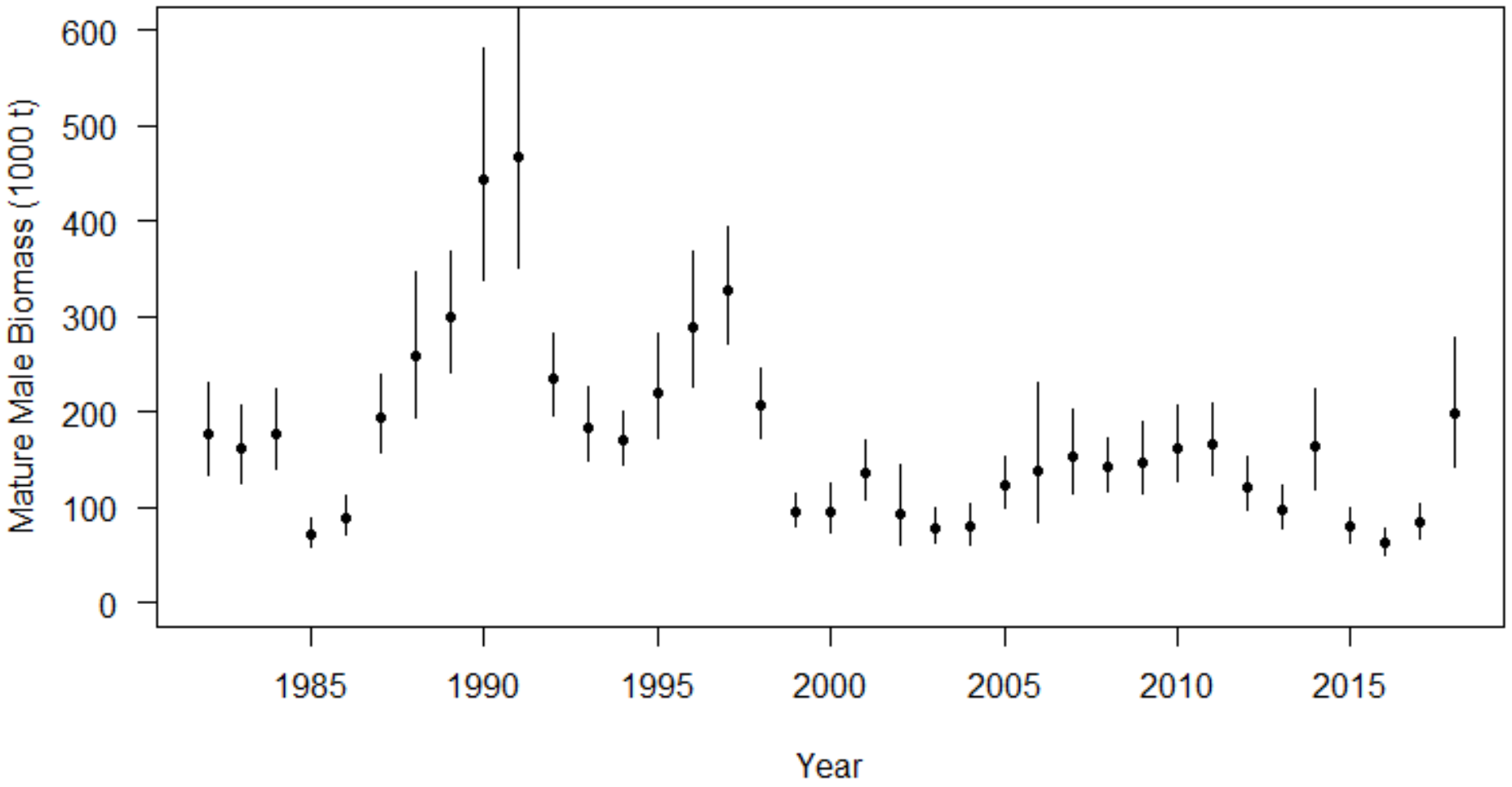
Eastern Bering Sea snow crab stock assessment

