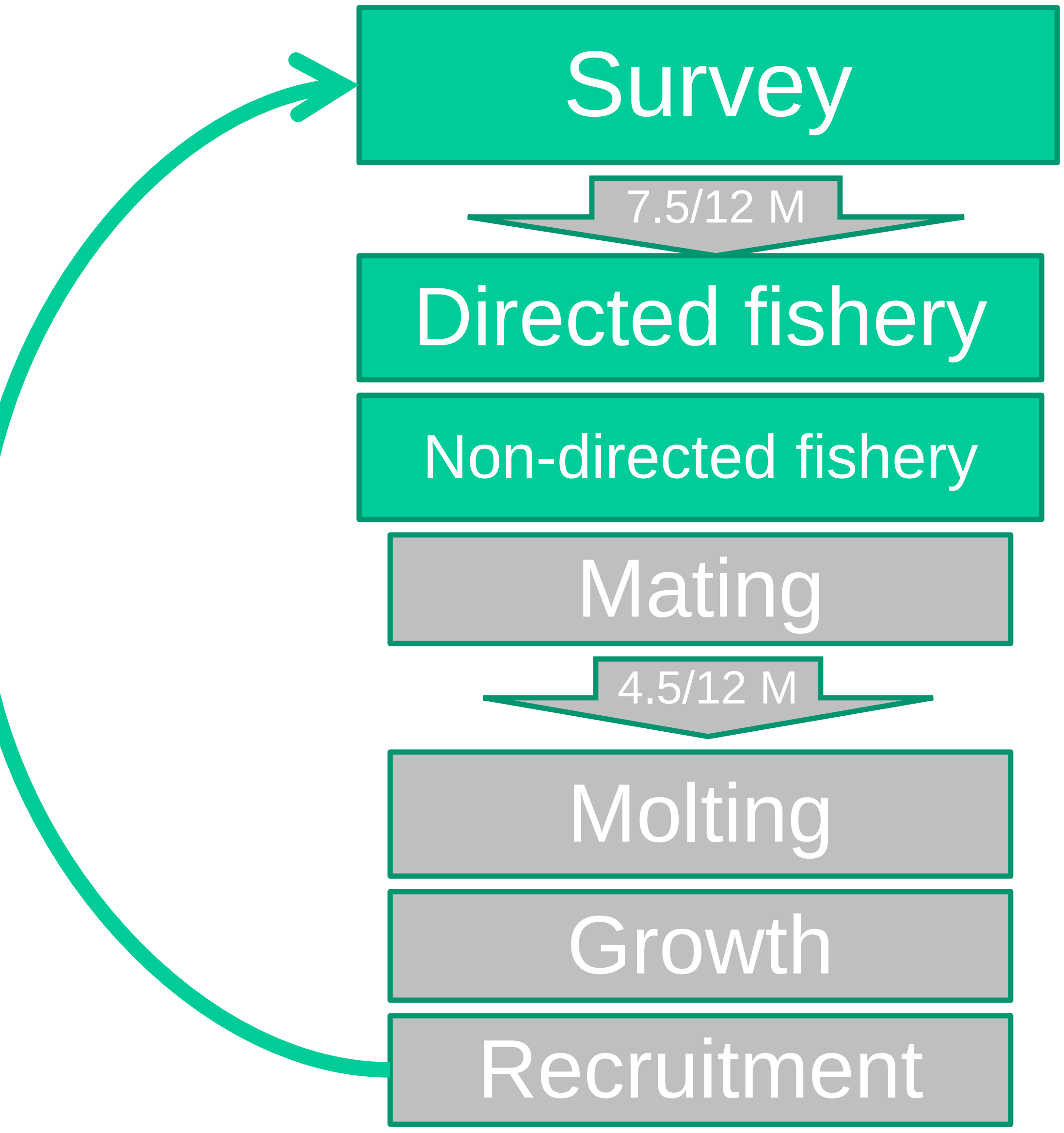
Figure 9: Observed relative numbers at length at the time of the survey

Model overview



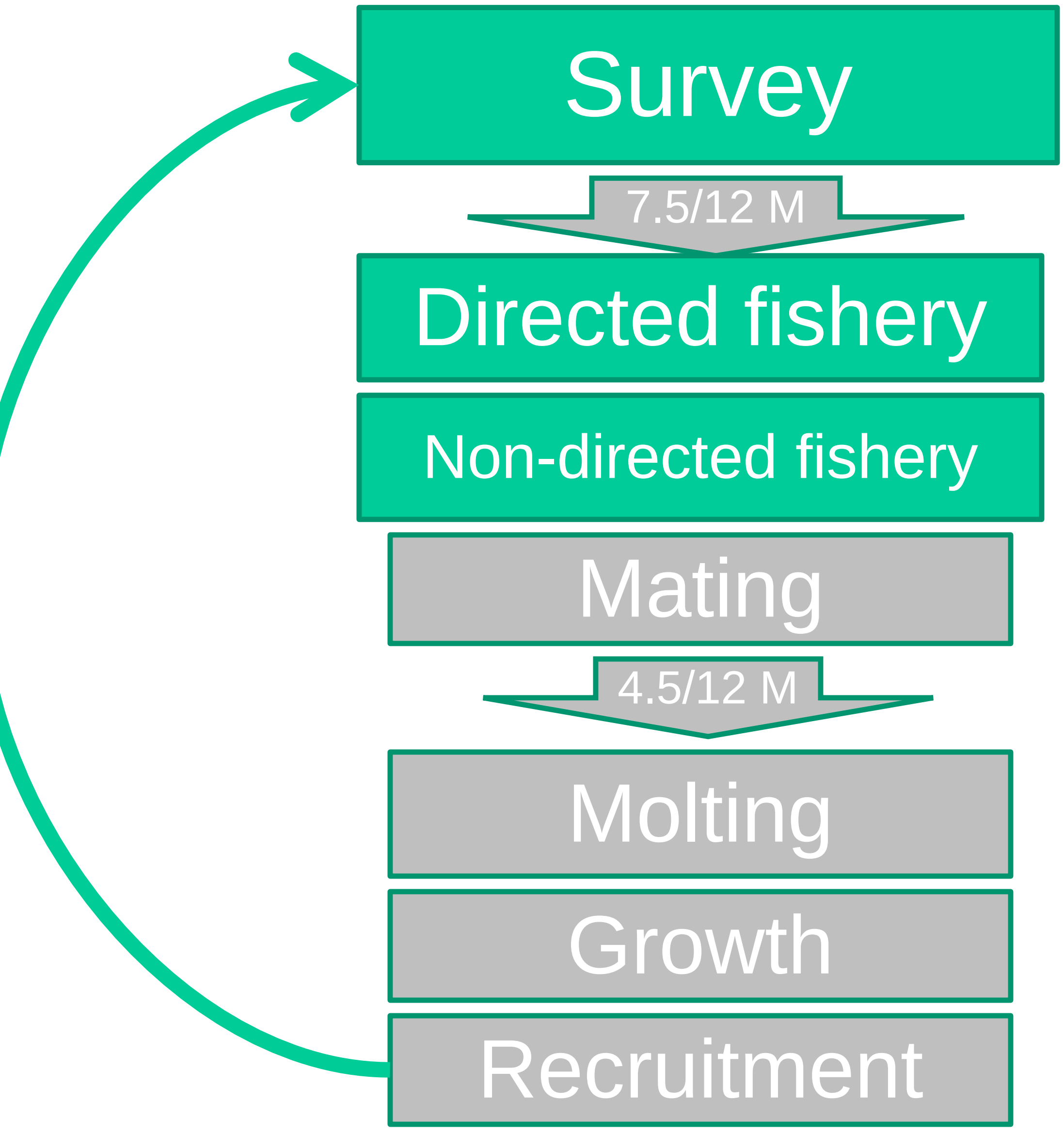
1. Logistic selectivity in 3 ‘eras’
2. Linked to BSFRF data through a common selectivity
3. Size composition and biomass index

Model overview



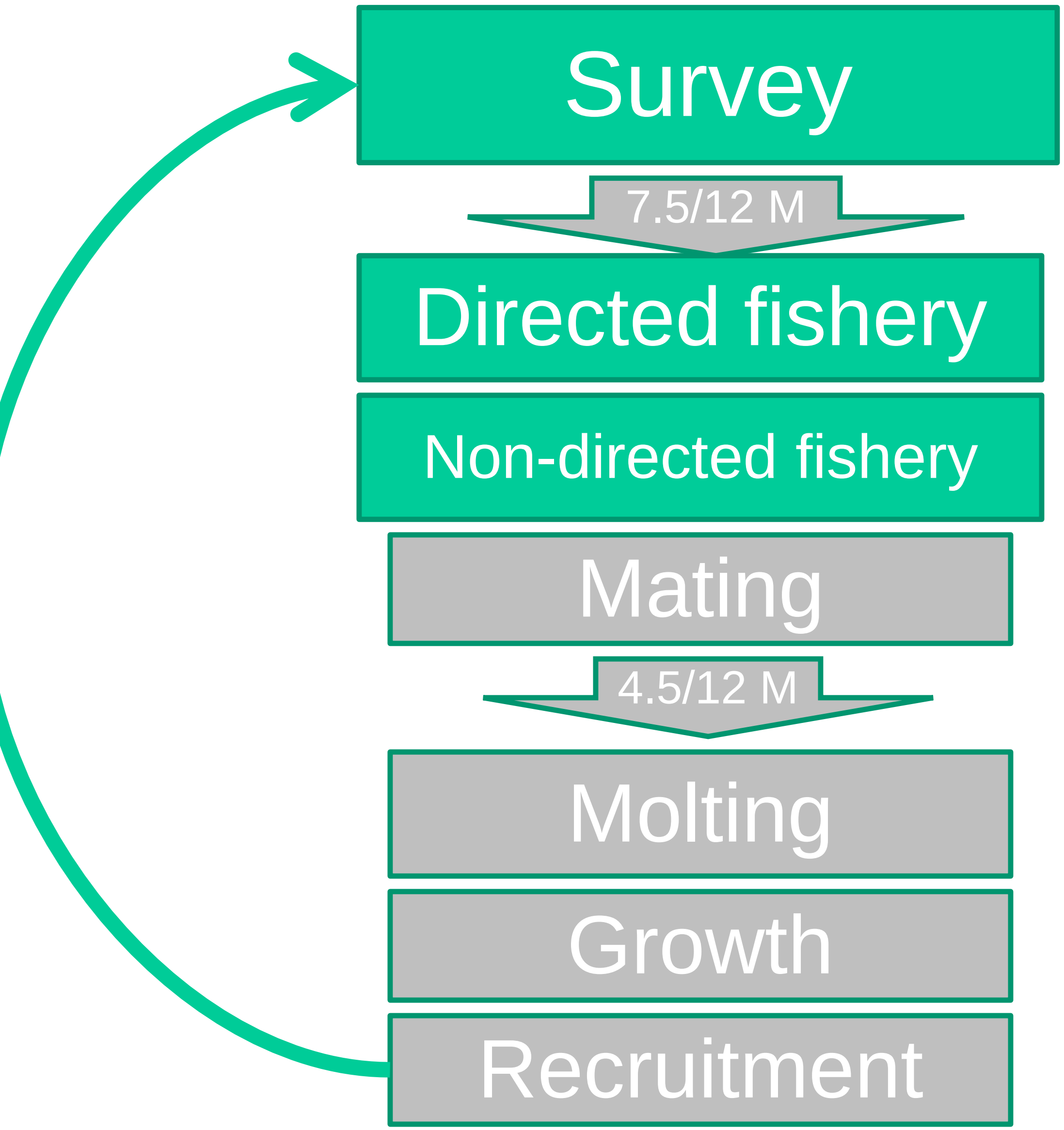
1. Mature males, mature females, immature for both sexes
2. Estimated with a prior

Model overview



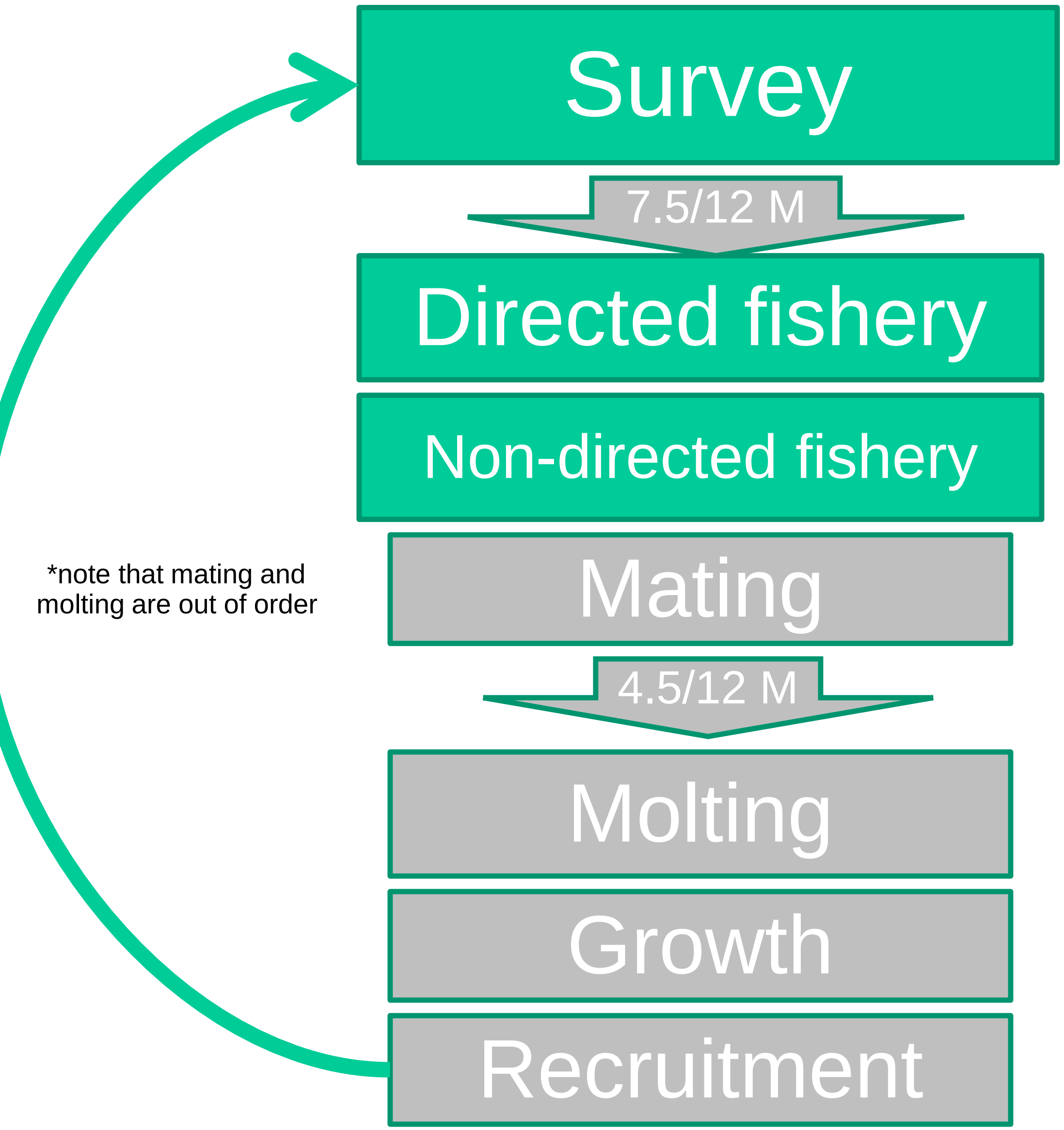
1. Logistic selectivity
2. Retention selectivity
3. Discard mortality equal to 30%

Model overview



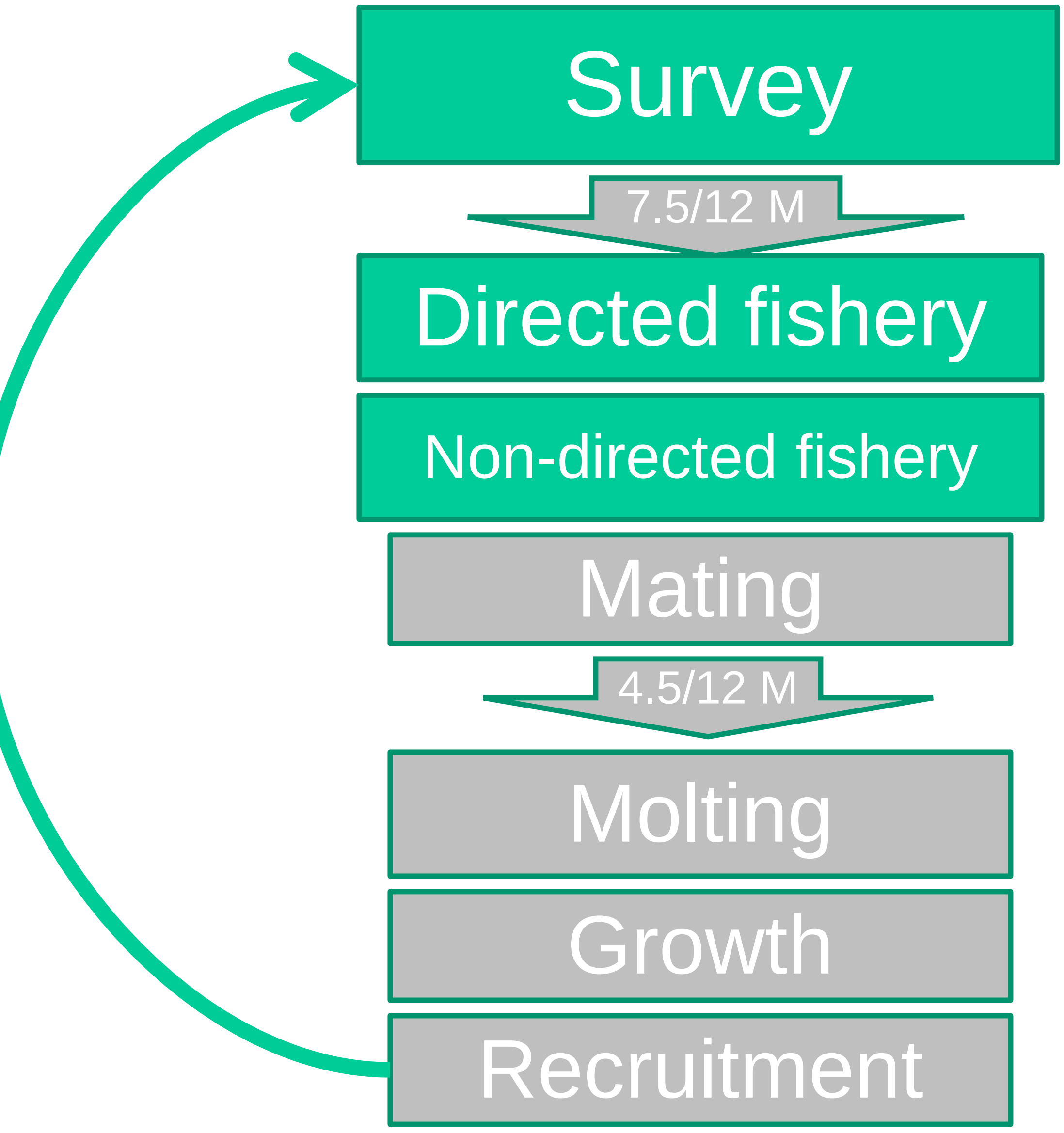
1. Logistic selectivity
2. Discard mortality equal to 80%