Cody Szuwalski

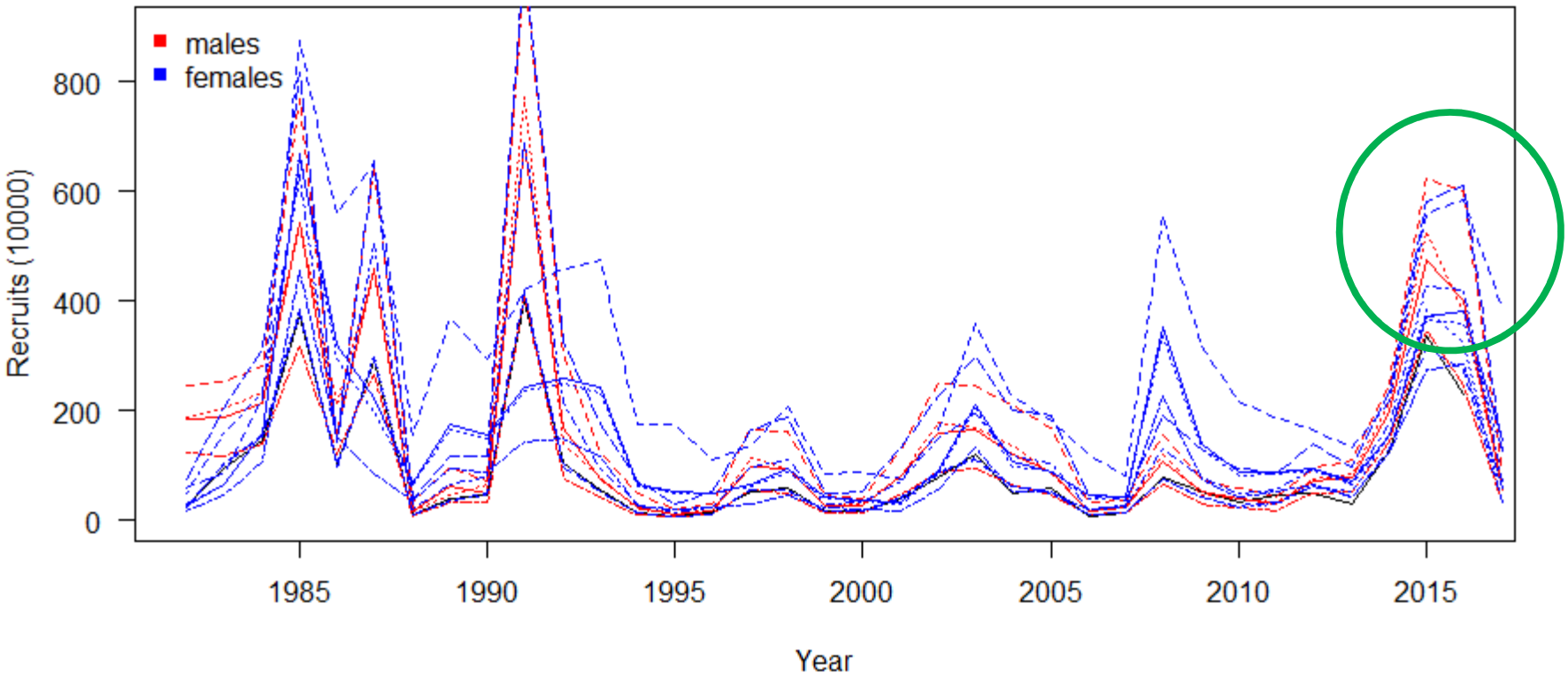
Crab Plan Team

September 12, 2018

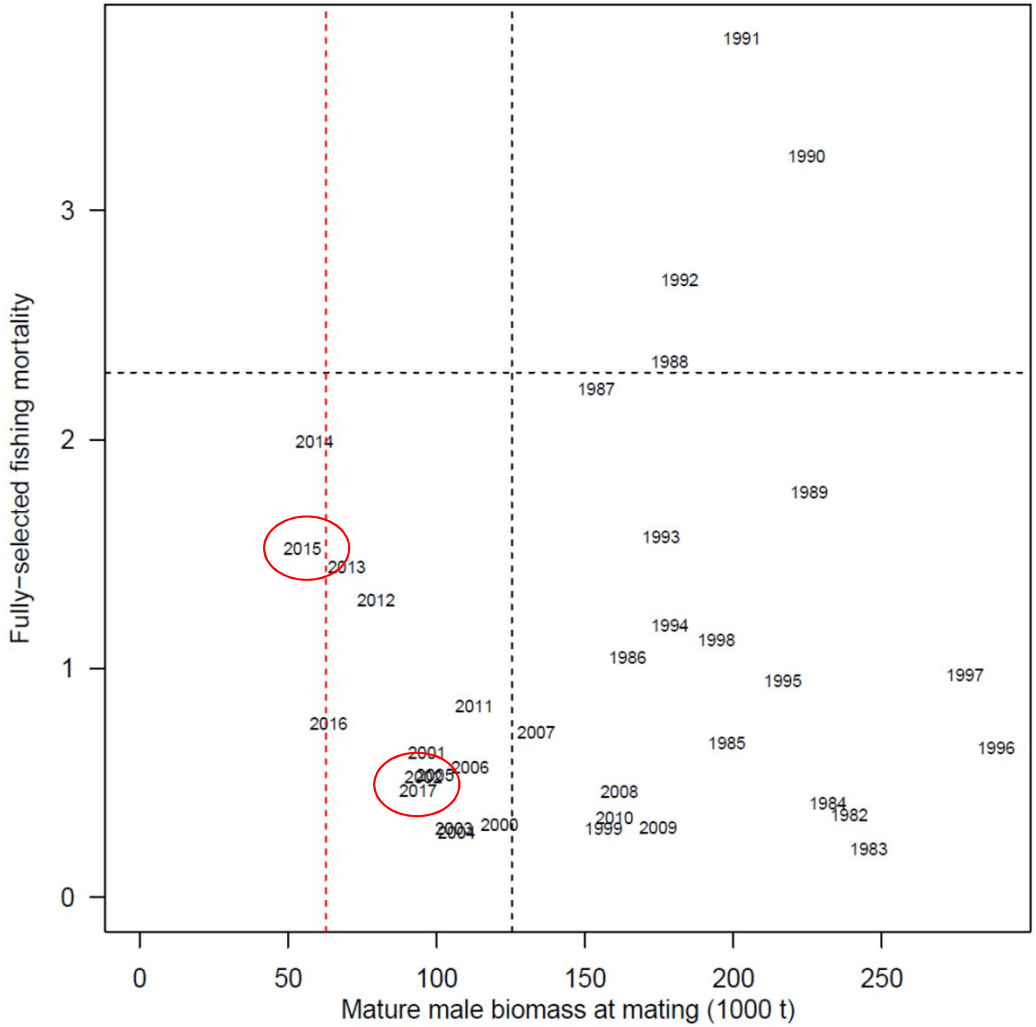
- Highest observed survey mature male biomass since 1998



- This was due to a large recruitment in 2014/2015, which is beginning to be seen in the mature male biomass

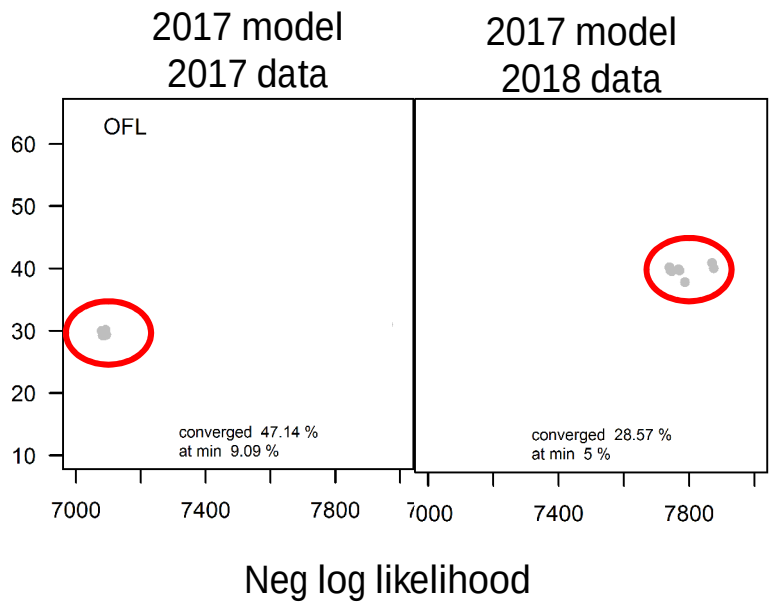


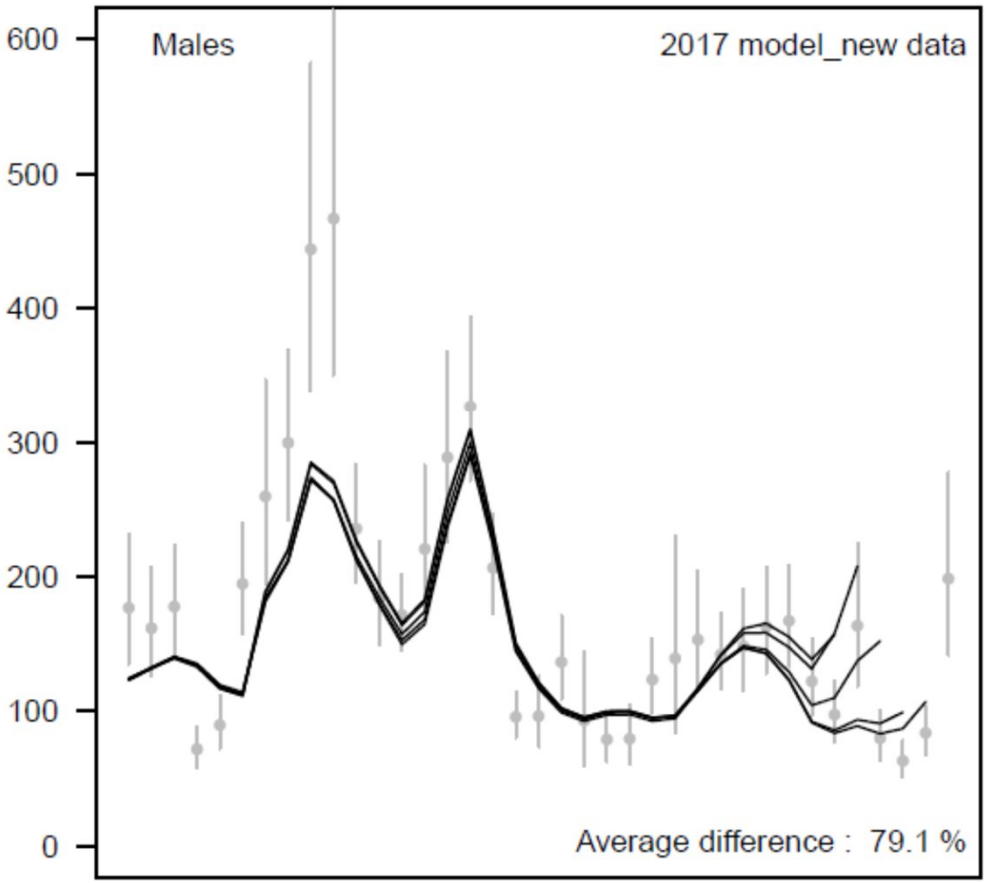
- The stock remains above MSST and fishing pressure remains below $F_{35\%}$



Instability

- Jitters
- Retrospective patterns





Models considered

chosen vs. rec; small changes

1. “2017 Accepted” : Last year’s model; last year’s data
2. “New Data”: Last year’s model; this year’s data

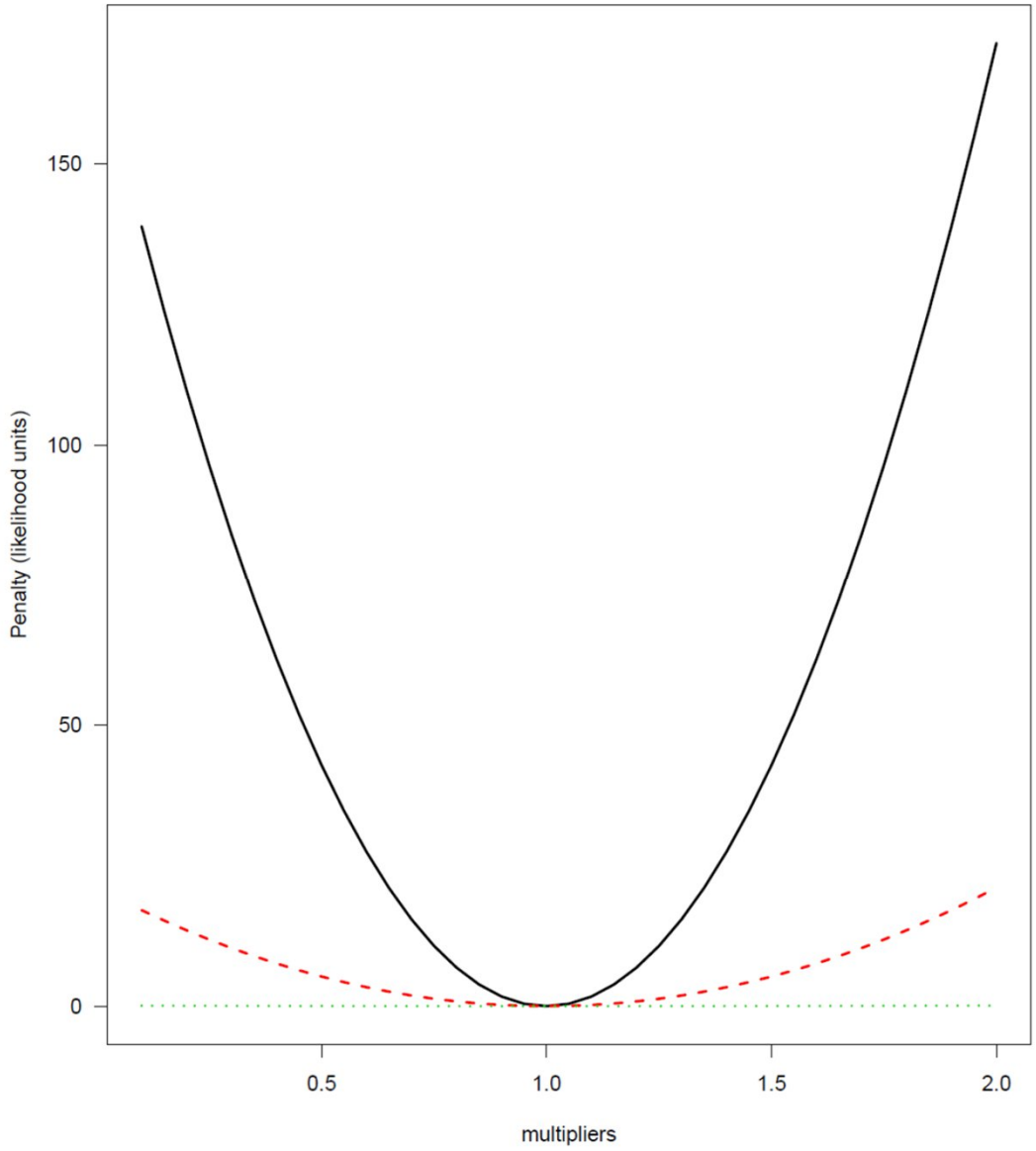
3. “Fix fem M” : Fix mature female M at 0.23 as in 2016 assessment
4. “Loose prior M” : Estimate all natural mortalities with a looser prior on M
5. “Looser prior M” : Estimate all natural mortalities with an even looser prior on M

6. “Sep devs” : Estimate separate recruitment deviations for females and males
7. “Sep devs + loose prior M” : Combine 6 and 4
8. “Sep devs + looser prior M” : Combine 6 and 5

9. “Sep devs + loose + growth” : Model 7, but estimate linear growth curve instead of ‘kinked’

SSC and CPT suggestion

- “Second, the SSC briefly discussed the importance of estimates of natural mortality (M) as q and M are confounded in stock assessments.”
- “The SSC recommends some experimental model runs with higher (and lower) priors on M to confirm the generality of model convergence to the reported model-estimated values of M and q.”



Natural mortality

2016	Immature	Mature
Female	0.41	0.23
Male	0.41	0.26

Natural mortality

2017	Immature	Mature
Female	0.28	0.27
Male	0.28	0.36

Estimation of annual, time-varying natural mortality and survival for Eastern Bering Sea snow crab (*Chionoecetes opilio*) with state-space population models

James T. Murphy[a,*], Louis J. Rugolo[b], Benjamin J. Turnock[b]

[a] *Cascadia Sciences, 4403 Francis Ave. N. #4, Seattle, WA, 98103, USA*
[b] *Alaska Fisheries Science Center, National Oceanic and Atmospheric Administration, 7600 Sand Point Way Northeast, Seattle, WA, 98125, USA*