Model overview



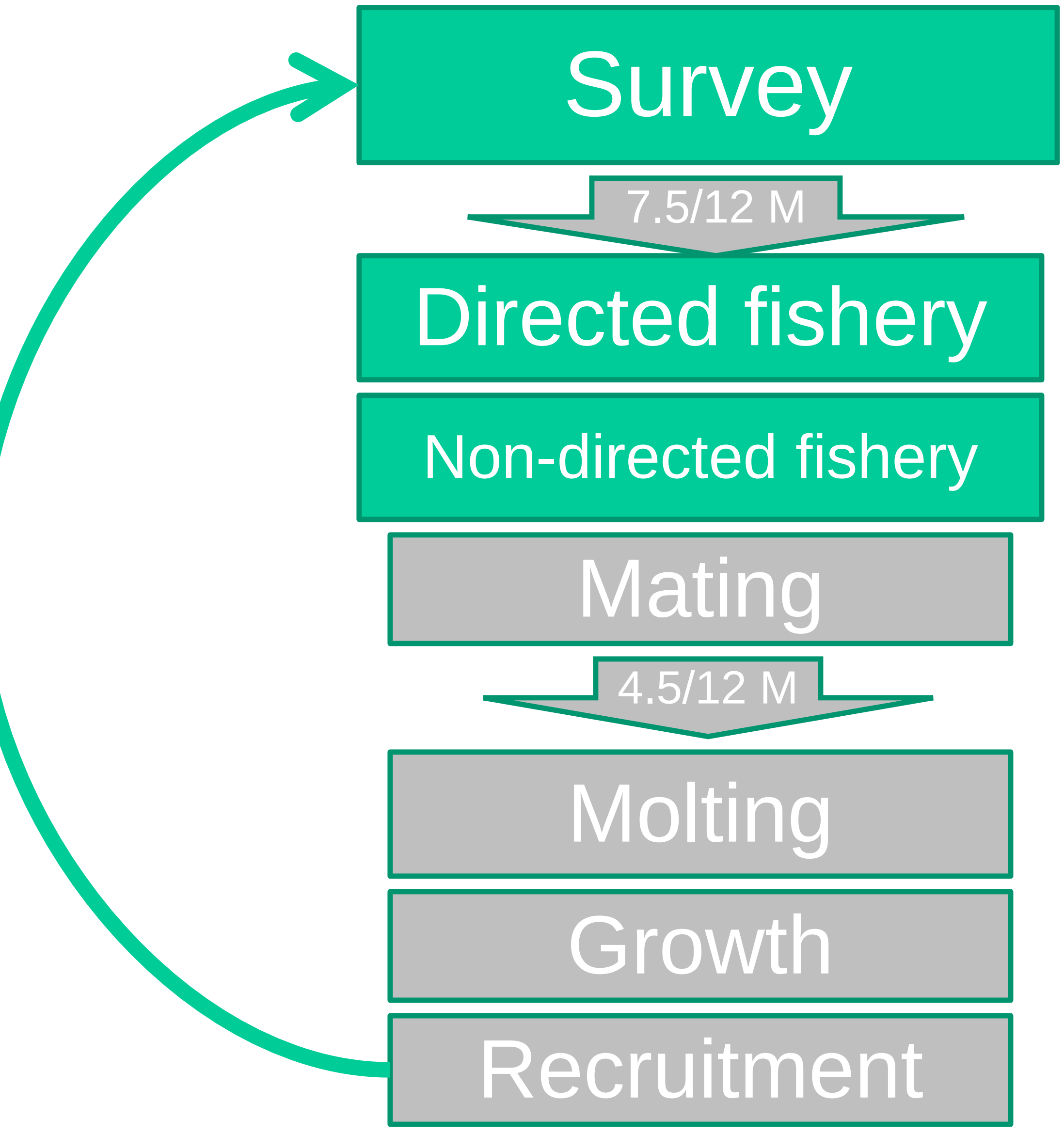
1. Freely estimated probability of maturing
2. Priors and smoothing parameters

Model overview



1. All immature crab assumed to molt
2. Terminal molt to maturity

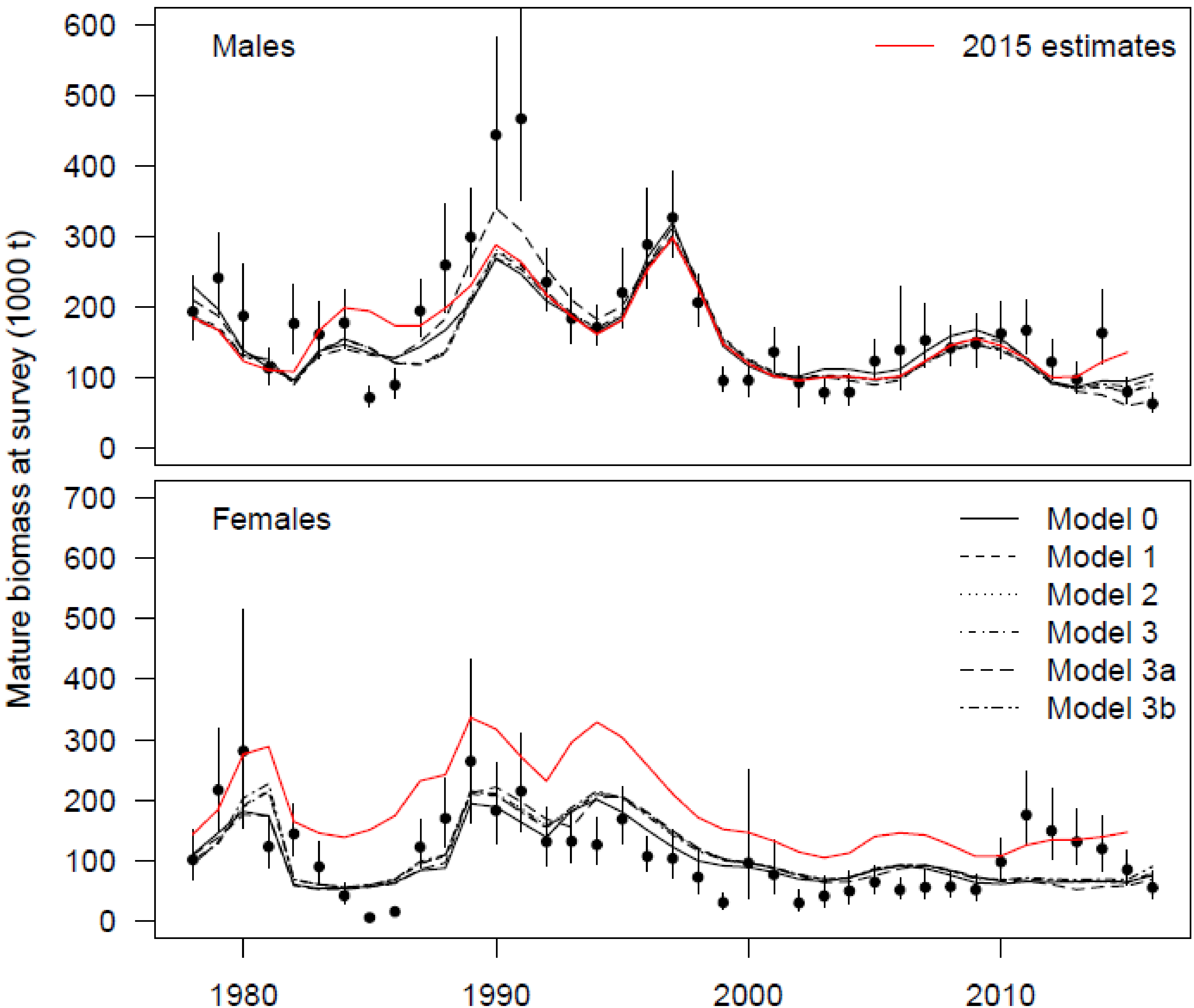
Model overview



1. Two piece linear growth models estimated for both sexes

- Model 0:
  - Only small structural changes from above were implemented to provide a comparison to last year's model (described below)
- Model 1: Trawl mortality
  - All changes in model 0
  - Estimate average F for the groundfish trawl, rather than specifying it
  - Remove penalties on F from 1992 to present
  - Estimate a separate vector of F_devs for 1978-90 and 1991-present
  - Estimate a constant of proportionality between fishing effort in the pot fishery and F for the females in the pot fishery
- Model 2: Probability of maturing
  - All changes in model 1
  - Remove priors on probabillity of maturing for males and females
- Model 3: Female discards
  - Increase the weight on the smoothness penalty for the probability of maturity
  - Estimate the 50% selectivity parameter for female discard
- Model 3a: Size composition weights
  - All changes in model 3
  - Decrease the effective sample sizes for survey size composition data by applying Francis' weighting methodology
- Model 3b: Growth weight and M prior
  - All changes in model 3
  - Increase weighting on female growth likelihood
  - Decrease the variance for the prior on natural mortality

Model fits



Males
2015 estimates
Females
Model 0
Model 1
Model 2
Model 3
Model 3a
Model 3b
Mature biomass at survey (1000 t)
0
100
200
300
400
500
600
700
1980
1990
2000
2010

Model evaluation

Model 0:
- Fits the terminal year of MMB worst

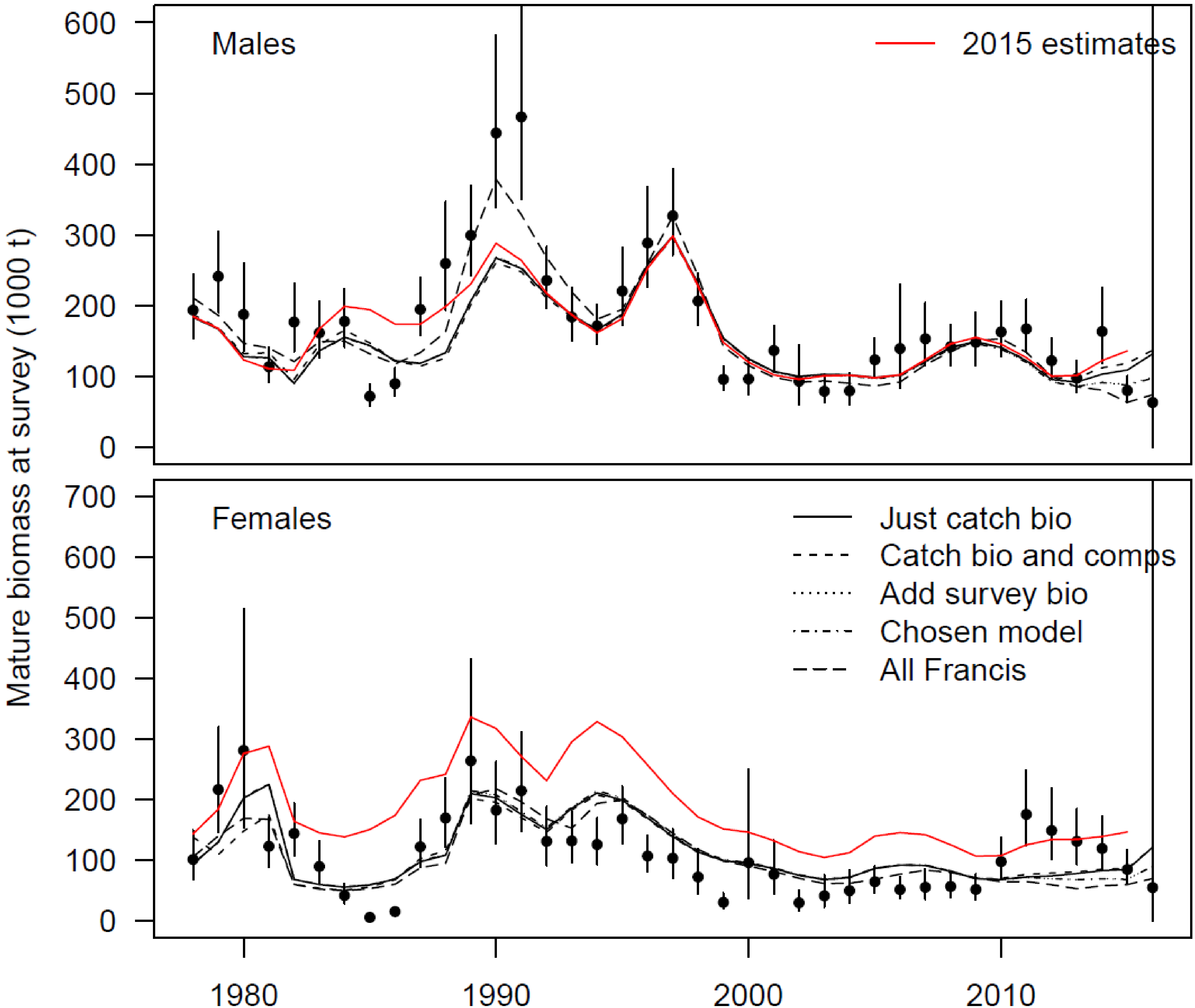
Model 1:

Model 2:

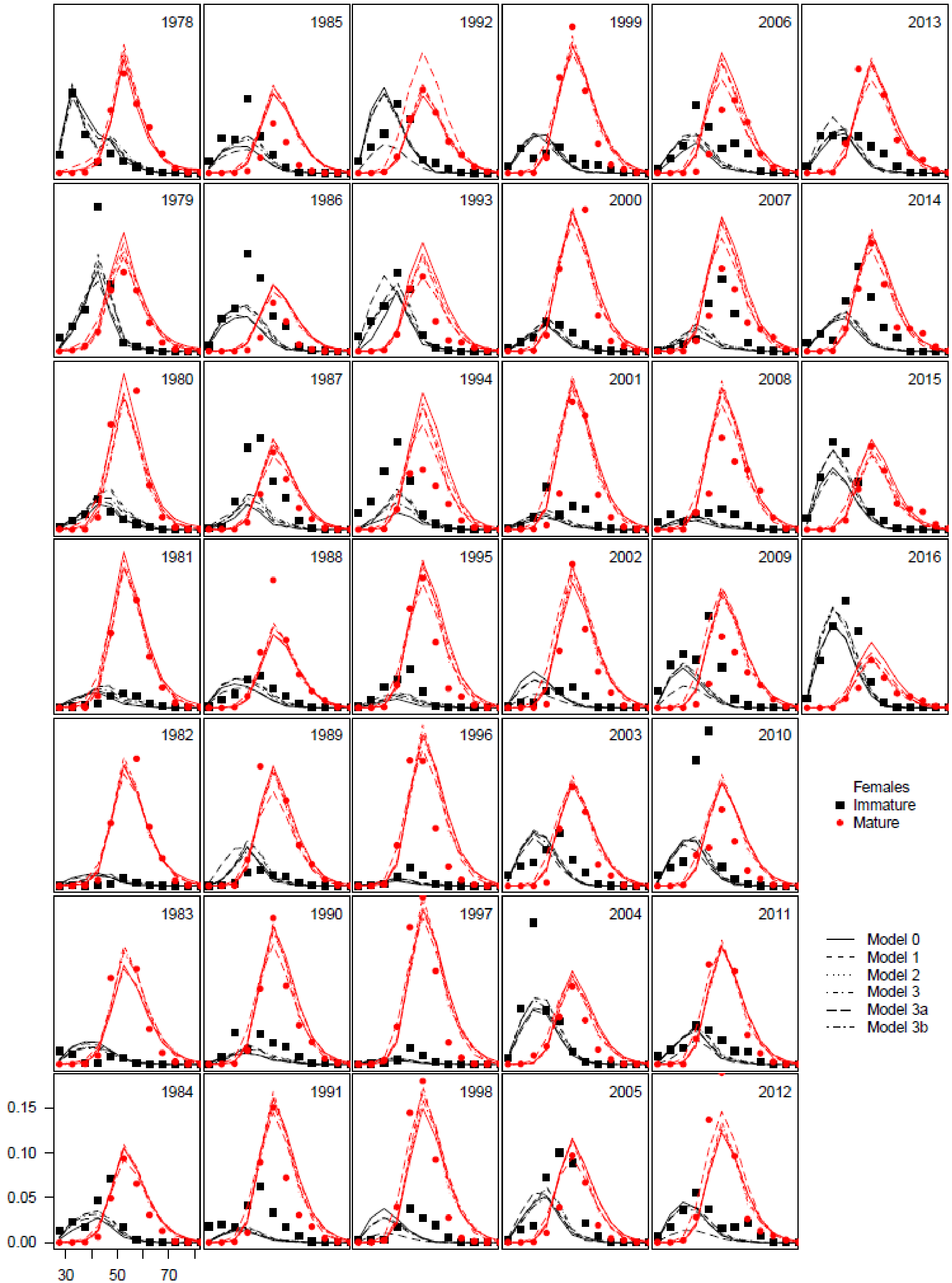
Model 3:

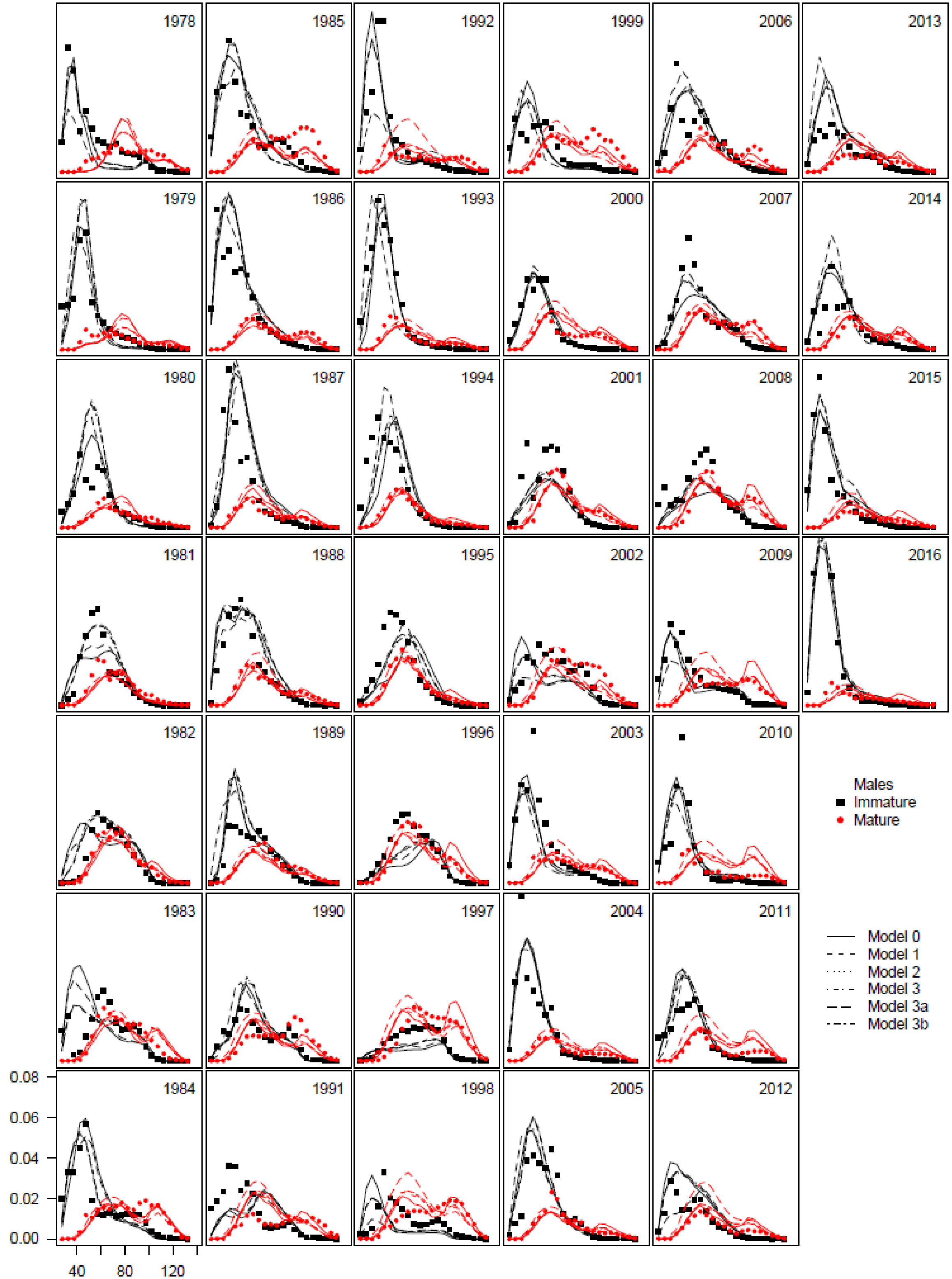
Model 3a:
- Fits the terminal year of MMB best

Model 3b:



Males
2015 estimates
Females
Just catch bio
Catch bio and comps
Add survey bio
Chosen model
All Francis
Mature biomass at survey (1000 t)
0
100
200
300
400
500
600
700
1980
1990
2000
2010


1978
1985
1992
1999
2006
2013
1979
1986
1993
2000
2007
2014
1980
1987
1994
2001
2008
2015
1981
1988
1995
2002
2009
2016
1982
1989
1996
2003
2010
1983
1990
1997
2004
2011
1984
1991
1998
2005
2012
Females
Immature
Mature
Model 0
Model 1
Model 2
Model 3
Model 3a
Model 3b
0.15
0.10
0.05
0.00
30
50
70


1978
1985
1992
1999
2006
2013
1979
1986
1993
2000
2007
2014
1980
1987
1994
2001
2008
2015
1981
1988
1995
2002
2009
2016
1982
1989
1996
2003
2010
1983
1990
1997
2004
2011
1984
1991
1998
2005
2012
Males
Immature
Mature
Model 0
Model 1
Model 2
Model 3
Model 3a
Model 3b
0.08
0.06
0.04
0.02
0.00
40
80
120

Model evaluation

Model 0:
- Fits the terminal year of MMB worst

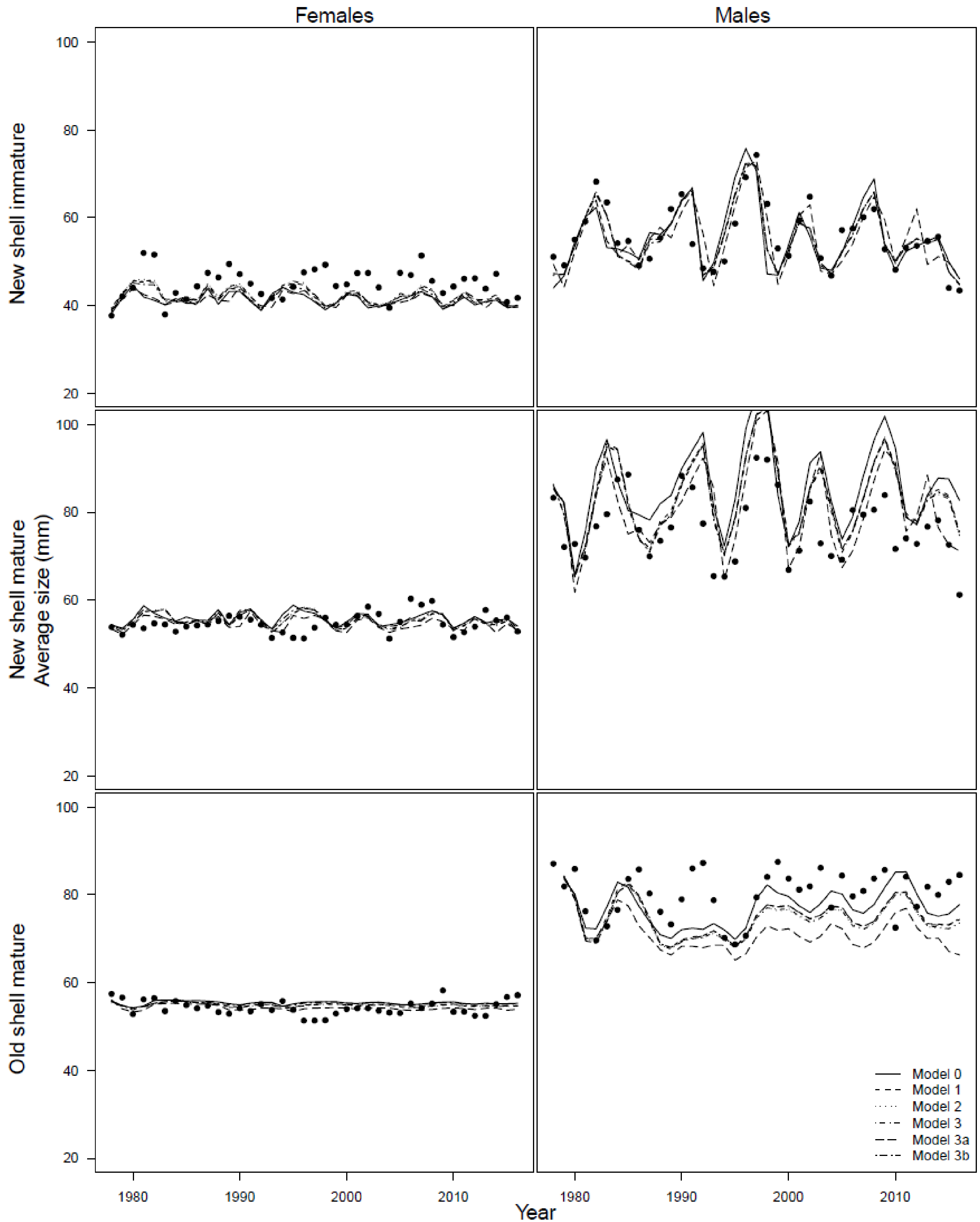
Model 1:

Model 2:

Model 3:

Model 3a:
- Fits the terminal year of MMB best
- Fits the survey size composition data poorly in some years

Model 3b:



Females
Males
New shell immature
New shell mature
Average size (mm)
Old shell mature
100
80
60
40
20
1980
1990
2000
2010
Year
Model 0
Model 1
Model 2
Model 3
Model 3a
Model 3b

Model evaluation

Model 0:
- Fits the terminal year of MMB worst

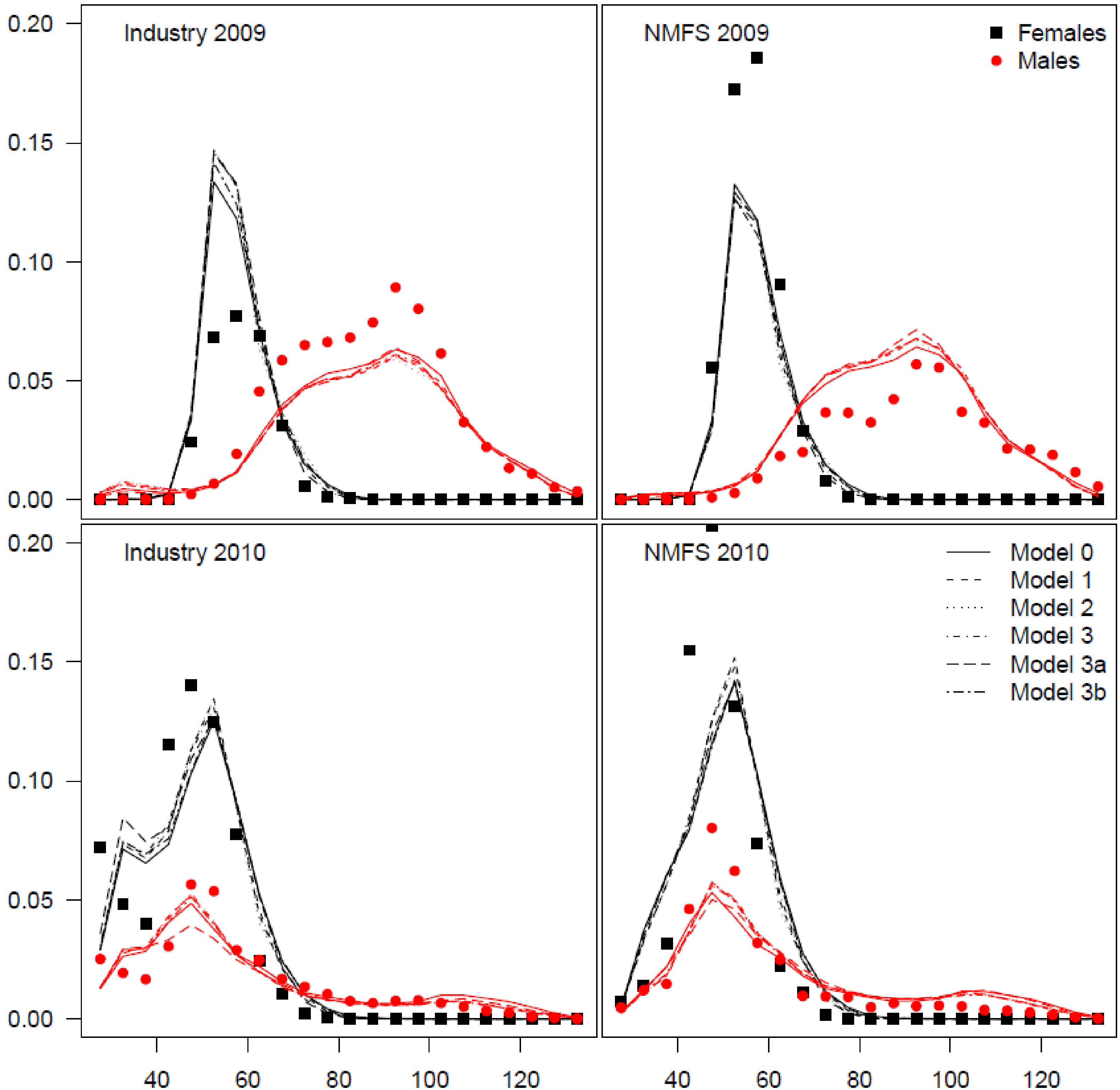
Model 1:

Model 2:

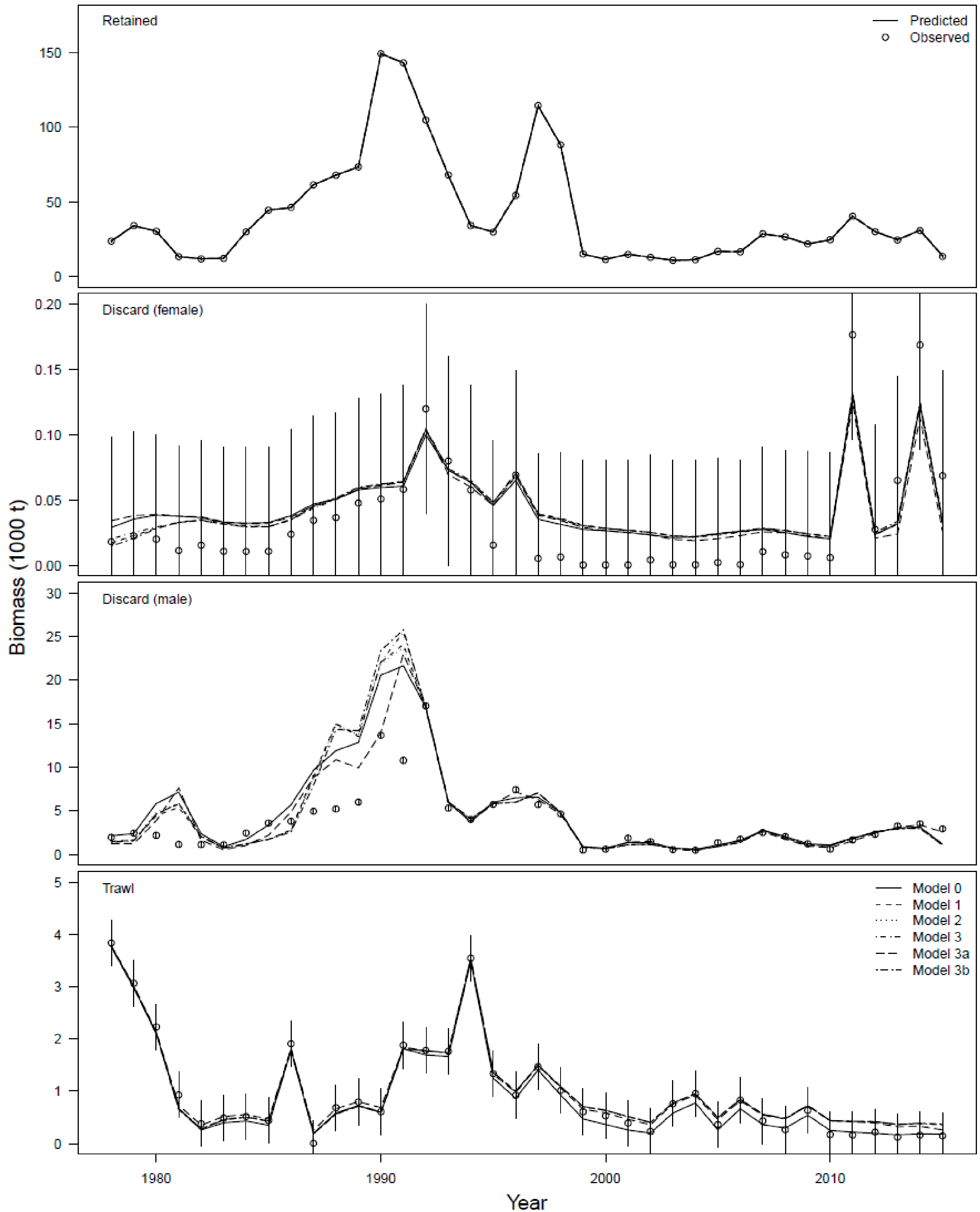
Model 3:

Model 3a:
- Fits the terminal year of MMB best
- Fits the survey size composition data poorly in some years
- Fit the average size of catch in the survey most poorly

Model 3b:



Industry 2009
NMFS 2009
Females
Males
Industry 2010
NMFS 2010
Model 0
Model 1
Model 2
Model 3
Model 3a
Model 3b
0.00
0.05
0.10
0.15
0.20
40
60
80
100
120



Retained
Predicted
Observed
Discard (female)
Discard (male)
Trawl
Model 0
Model 1
Model 2
Model 3
Model 3a
Model 3b
Biomass (1000 t)
Year

Model evaluation

Model 0:

- Fits the terminal year of MMB worst

Model 1:

Model 2:

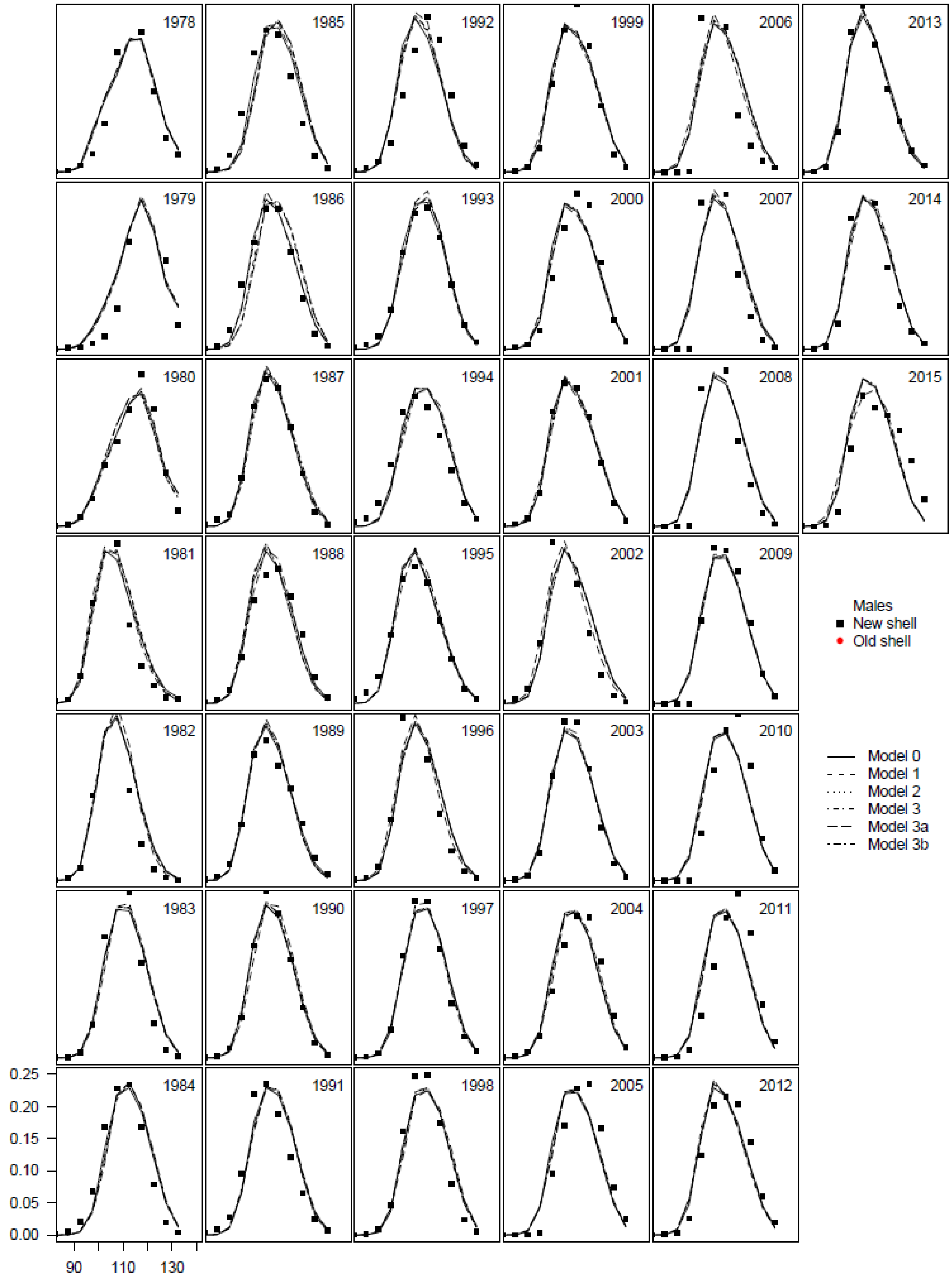
Model 3:

Model 3a:

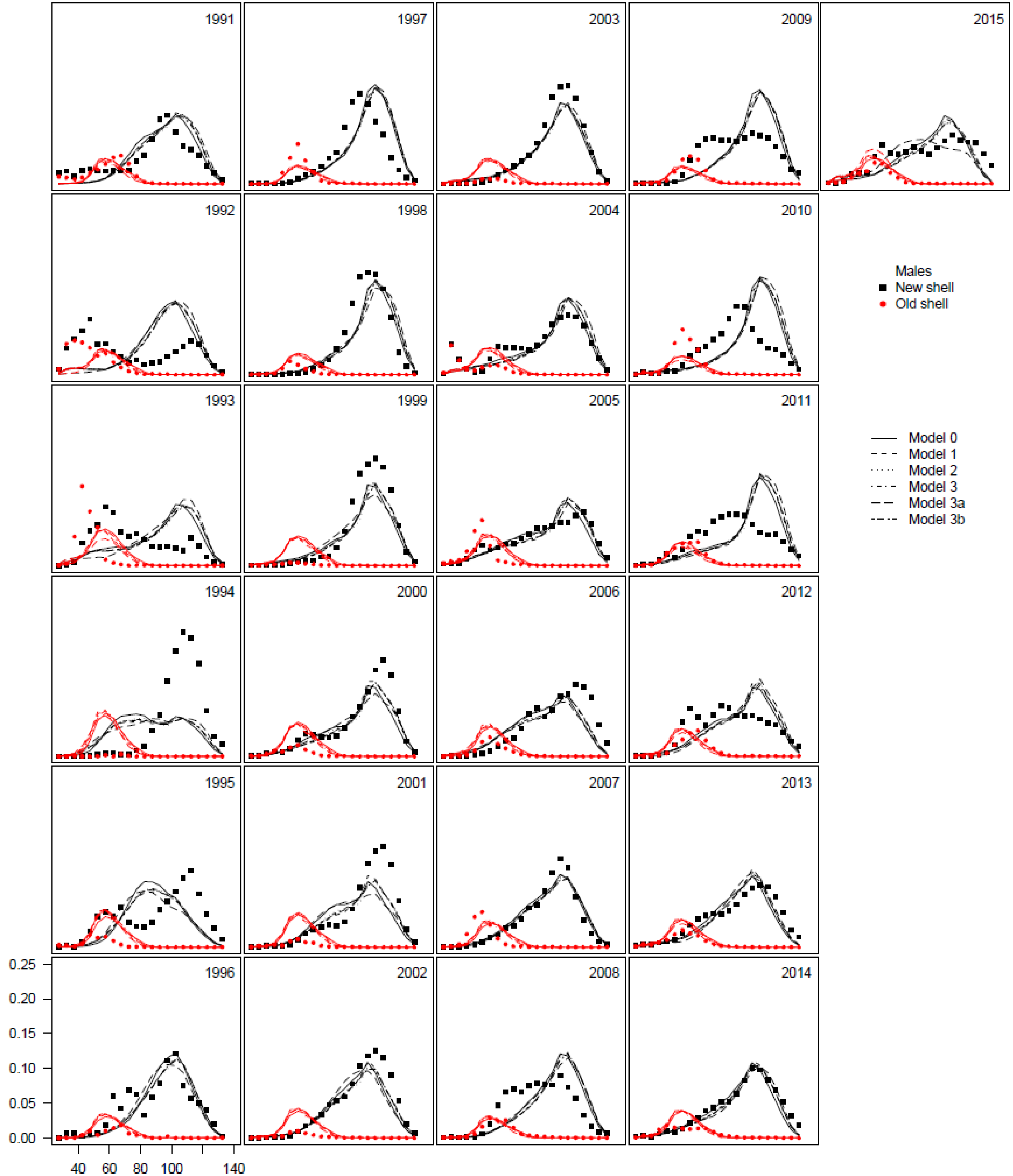
- Fits the terminal year of MMB best
- Fits the survey size composition data poorly in some years
- Fit the average size of catch in the survey most poorly

Model 3b:

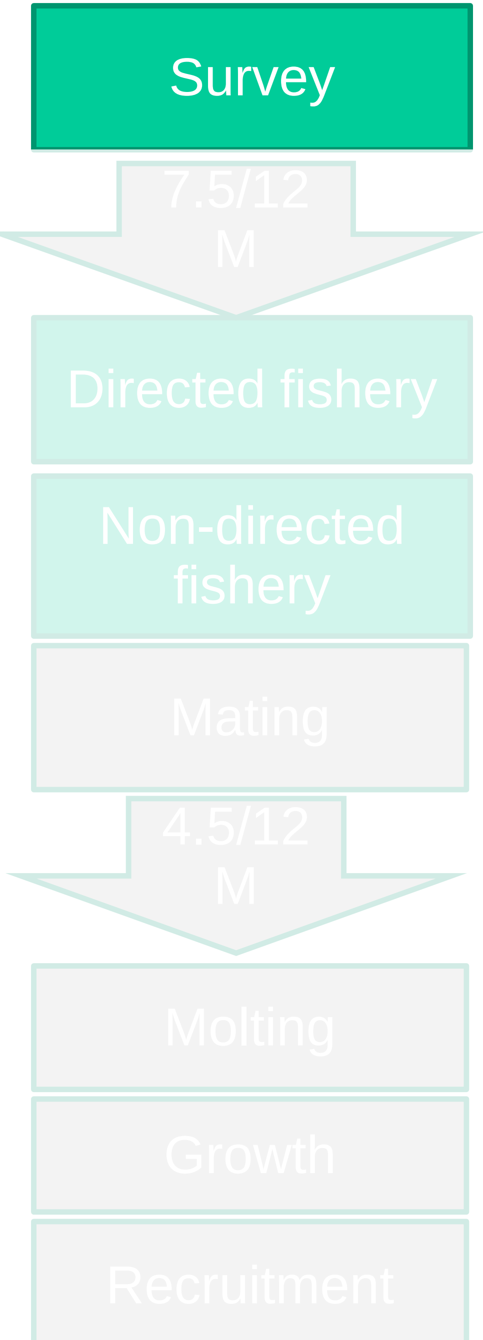
Retained catch

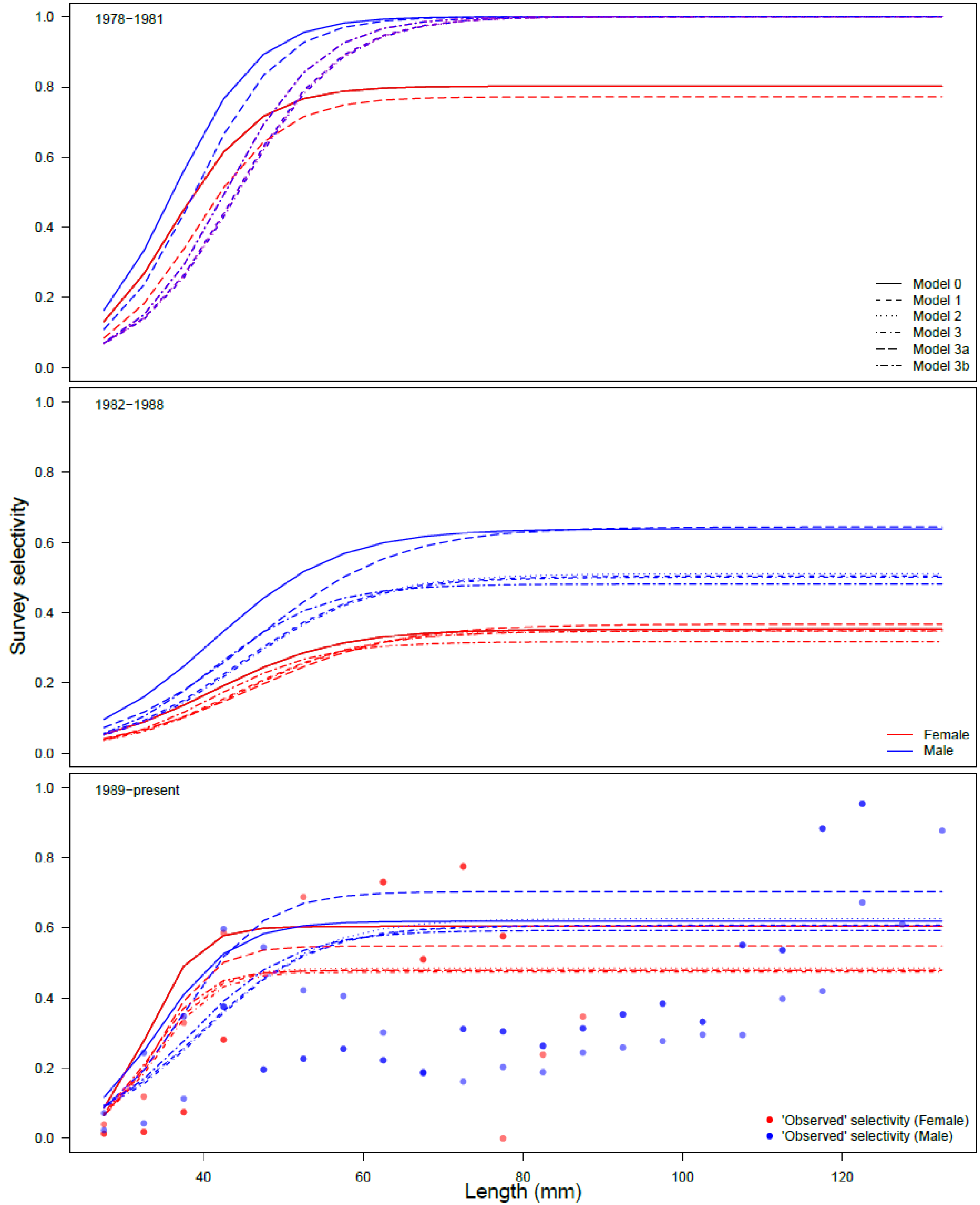


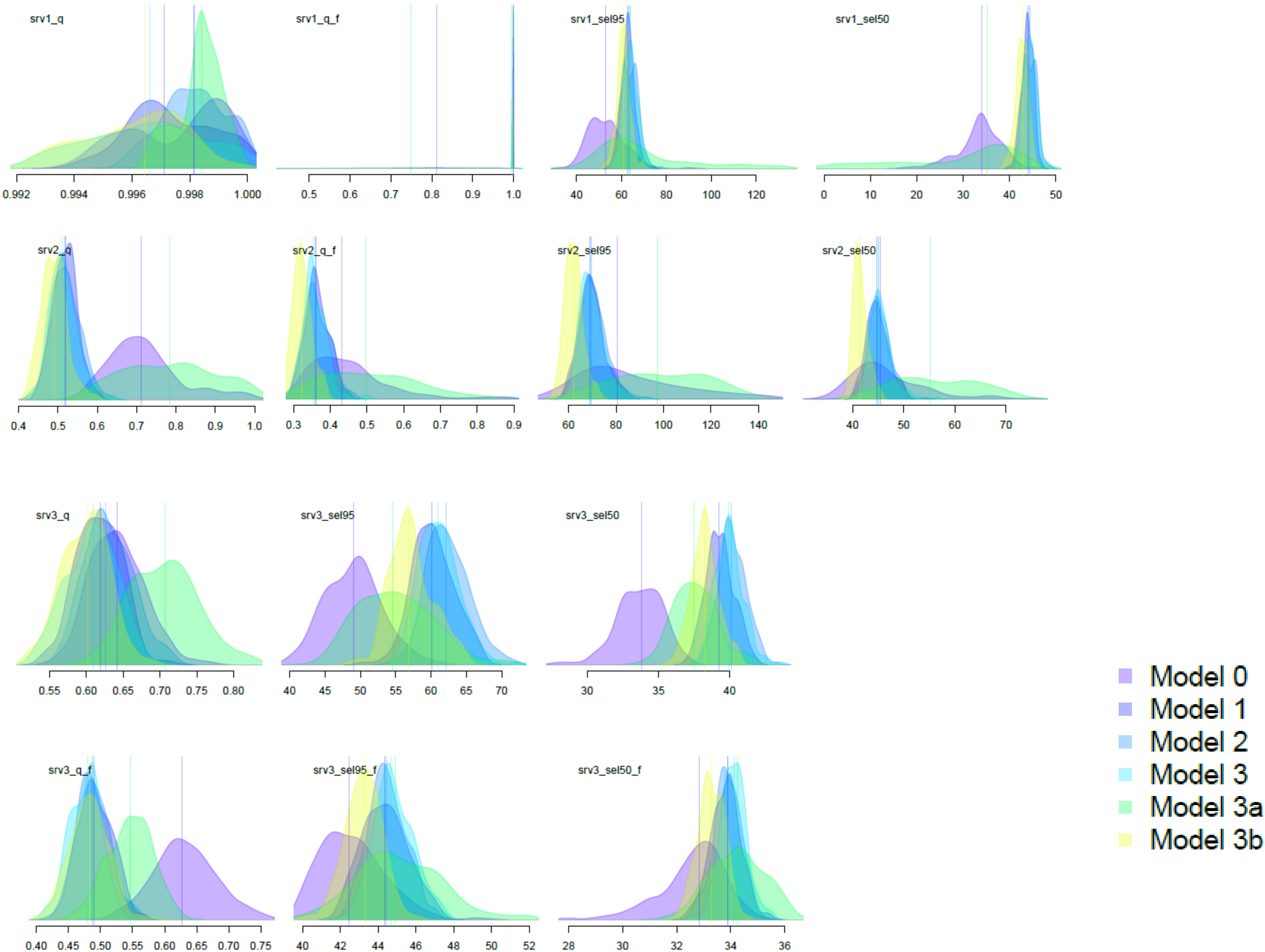
Trawl


1991
1997
2003
2009
2015
1992
1998
2004
2010
Males
New shell
Old shell
1993
1999
2005
2011
Model 0
Model 1
Model 2
Model 3
Model 3a
Model 3b
1994
2000
2006
2012
1995
2001
2007
2013
0.25
0.20
0.15
0.10
0.05
0.00
1996
2002
2008
2014
40
60
80
100
140

Estimated population processes


Survey
7.5/12 M
Directed fishery
Non-directed fishery
Mating
4.5/12 M
Molting
Growth
Recruitment


1978−1981
Model 0
Model 1
Model 2
Model 3
Model 3a
Model 3b
1982−1988
Female
Male
1989−present
'Observed' selectivity (Female)
'Observed' selectivity (Male)
Survey selectivity
Length (mm)


srv1_q
srv1_q_f
srv1_sel95
srv1_sel50
srv2_q
srv2_q_f
srv2_sel95
srv2_sel50
srv3_q
srv3_sel95
srv3_sel50
srv3_q_f
srv3_sel95_f
srv3_sel50_f
Model 0
Model 1
Model 2
Model 3
Model 3a
Model 3b

Model evaluation

Model 0:
- Fits the terminal year of MMB worst

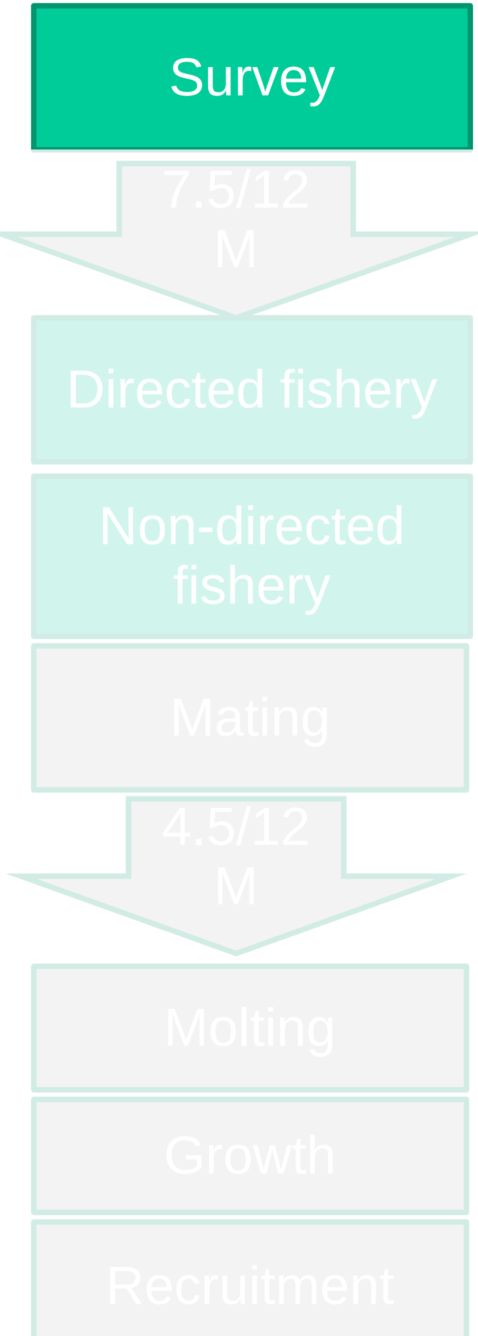
Model 1:

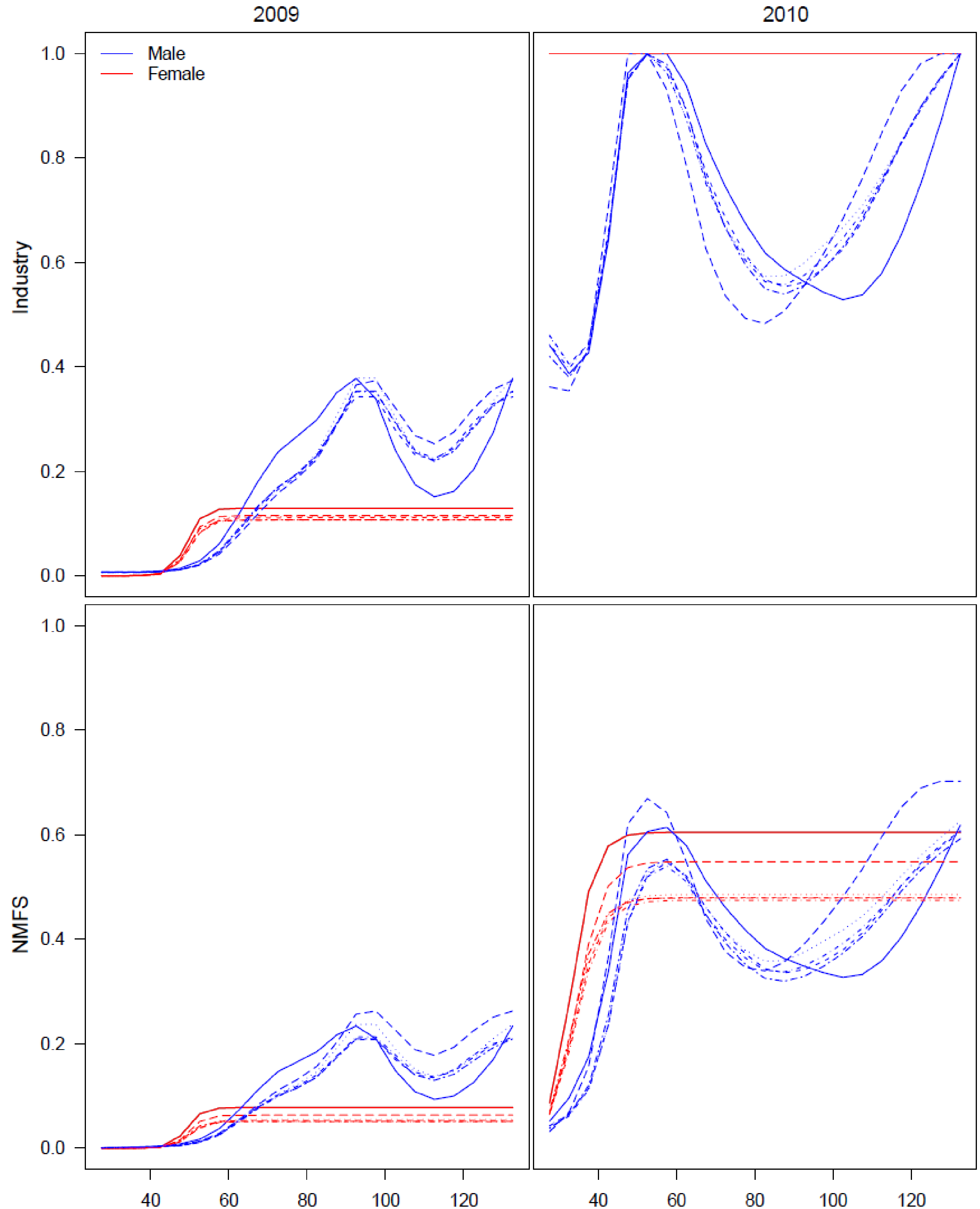
Model 2:

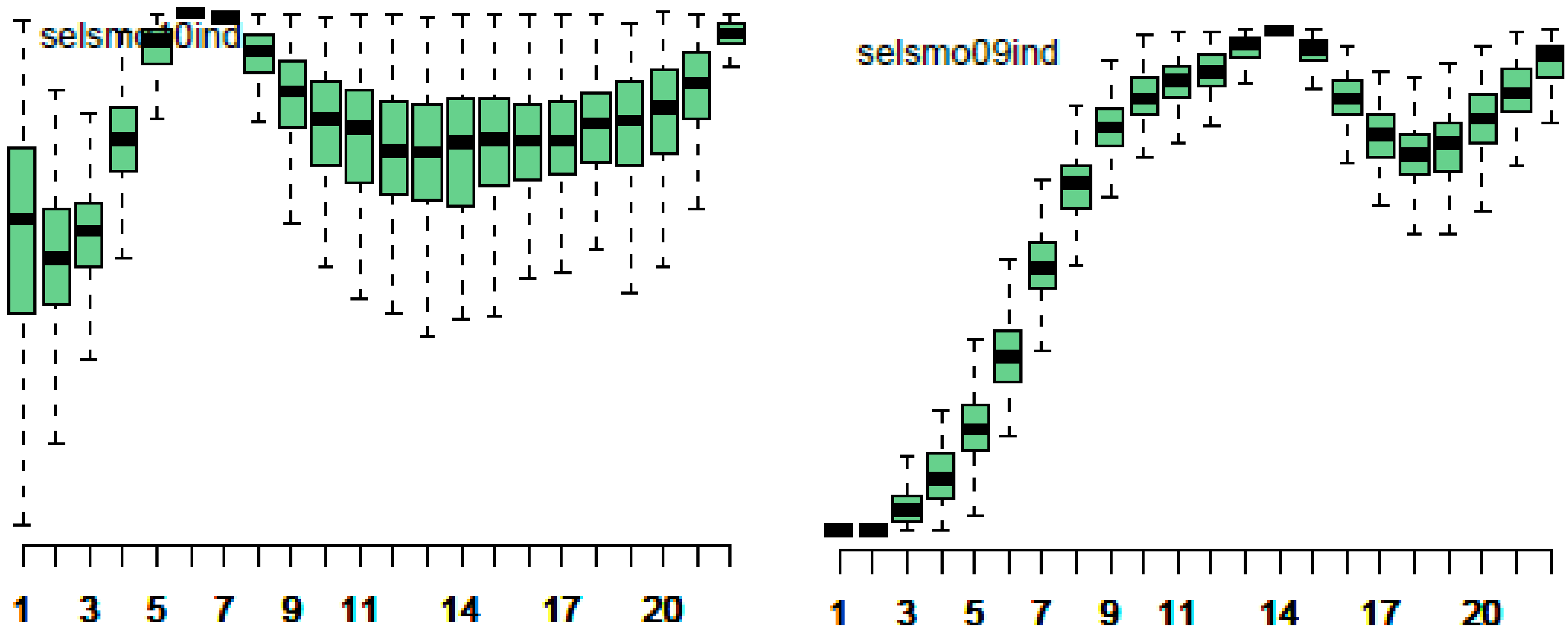
Model 3:

Model 3a:
- Fits the terminal year of MMB best
- Fits the survey size composition data poorly in some years
- Fit the average size of catch in the survey most poorly
- Estimates catchability in the most recent survey era higher than implied by the BSFRF data

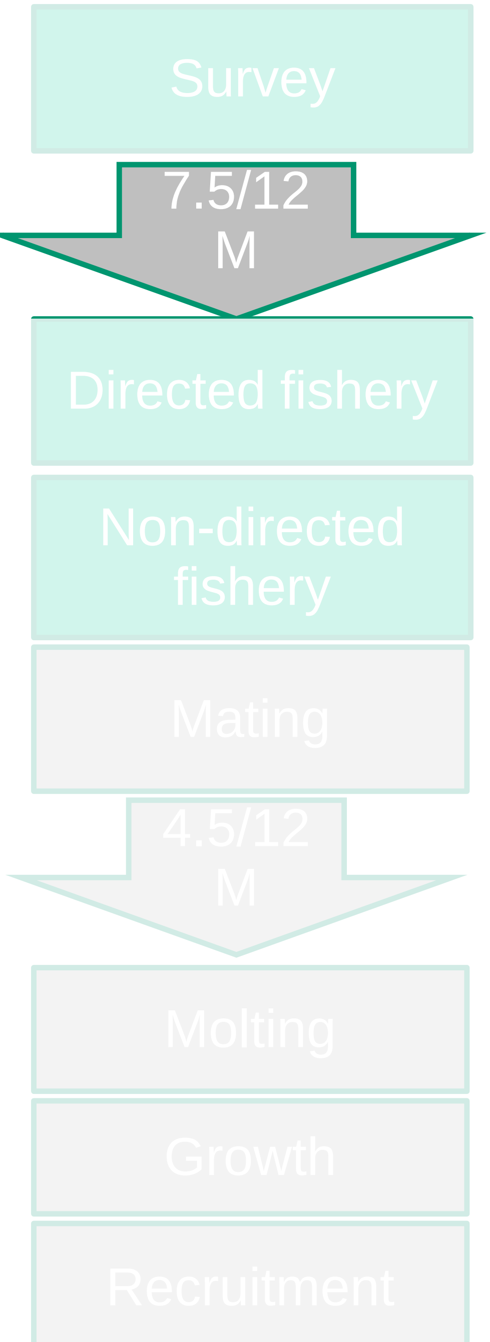
Model 3b:

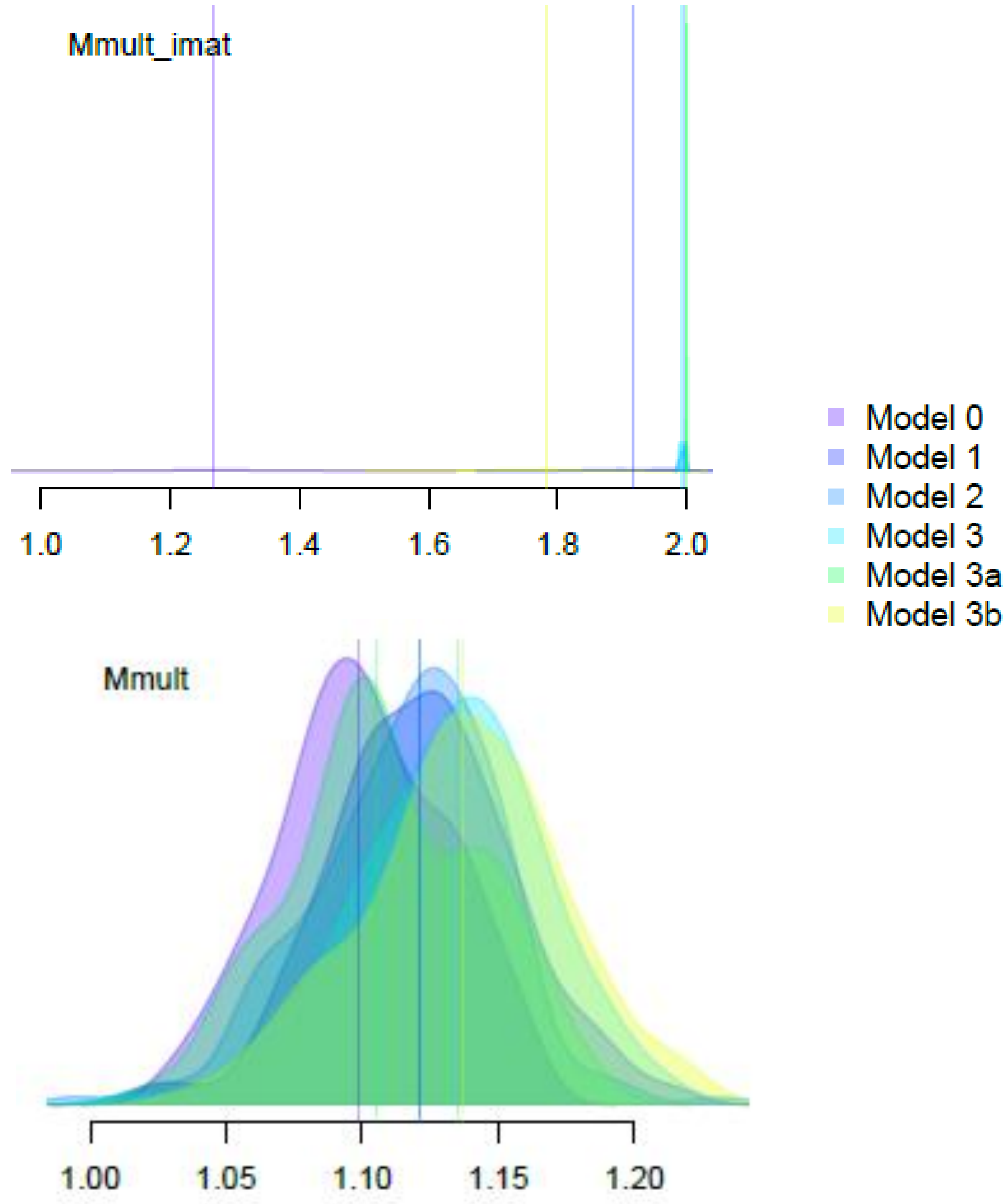

Survey
7.5/12 M
Directed fishery
Non-directed fishery
Mating
4.5/12 M
Molting
Growth
Recruitment


2009
2010
Male
Female
Industry
NMFS
0.0
0.2
0.4
0.6
0.8
1.0
40
60
80
100
120



1 3 5 7 9 11 14 17 20
selsmo09ind
1 3 5 7 9 11 14 17 20


Survey
7.5/12 M
Directed fishery
Non-directed fishery
Mating
4.5/12 M
Molting
Growth
Recruitment


Mmult_imat
1.0
1.2
1.4
1.6
1.8
2.0
Model 0
Model 1
Model 2
Model 3
Model 3a
Model 3b
Mmult
1.00
1.05
1.10
1.15
1.20

Model evaluation

Model 0:
- Fits the terminal year of MMB worst

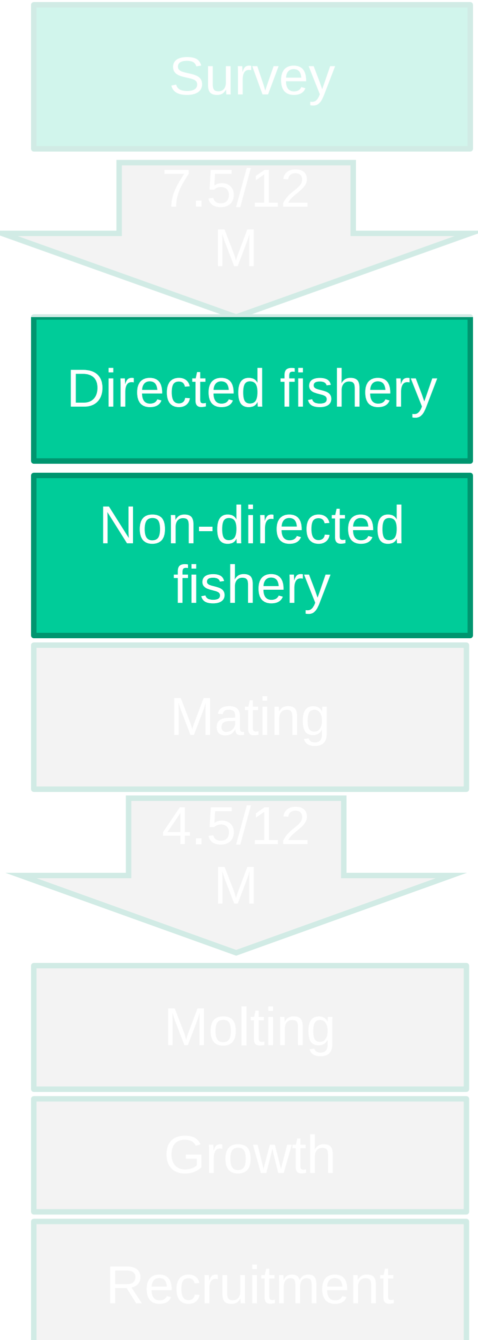
Model 1:

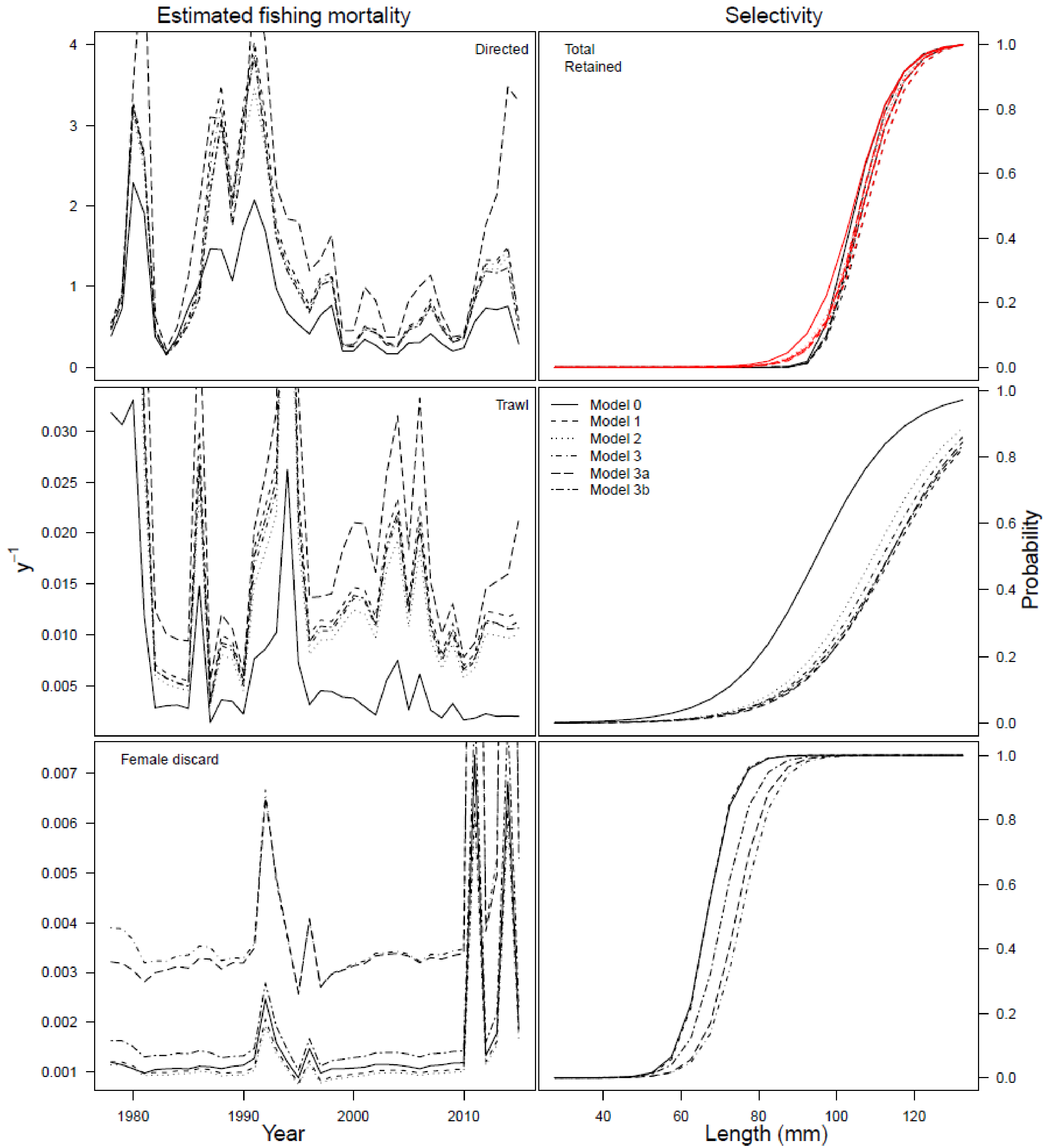
Model 2:

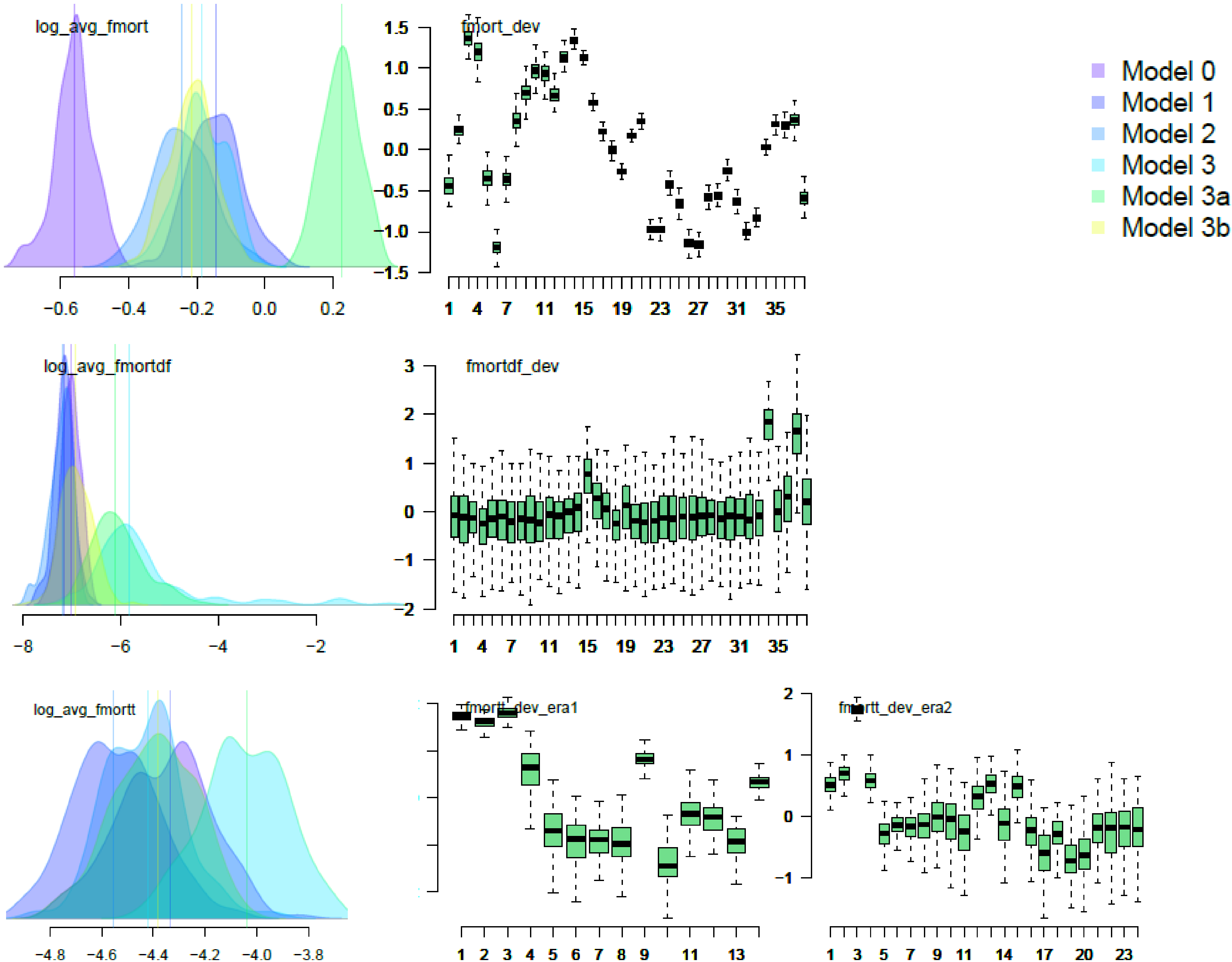
Model 3:

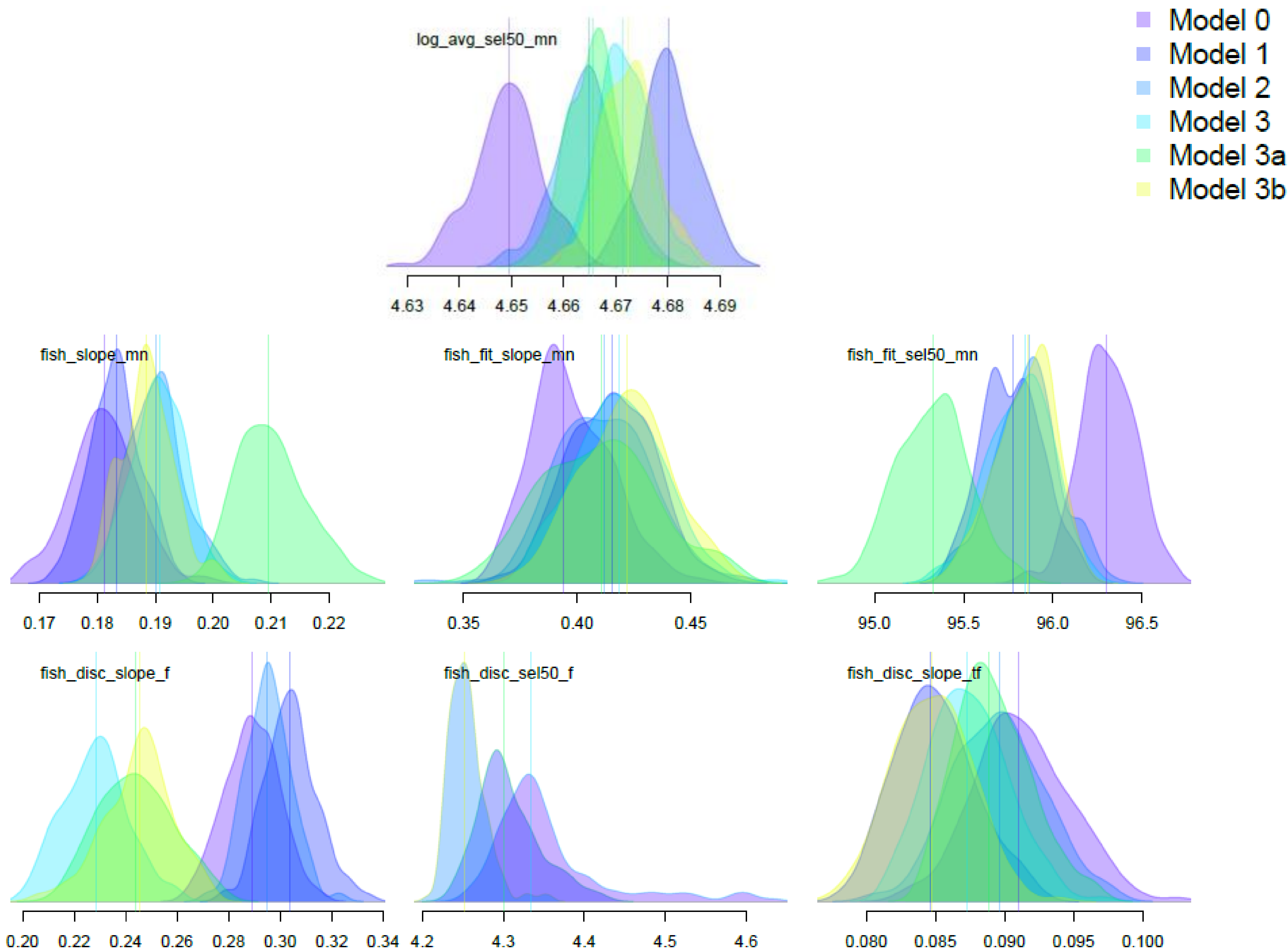
Model 3a:
- Fits the terminal year of MMB best
- Fits the survey size composition data poorly in some years
- Fit the average size of catch in the survey most poorly
- Estimates catchability in the most recent survey era higher than implied by the BSFRF data

Model 3b:
- Only model other than the Model 0 that does not hit the bound for natural mortality


Survey
7.5/12
M
Directed fishery
Non-directed
fishery
Mating
4.5/12
M
Molting
Growth
Recruitment


Estimated fishing mortality
Selectivity
Directed
Total
Retained
Trawl
Model 0
Model 1
Model 2
Model 3
Model 3a
Model 3b
Female discard
y^{-1}
Probability
Year
Length (mm)
1980
1990
2000
2010
40
60
80
100
120


log_avg_fmort
fmort_dev
Model 0
Model 1
Model 2
Model 3
Model 3a
Model 3b
log_avg_fmortdf
fmortdf_dev
log_avg_fmortt
fmortt_dev_era1
fmortt_dev_era2



Model 0
Model 1
Model 2
Model 3
Model 3a
Model 3b
log_avg_sel50_mn
4.63
4.64
4.65
4.66
4.67
4.68
4.69
fish_slope_mn
0.17
0.18
0.19
0.20
0.21
0.22
fish_fit_slope_mn
0.35
0.40
0.45
fish_fit_sel50_mn
95.0
95.5
96.0
96.5
fish_disc_slope_f
0.20
0.22
0.24
0.26
0.28
0.30
0.32
0.34
fish_disc_sel50_f
4.2
4.3
4.4
4.5
4.6
fish_disc_slope_tf
0.080
0.085
0.090
0.095
0.100

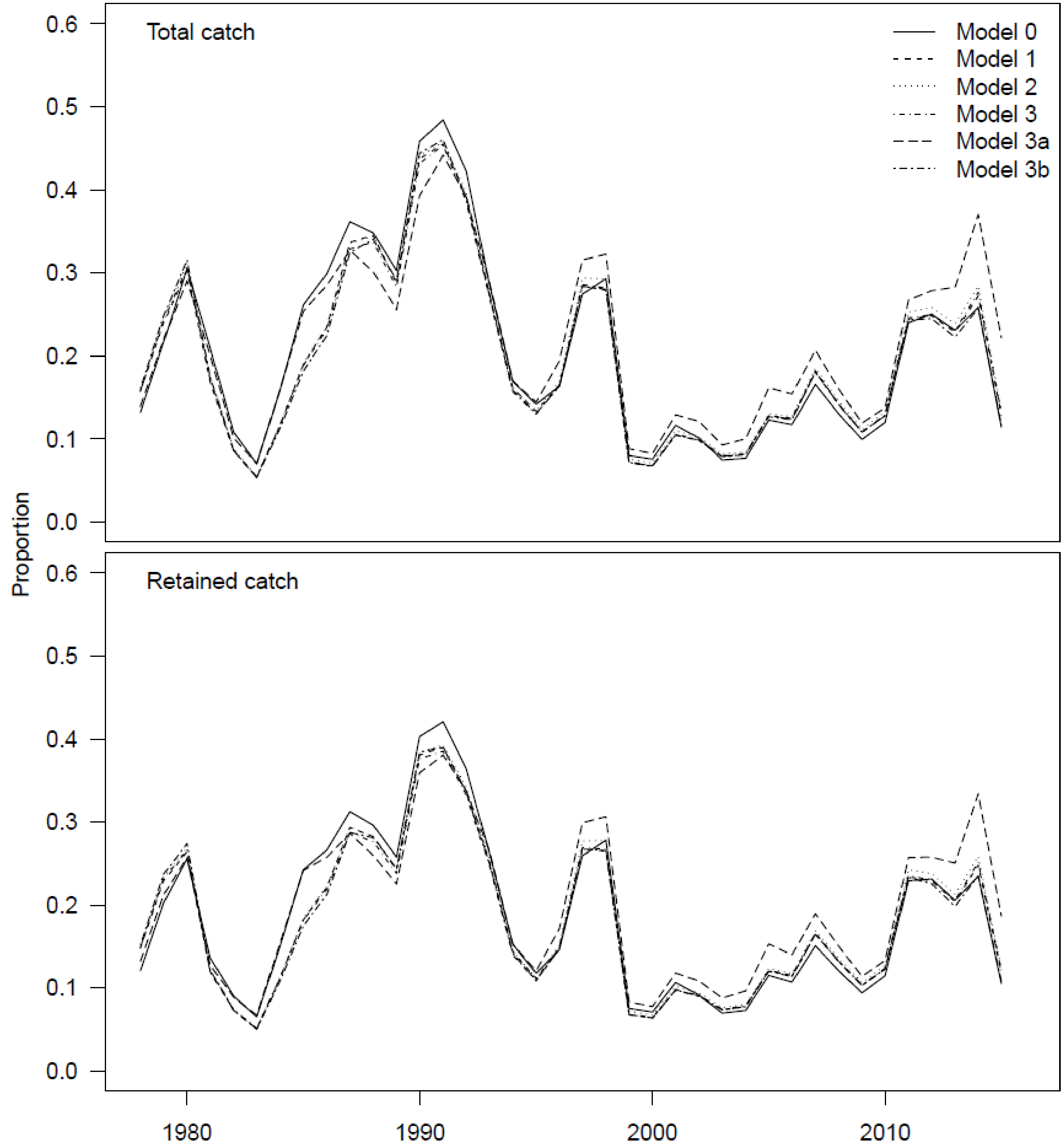


Figure 7: Model predicted ratio of catch to mature male biomass

Model evaluation

Model 0:
- Fits the terminal year of MMB worst
- Lower estimates of trawl selectivity

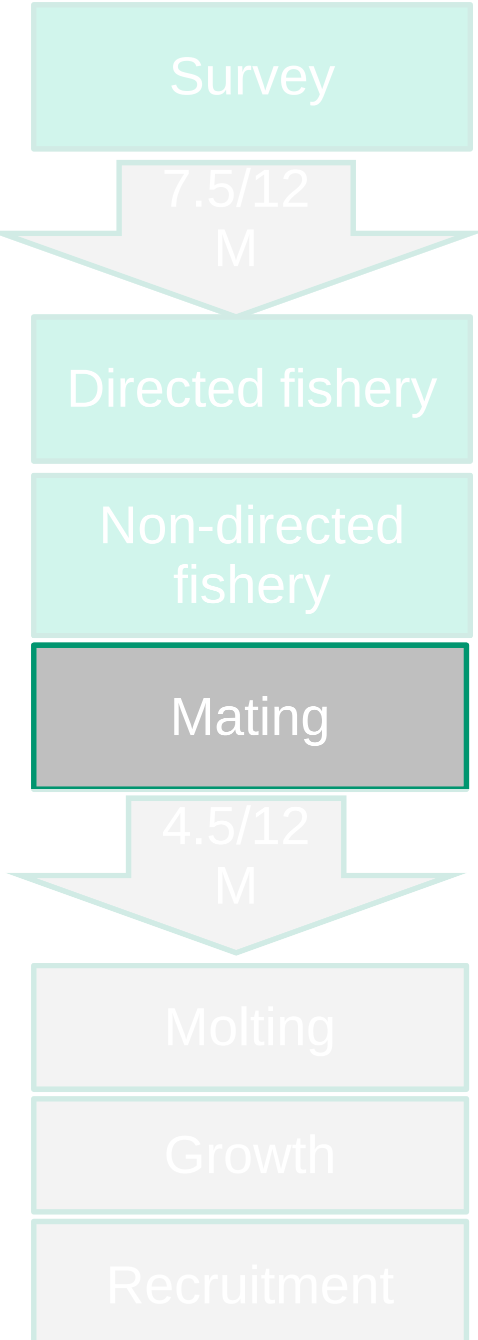
Model 1:

Model 2:

Model 3:
- Higher female discard mortality and selectivity

Model 3a:
- Fits the terminal year of MMB best
- Fits the survey size composition data poorly in some years
- Fit the average size of catch in the survey most poorly
- Estimates catchability in the most recent survey era higher than implied by the BSFRF data
- Estimates very high directed F in recent years
- Higher female discard mortality and selectivity

Model 3b:
- Only model other than the Model 0 that does not hit the bound for natural mortality