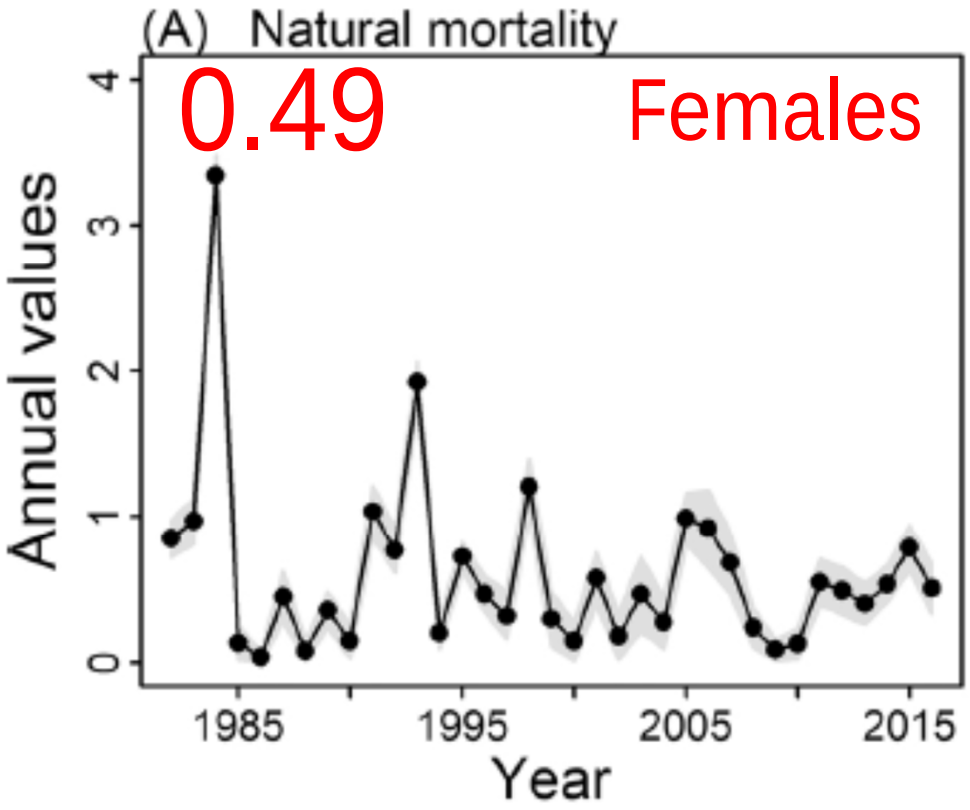
ARTICLE INFO

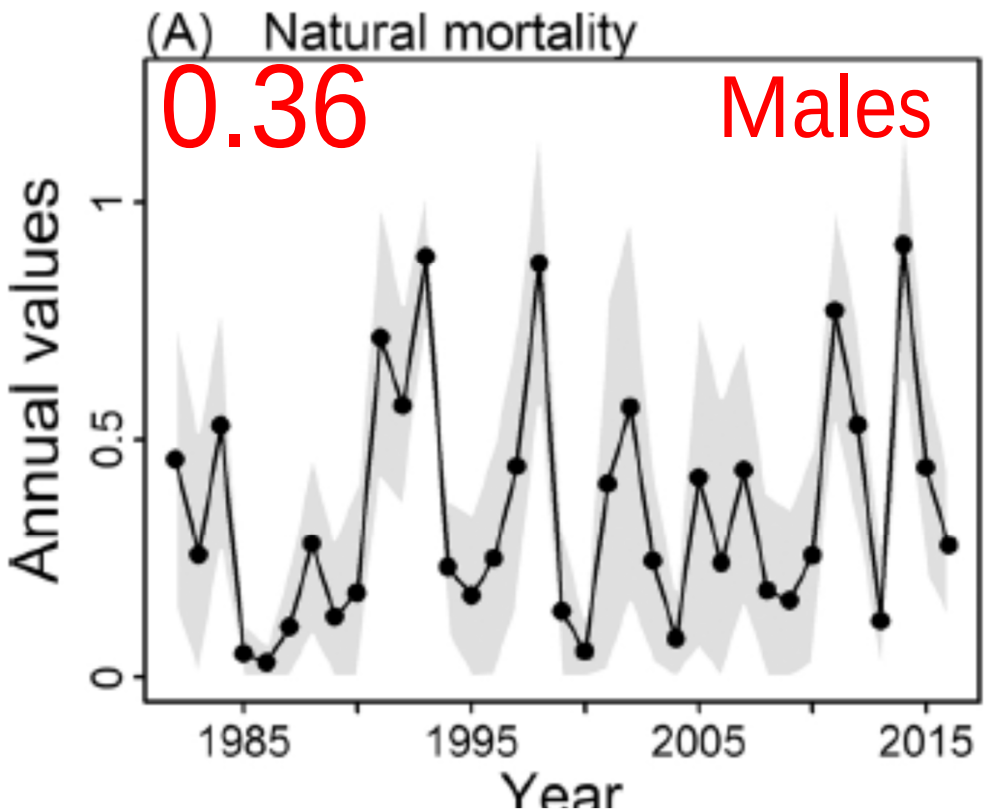
Handled by A.E. Punt

Keywords:
Eastern Bering Sea
Snow crab
State-space population model
Natural mortality
Random effects

ABSTRACT

Sex-specific, state-space population models with size and stage structure and fit to survey and fishery data were developed for the eastern Bering Sea (EBS) snow crab for the years 1982–2017. Motivation for model development was to estimate population dynamics by shell condition for female crabs; estimate sex-specific annual, time-varying natural morality rates; and explore in general the feasibility of state space modeling for EBS snow crab. Model fits were very good and mean natural mortality estimates agreed with previous studies but several quite high and/or quite low annual natural mortality values were estimated for both sexes. Estimated mean female natural mortality was 0.49 yr^{-1} (s.d. = 0.01) with annual values from 0.04 yr^{-1} to 3.34 yr^{-1}. Estimated mean male natural mortality was 0.36 yr^{-1} (s.d. = 0.07) with annual values from 0.03 yr^{-1} to 0.91 yr^{-1}. Episodic high and low annual natural mortality estimates indicate potential model overfitting which an autoregressive or random walk estimation framework for natural mortality may address. We consider the models as proof-of-concept estimation frameworks and their results preliminary. After further refinement and testing, they could be a complementary approach to ongoing stock assessment modeling or prototypes for state-space assessment models. Additional process variability, such as for growth and maturation, can be incorporated in future work. Abundance estimates by mature female shell condition makes feasible estimation of annual and biennial spawner abundances, necessary for accurate egg production estimation. State-space population dynamics models of other *Chionoecetes* populations with both size and stage-based data (e.g., maturity status or shell condition) can be developed utilizing this study's modeling framework.





“We consider the models as proof-of-concept estimation frameworks and their results preliminary.”

CONFOUNDING

Recruitment
Natural mortality
Catchability
Growth

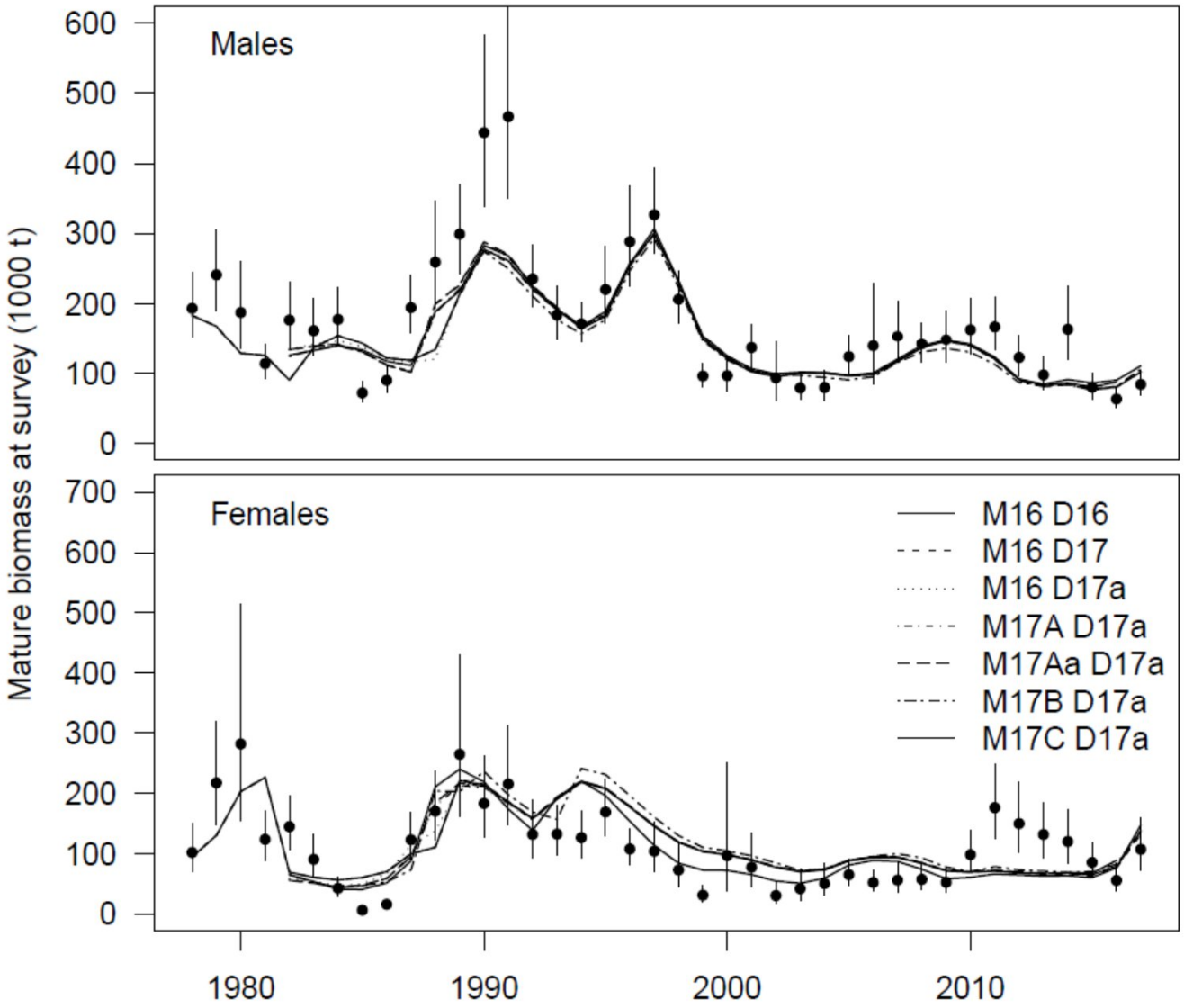
Models considered

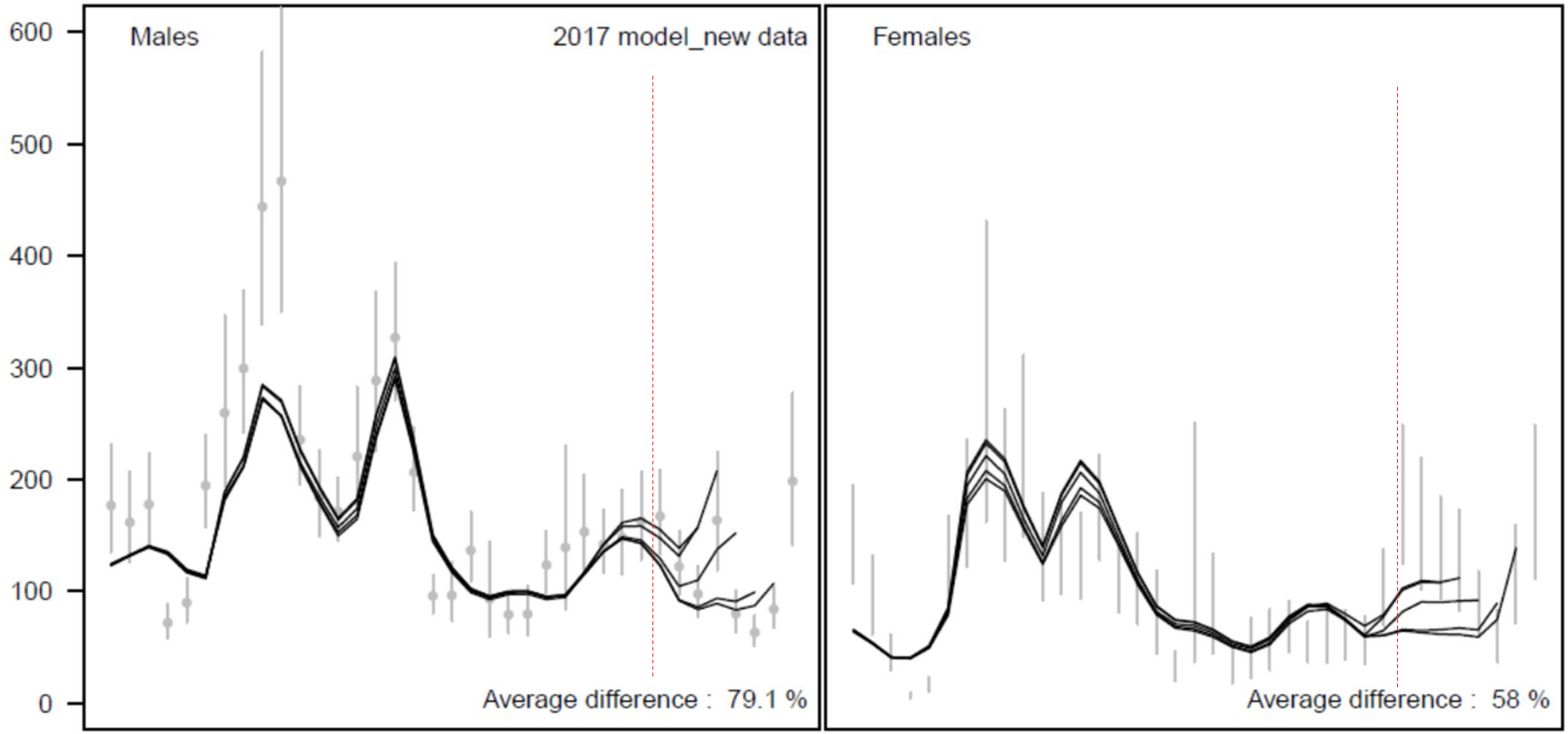
1. “2017 Accepted” : Last year’s model; last year’s data
2. “New Data”: Last year’s model; this year’s data

3. “Fix fem M” : Fix mature female M at 0.23 as in 2016 assessment
4. “Loose prior M” : Estimate all natural mortalities with a looser prior on M
5. “Looser prior M” : Estimate all natural mortalities with an even looser prior on M

6. “Sep devs” : Estimate separate recruitment deviations for females and males
7. “Sep devs + loose prior M” : Combine 6 and 4
8. “Sep devs + looser prior M” : Combine 6 and 5

9. “Sep devs + loose + growth” : Model 7, but estimate linear growth curve instead of ‘kinked’


Males
Females
Mature biomass at survey (1000 t)
600
500
400
300
200
100
0
700
600
500
400
300
200
100
0
1980
1990
2000
2010
M16 D16
M16 D17
M16 D17a
M17A D17a
M17Aa D17a
M17B D17a
M17C D17a


Males
2017 model_new data
Average difference : 79.1 %
Females
Average difference : 58 %
600
500
400
300
200
100
0