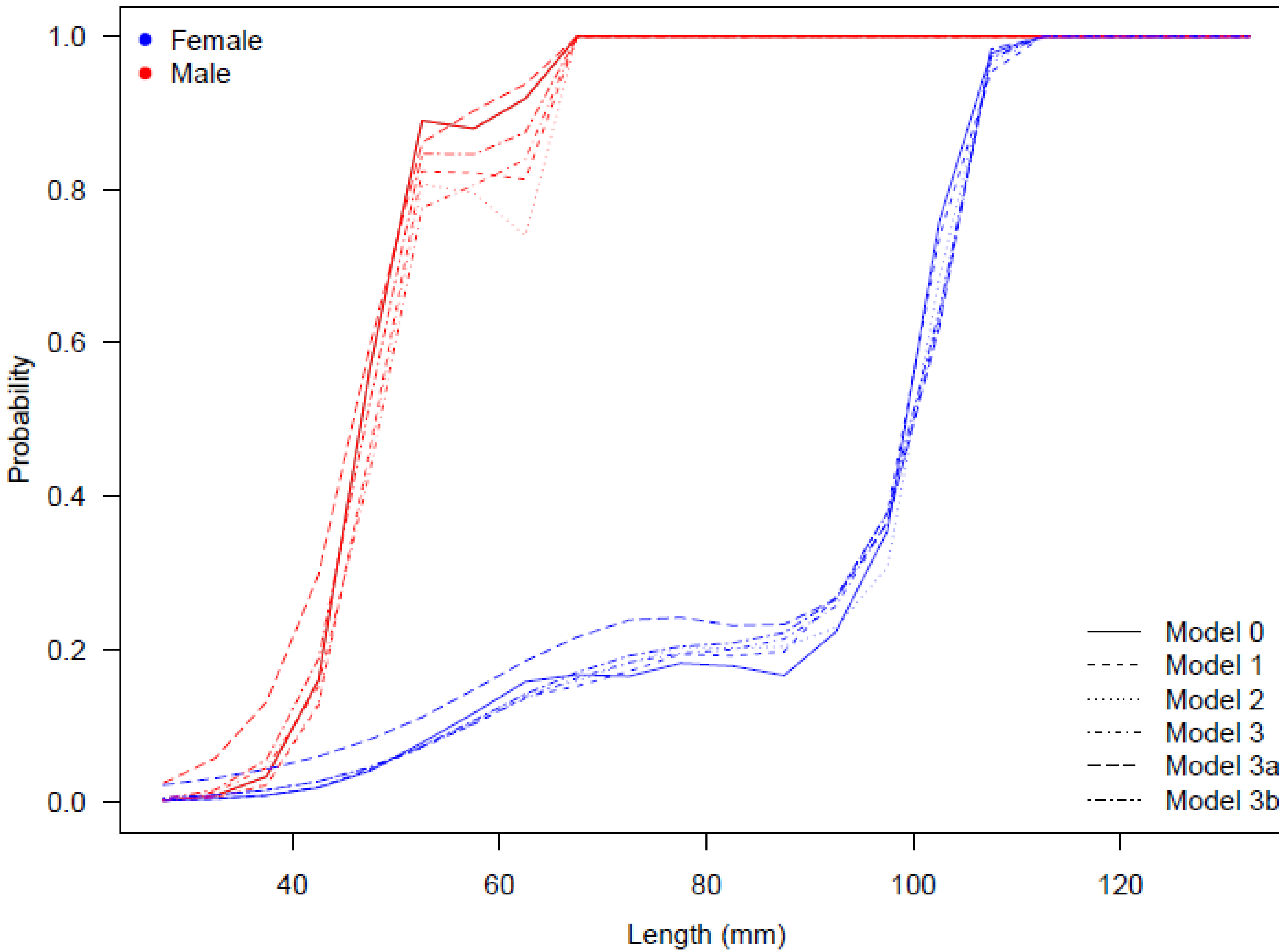
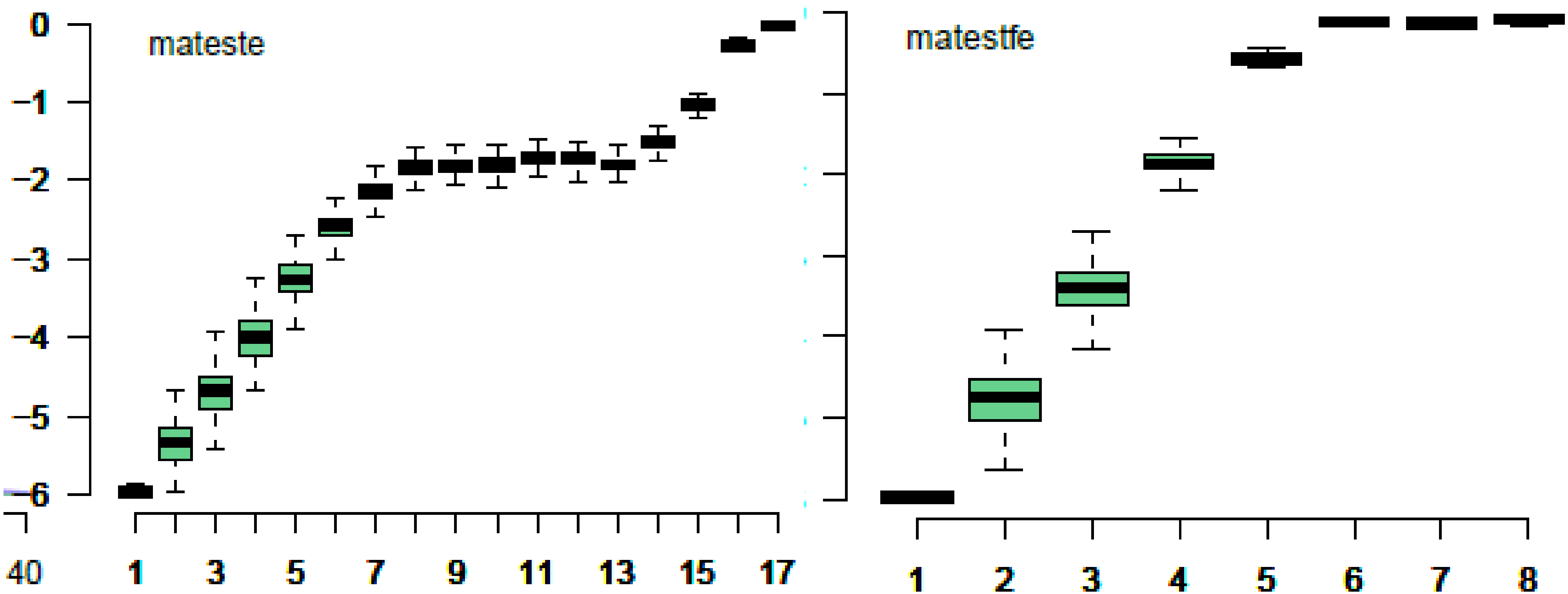


Figure 39: Estimated probability of maturing


mateste
0
−1
−2
−3
−4
−5
−6
40
1
3
5
7
9
11
13
15
17
matestfe
1
2
3
4
5
6
7
8

Model evaluation

Model 0:
- Fits the terminal year of MMB worst
- Lower estimates of trawl selectivity

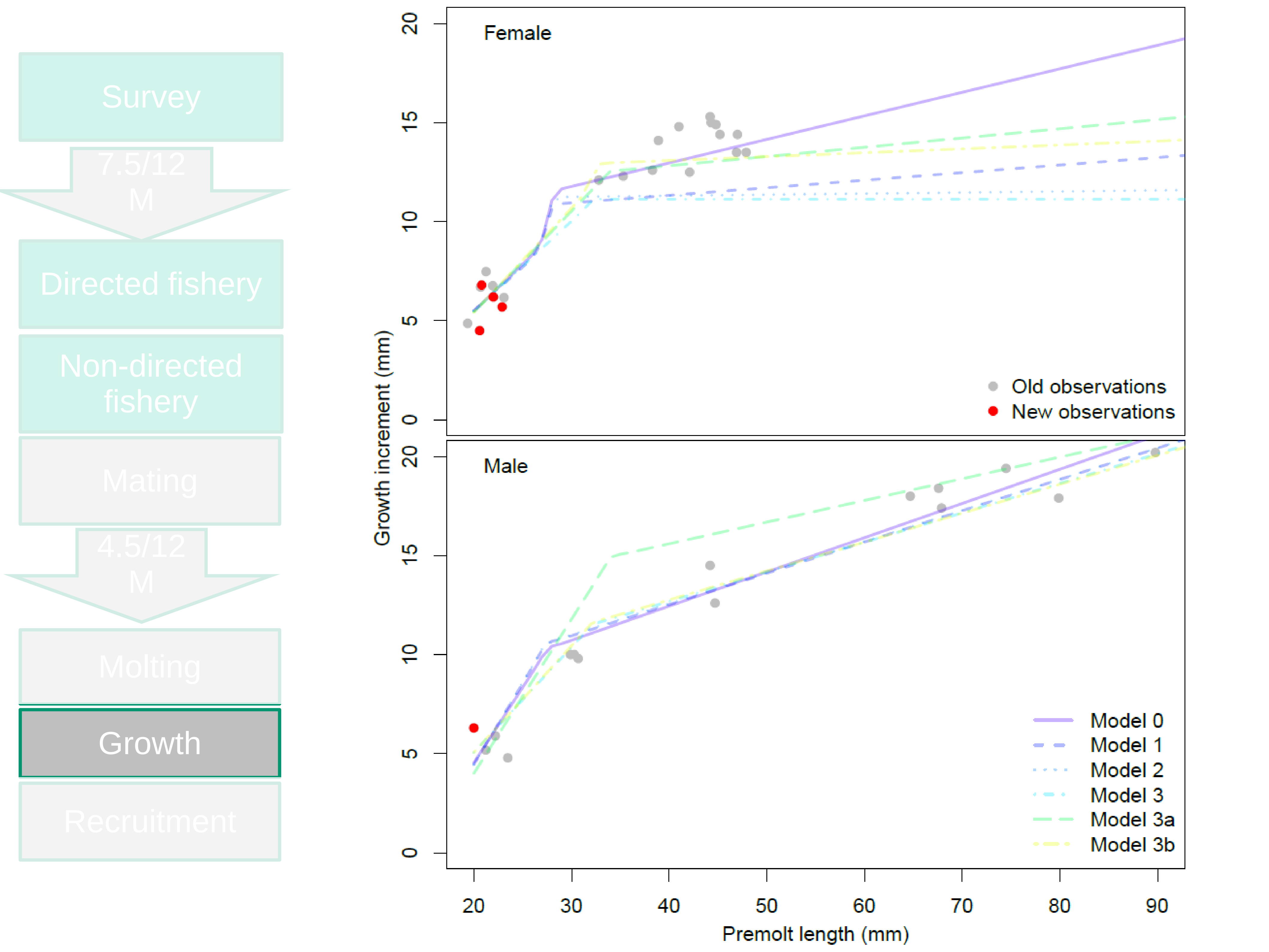
Model 1:

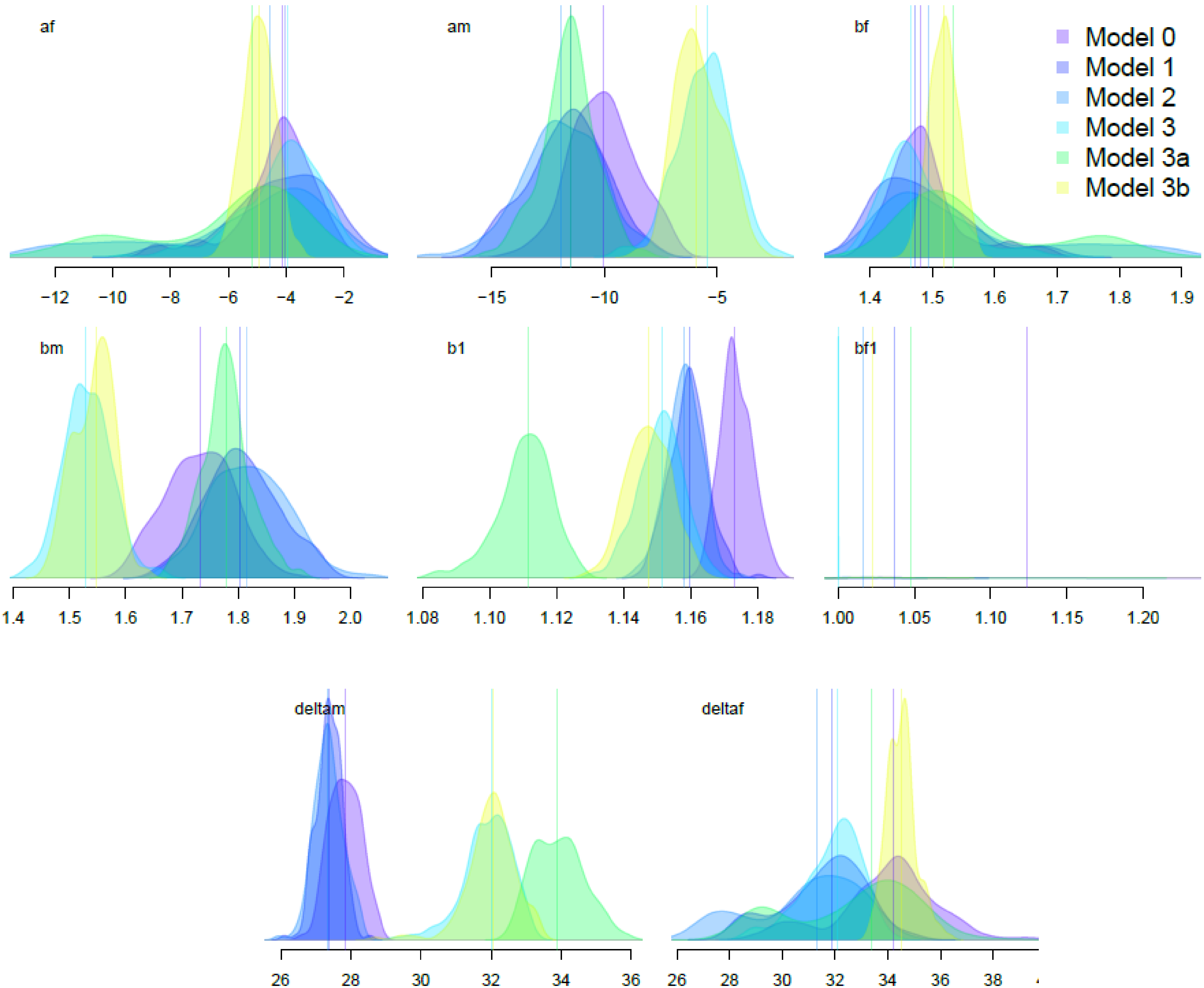
Model 2:

Model 3:
- Higher female discard mortality and selectivity

Model 3a:
- Fits the terminal year of MMB best
- Fits the survey size composition data poorly in some years
- Fit the average size of catch in the survey most poorly
- Estimates catchability in the most recent survey era higher than implied by the BSFRF data
- Estimates very high directed F in recent years
- Higher female discard mortality and selectivity
- Estimates higher probability of maturing for small males and females

Model 3b:
- Only model other than the Model 0 that does not hit the bound for natural mortality


Survey
7.5/12 M
Directed fishery
Non-directed fishery
Mating
4.5/12 M
Molting
Growth
Recruitment
Female
Old observations
New observations
Male
Model 0
Model 1
Model 2
Model 3
Model 3a
Model 3b
Growth increment (mm)
Premolt length (mm)


af
am
bf
Model 0
Model 1
Model 2
Model 3
Model 3a
Model 3b
−12 −10 −8 −6 −4 −2
−15 −10 −5
1.4 1.5 1.6 1.7 1.8 1.9
bm
b1
bf1
1.4 1.5 1.6 1.7 1.8 1.9 2.0
1.08 1.10 1.12 1.14 1.16 1.18
1.00 1.05 1.10 1.15 1.20
deltam
deltaf
26 28 30 32 34 36
26 28 30 32 34 36 38

Model evaluation

Model 0:
- Fits the terminal year of MMB worst
- Lower estimates of trawl selectivity

Model 1:
- Poor fits to female growth

Model 2:
- Poor fits to female growth

Model 3:
- Higher female discard mortality and selectivity
- Poor fits to female growth

Model 3a:
- Fits the terminal year of MMB best
- Fits the survey size composition data poorly in some years
- Fit the average size of catch in the survey most poorly
- Estimates catchability in the most recent survey era higher than implied by the BSFRF data
- Estimates very high directed F in recent years
- Higher female discard mortality and selectivity
- Estimates higher probability of maturing for small males and females
- Does not fit male growth

Model 3b:
- Only model other than the Model 0 that does not hit the bound for natural mortality