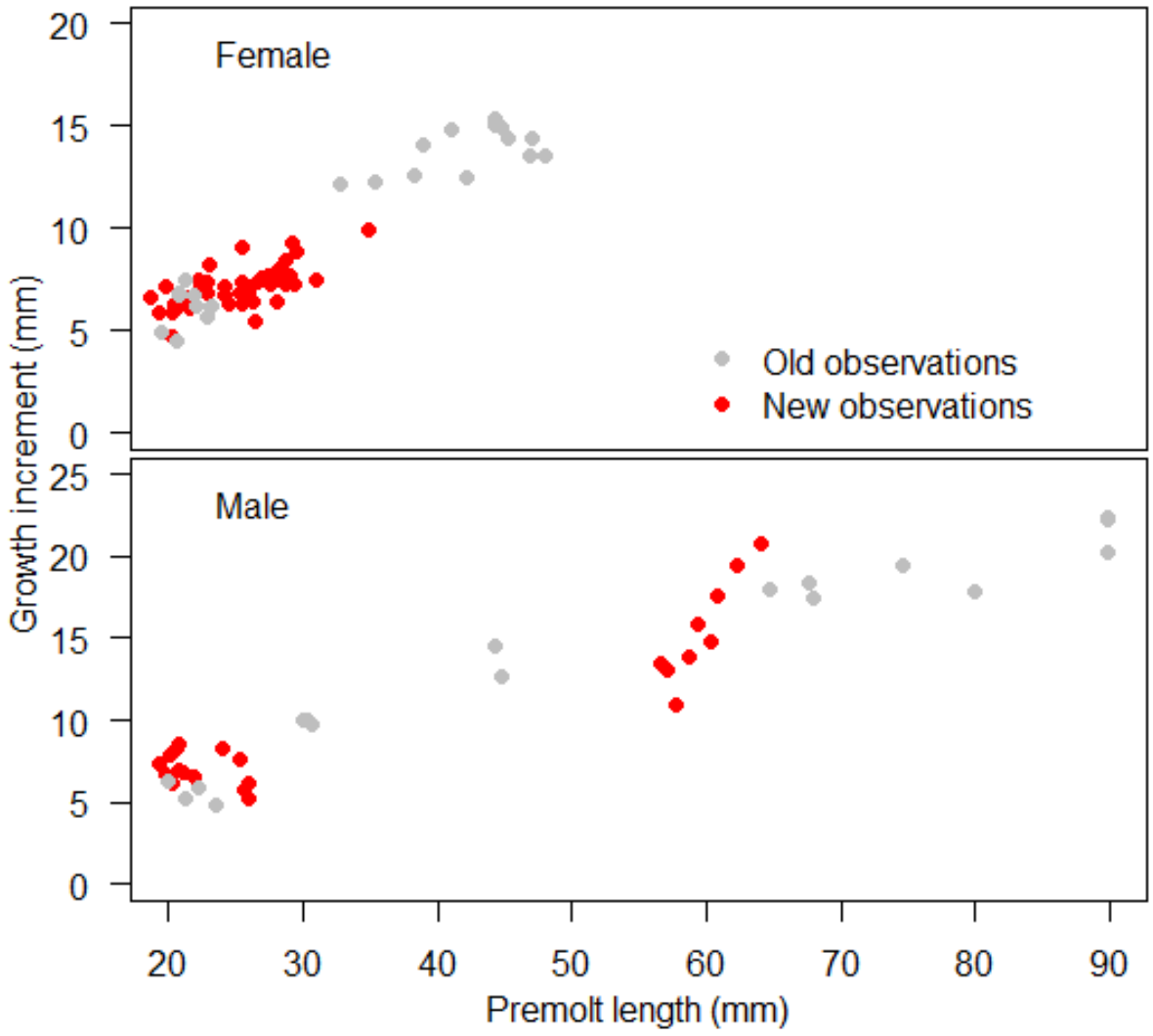
Models considered

1. “2017 Accepted” : Last year’s model; last year’s data
2. “New Data”: Last year’s model; this year’s data

3. “Fix fem M” : Fix mature female M at 0.23 as in 2016 assessment
4. “Loose prior M” : Estimate all natural mortalities with a looser prior on M
5. “Looser prior M” : Estimate all natural mortalities with an even looser prior on M

6. “Sep devs” : Estimate separate recruitment deviations for females and males
7. “Sep devs + loose prior M” : Combine 6 and 4
8. “Sep devs + looser prior M” : Combine 6 and 5

9. “Sep devs + loose + growth” : Model 7, but estimate linear growth curve instead of ‘kinked’

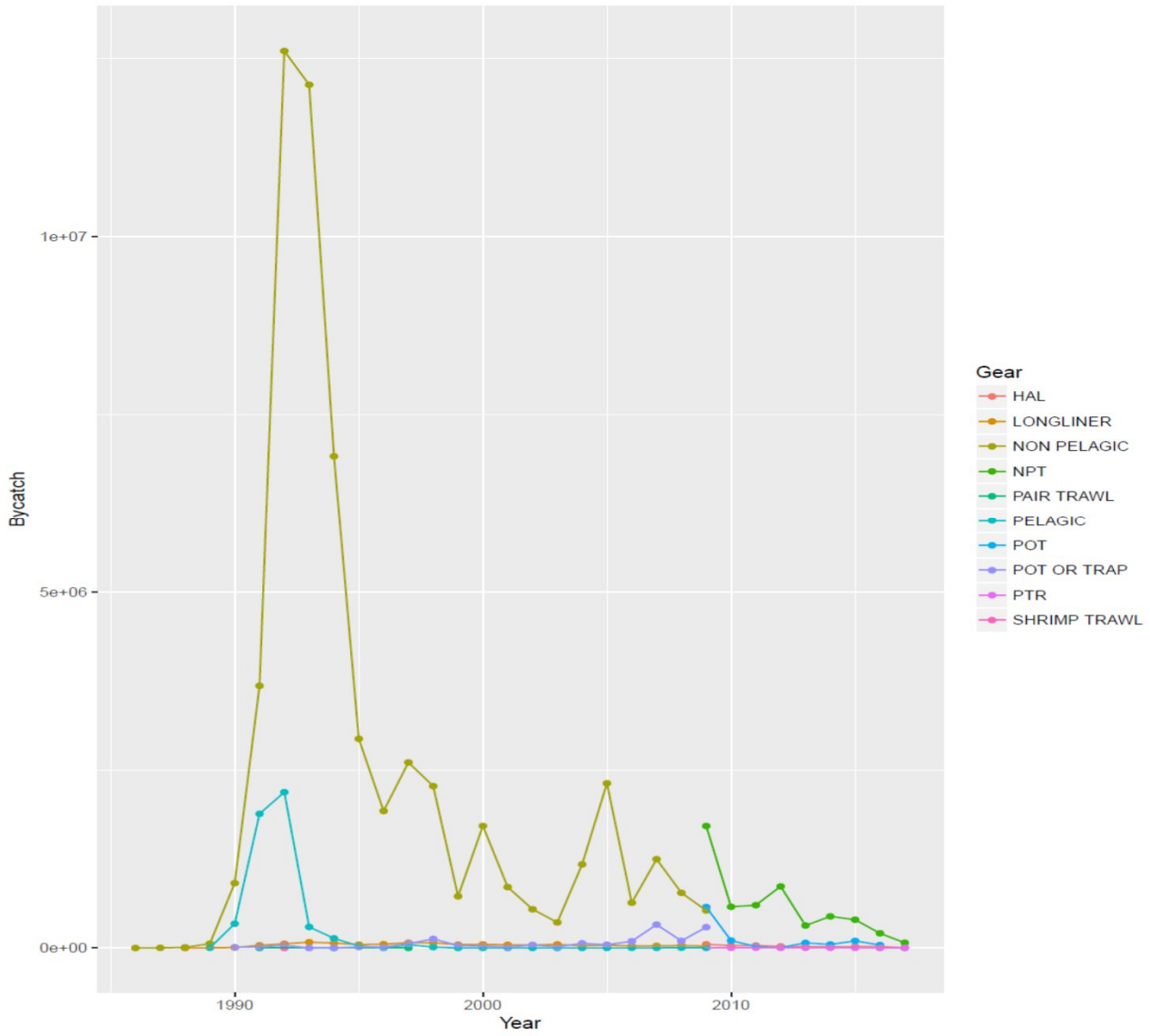

Female
Male
Old observations
New observations
Growth increment (mm)
Premolt length (mm)
0
5
10
15
20
25
20
30
40
50
60
70
80
90