Survey

7.5/12 M

Directed fishery

Non-directed fishery

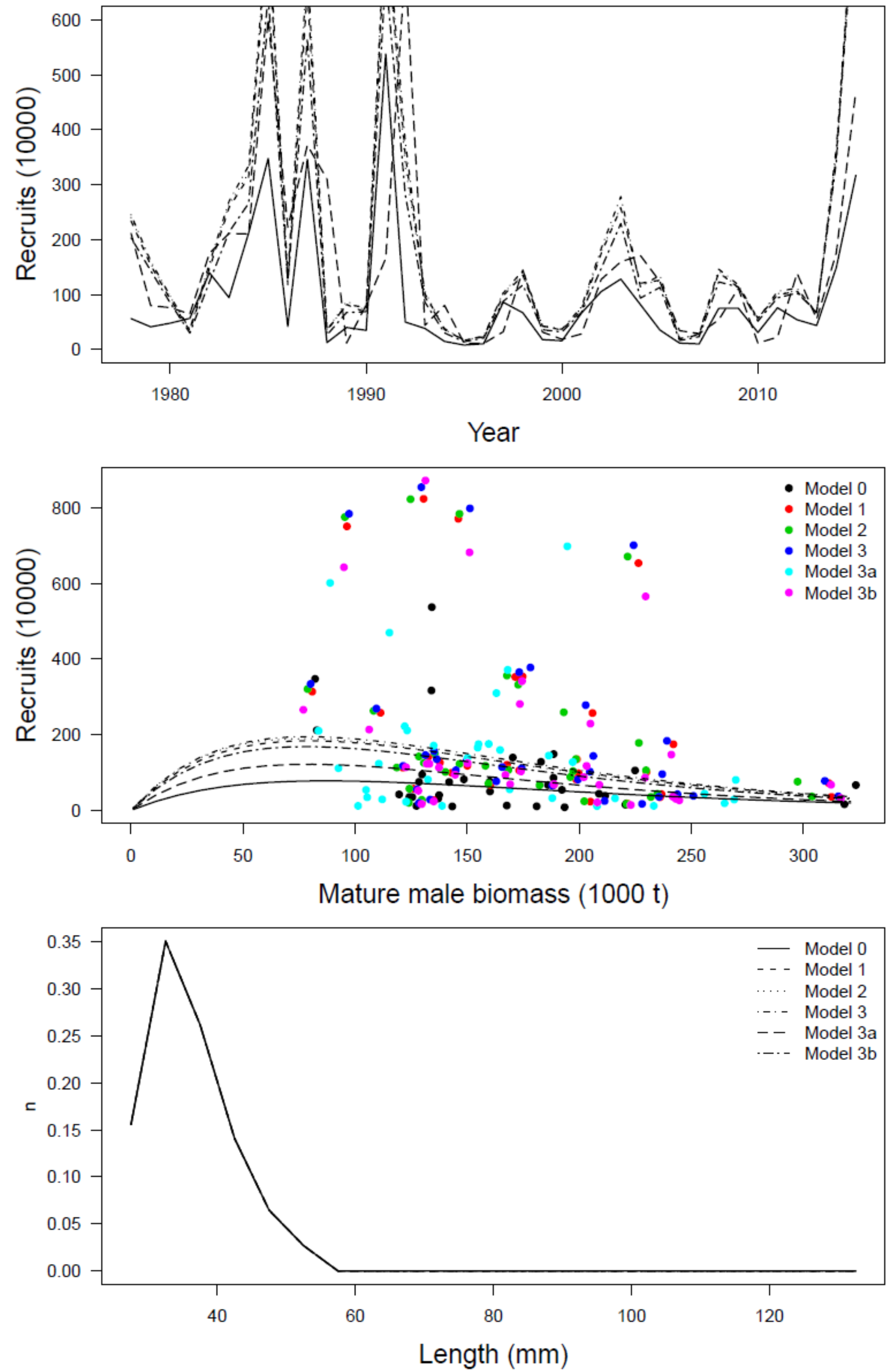
Mating

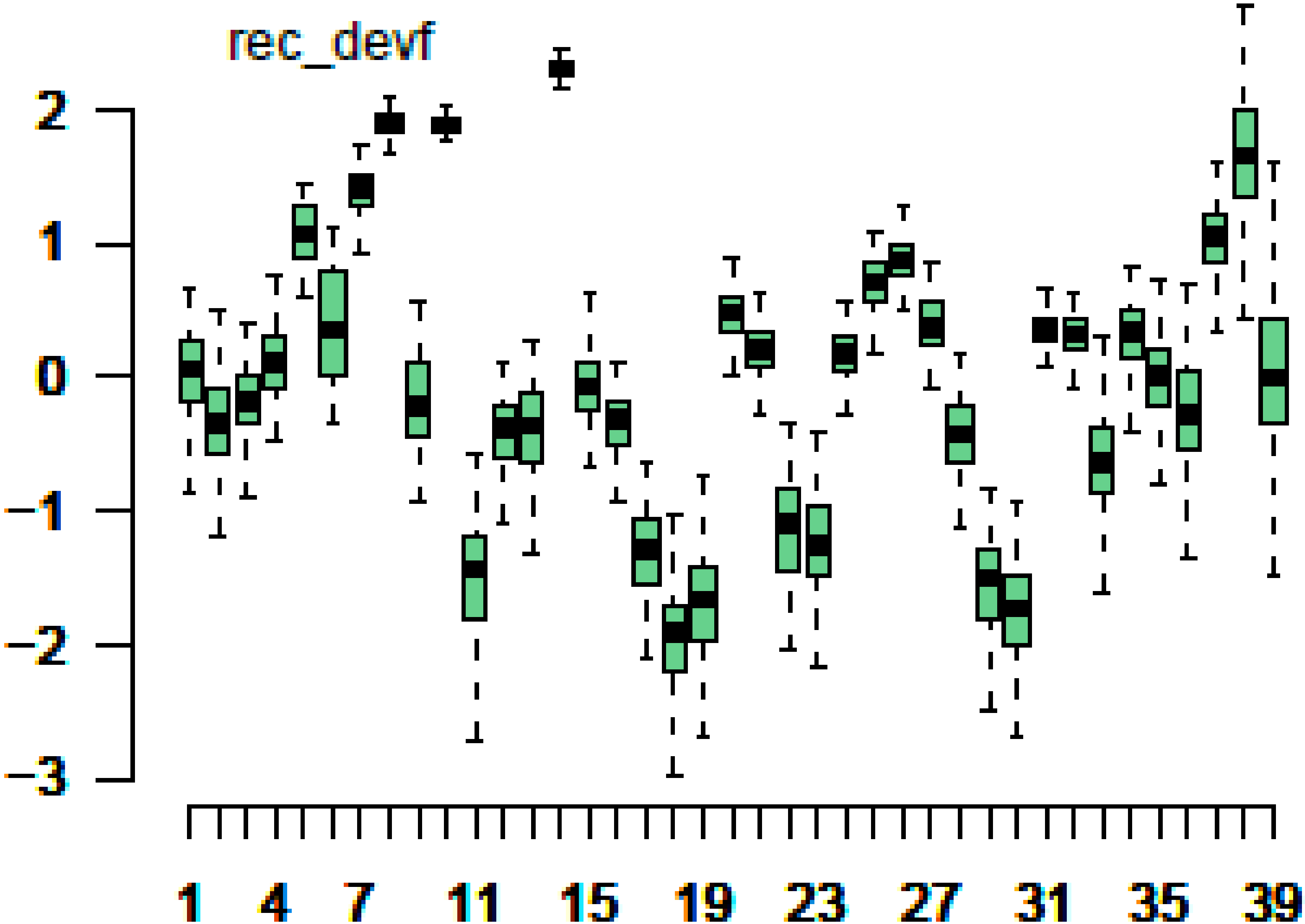
4.5/12 M

Molting

Growth

Recruitment




rec_devf
2
1
0
−1
−2
−3
1
4
7
11
15
19
23
27
31
35
39

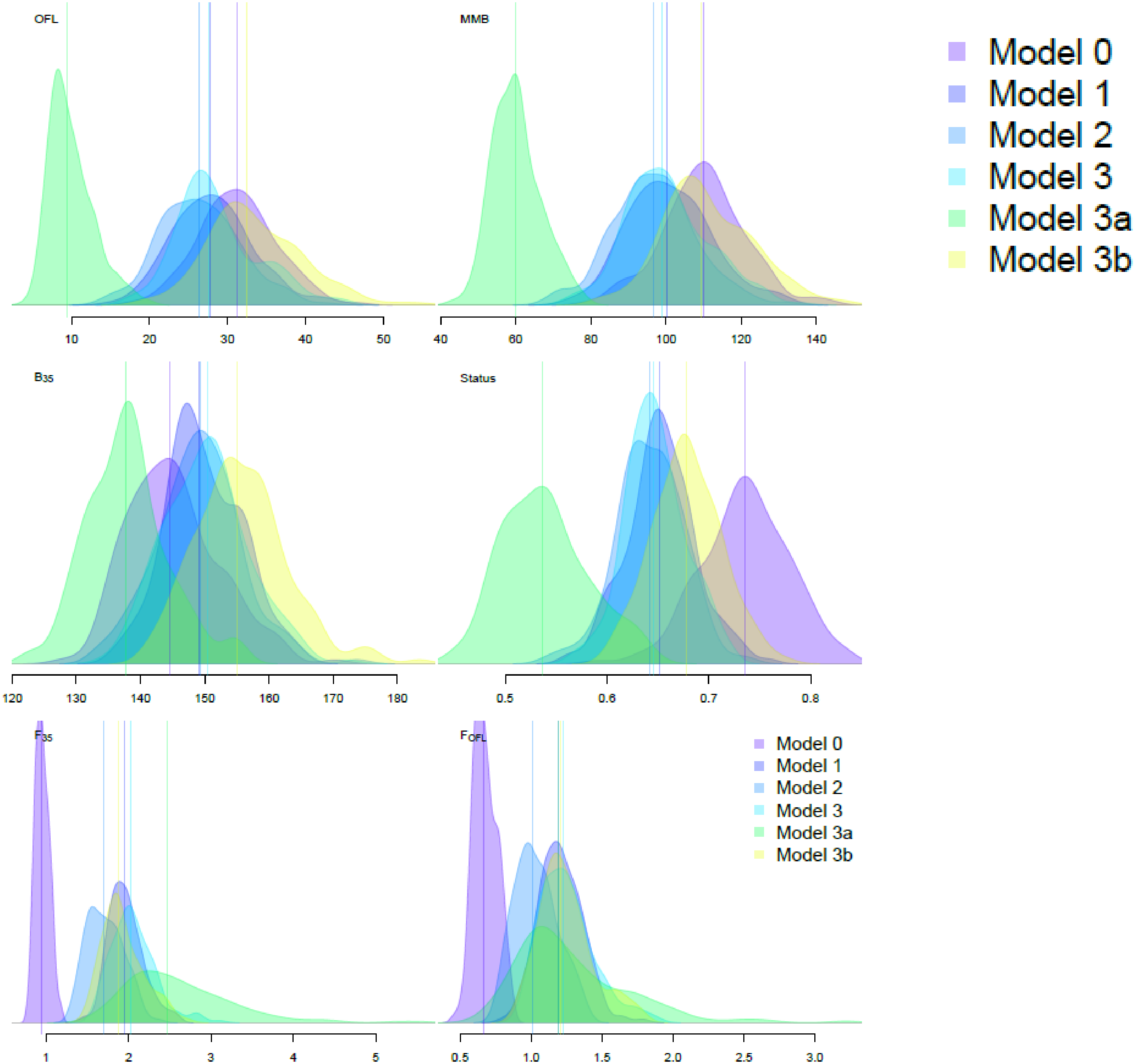


Figure 42: Posterior densities for management quantities by scenario

Model	OFL	OFL (ml)	B35	MMB	Status	F35	FOFL	ABC	ABC (ml)
Model 0	31.18	34.25	144.6	110	0.74	0.95	0.67	28.06	30.83
Model 1	27.75	28.35	149.2	100.1	0.65	1.95	1.19	24.97	25.51
Model 2	26.28	26.54	149.2	96.81	0.64	1.7	1.01	23.65	23.88
Model 3	27.54	28.14	150.4	98.9	0.65	2.03	1.23	24.79	25.32
Model 3a	9.36	9.53	137.7	59.81	0.54	2.48	1.19	8.42	8.58
Model 3b	32.43	34.02	155	109.4	0.68	1.88	1.21	29.19	30.62

Model evaluation

Model 0:
- Fits the terminal year of MMB worst
- Lower estimates of trawl selectivity

Model 1:
- Poor fits to female growth

Model 2:
- Poor fits to female growth

Model 3:
- Higher female discard mortality and selectivity
- Poor fits to female growth

Model 3a:
- Fits the terminal year of MMB best
- Fits the survey size composition data poorly in some years
- Fit the average size of catch in the survey most poorly
- Estimates catchability in the most recent survey era higher than implied by the BSFRF data
- Estimates very high directed F in recent years
- Higher female discard mortality and selectivity
- Estimates higher probability of maturing for small males and females
- Does not fit male growth

Model 3b:
- Only model other than the Model 0 that does not hit the bound for natural mortality

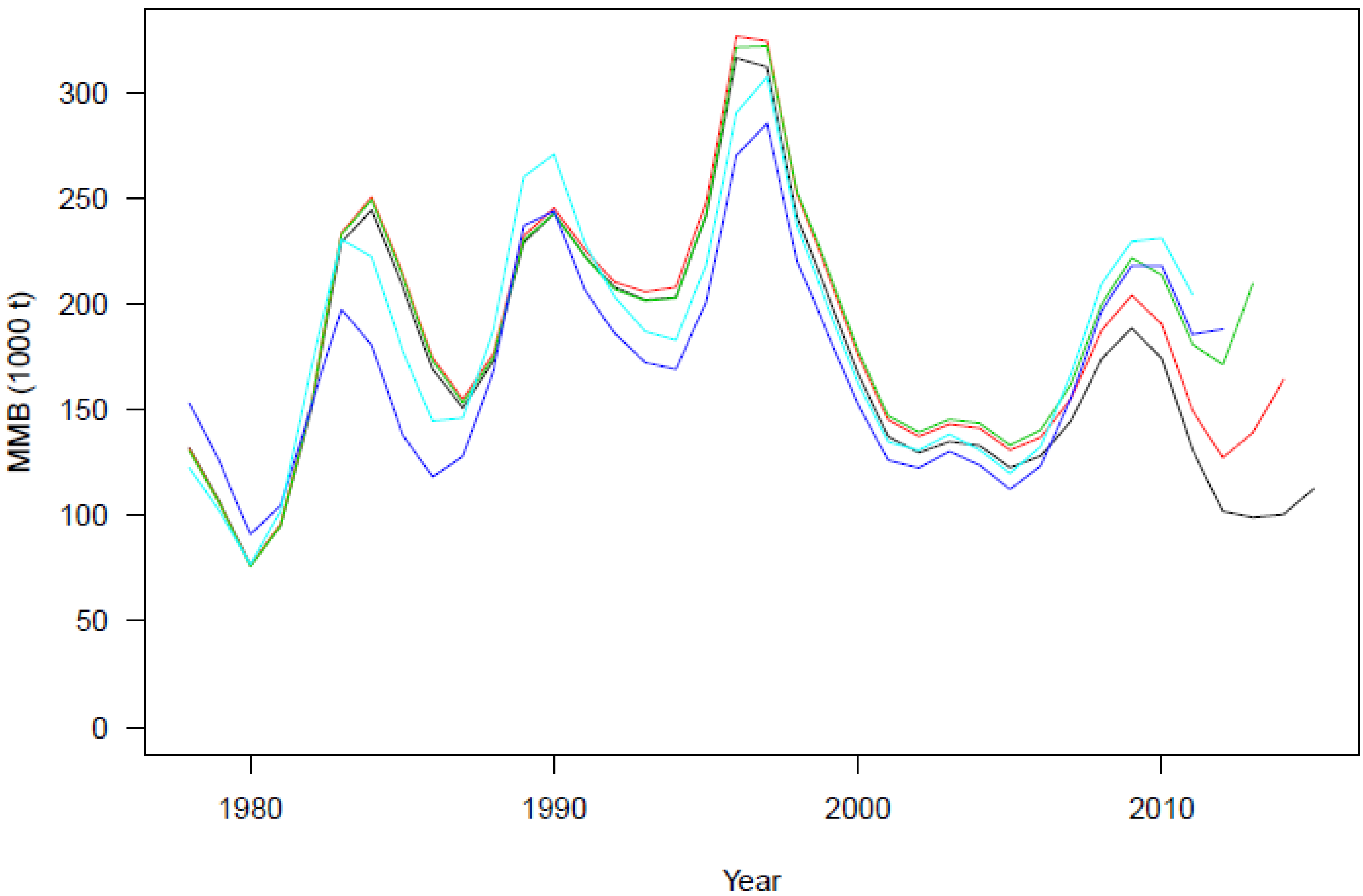
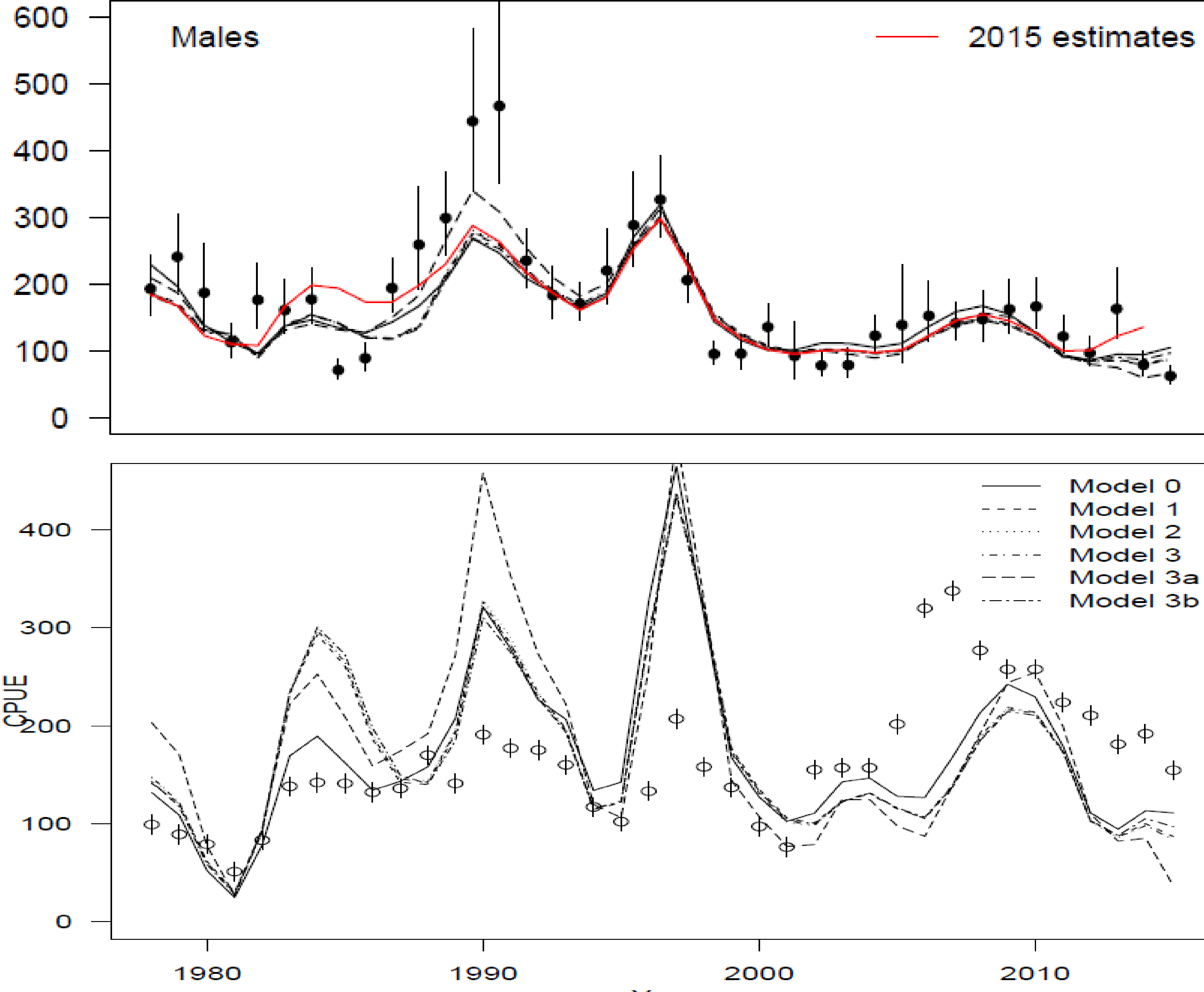


Figure 41: Retrospective pattern in MMB for chosen model



Males
2015 estimates
Model 0
Model 1
Model 2
Model 3
Model 3a
Model 3b
CPUE
0
100
200
300
400
500
600
1980
1990
2000
2010

Future directions

Posterior predictive intervals.
Get weight at length data into the model (if the SSC bites on the Bayesian bit).
Rework the weighting of the size composition data
Find an anchor for catchability (reconsider how the BSFRF data are used).
Consider the relationship between catchabilities in survey eras.
Split out bycatch.
Reconsider growth model.
Split out male weight at length by maturity state?
Think about priors on M and what they mean.

Andre:
Fit model to actual male data (rather than separated by maturity).
I’m not sure how to approach reference points if this is the case.
Change the way fishing mortality is modeled (learn from Buck).
Estimate more parameters.