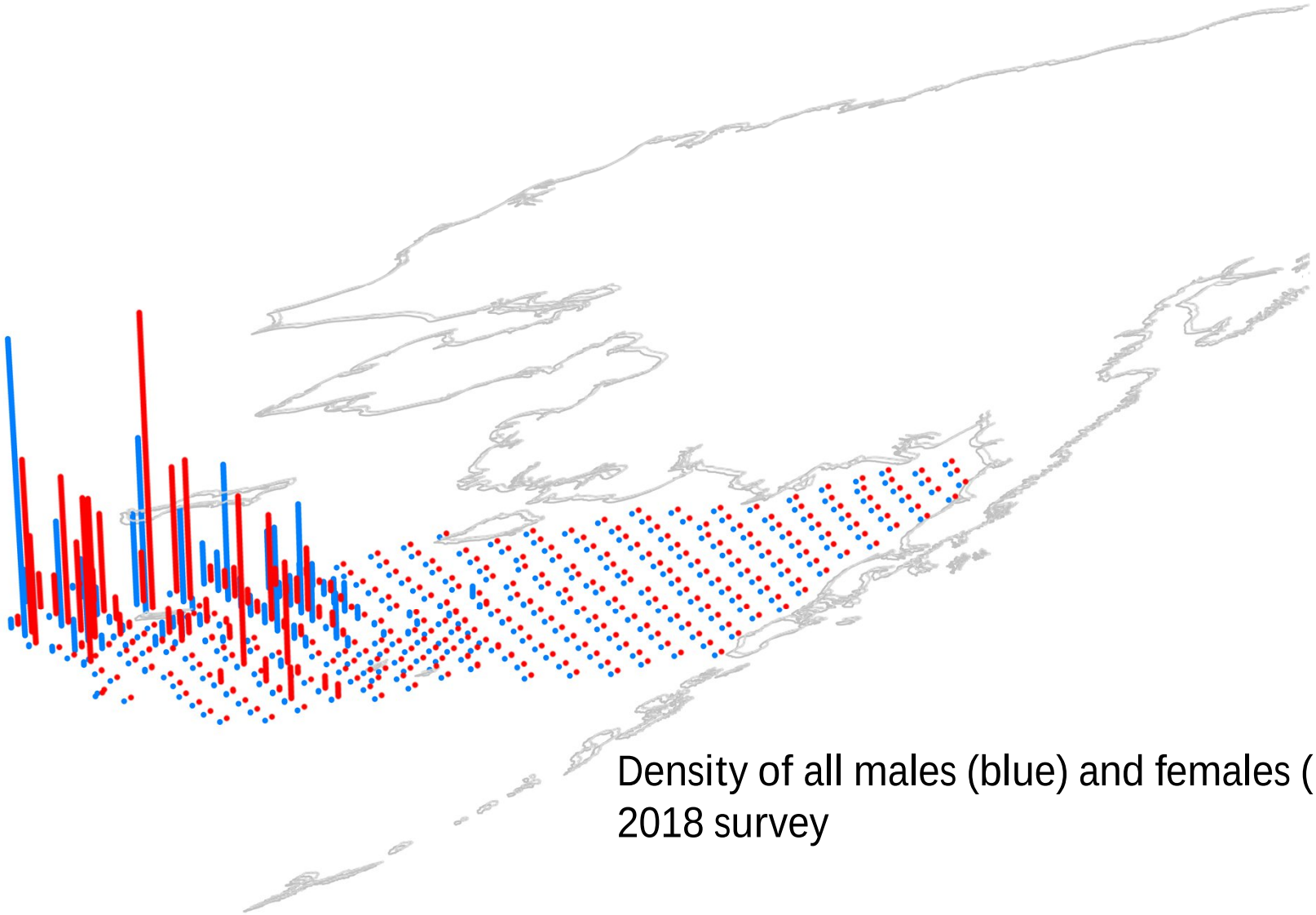
Other CPT and SSC asks

1. Parameters hitting bounds
2. Video for the potential BSFRF catchability was not 1
3. Issues with mixing in MCMC
4. “Things may be getting too complicated”

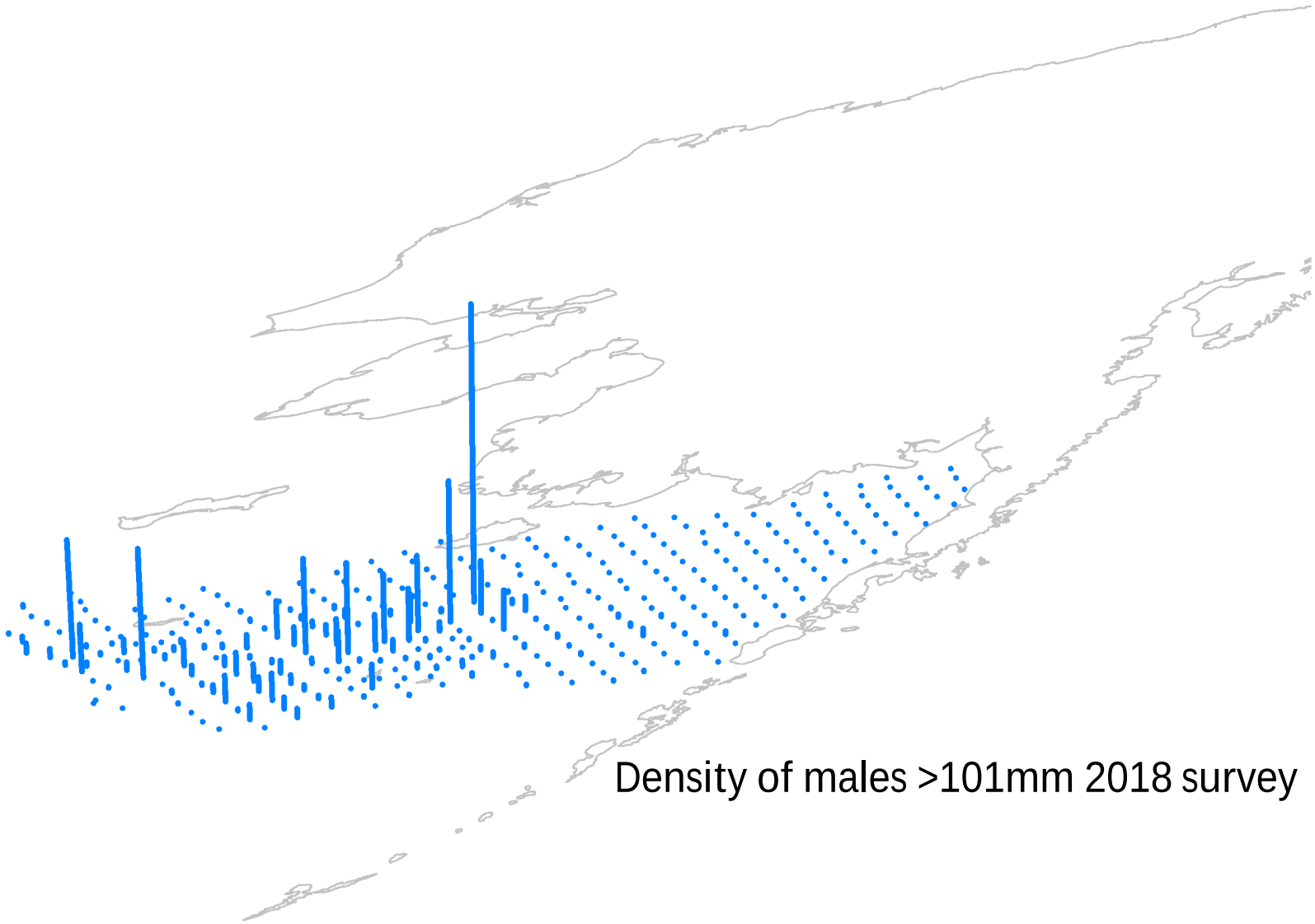
New data

Data component	Years
Retained male crab pot fishery size frequency by shell condition	1982 - 2017
Discarded Males and female crab pot fishery size frequencey	1992 - 2017
Trawl fishery bycatch size frequencies by sex	1991 - 2017
Survey size frequencies by sex and shell condition	1982 - 2018
Retained catch estimates	1982 - 2017
Discard catch estimates from crab pot fishery	1992 - 2017
Trawl bycatch estimates	1993 - 2017
Total survey biomass estimates and coefficients of variation	1982 - 2018
2009 study area biomass estimates, CVs, and size frequencey for BSFRF and NMFS tows	2009
2010 study area biomass estimates, CVs, and size frequencey for BSFRF and NMFS tows	2010

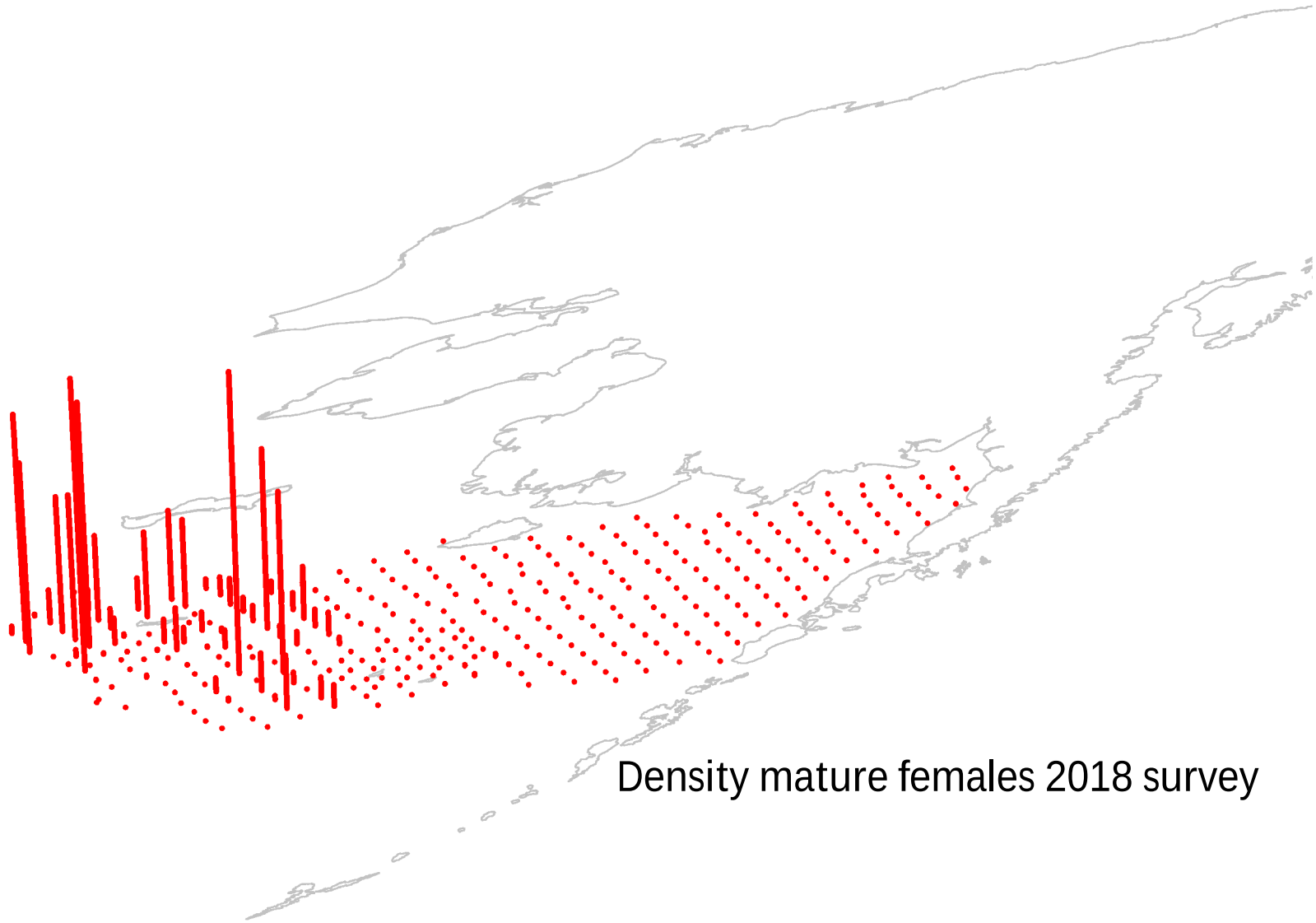

Bycatch
1e+07
5e+06
0e+00
1990
2000
2010
Year
Gear
HAL
LONGLINER
NON PELAGIC
NPT
PAIR TRAWL
PELAGIC
POT
POT OR TRAP
PTR
SHRIMP TRAWL

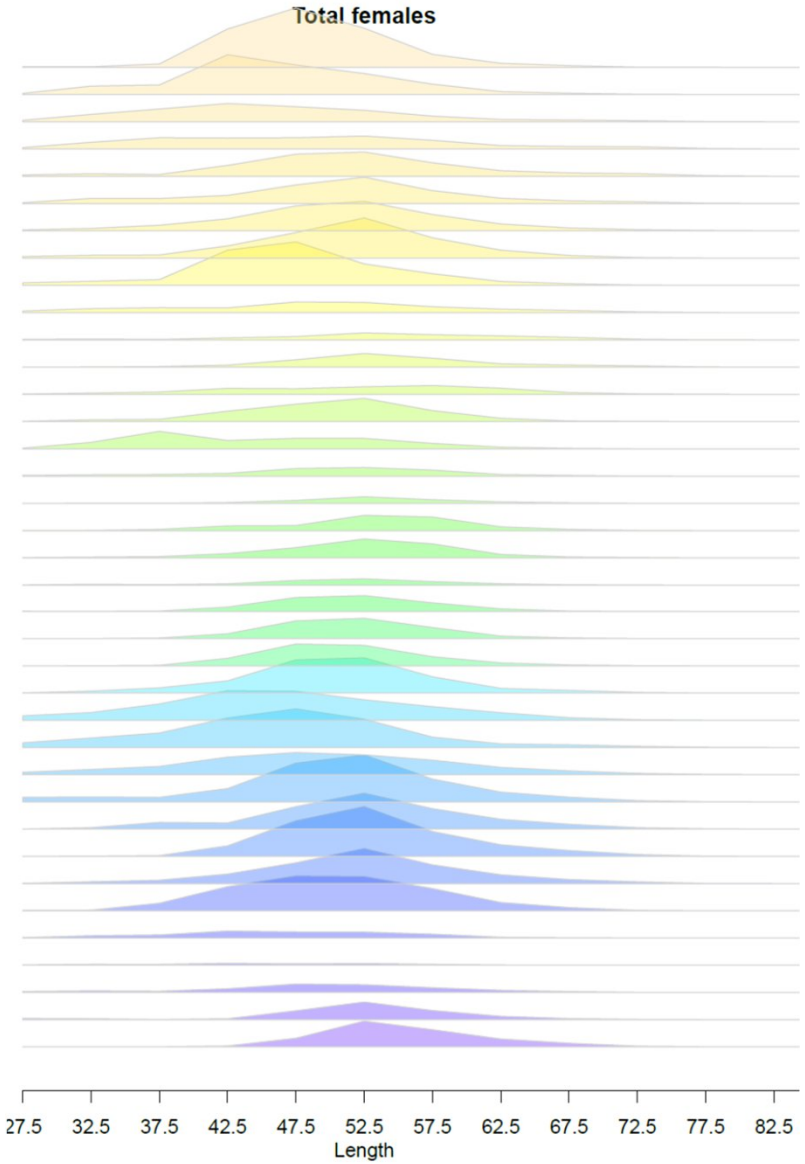


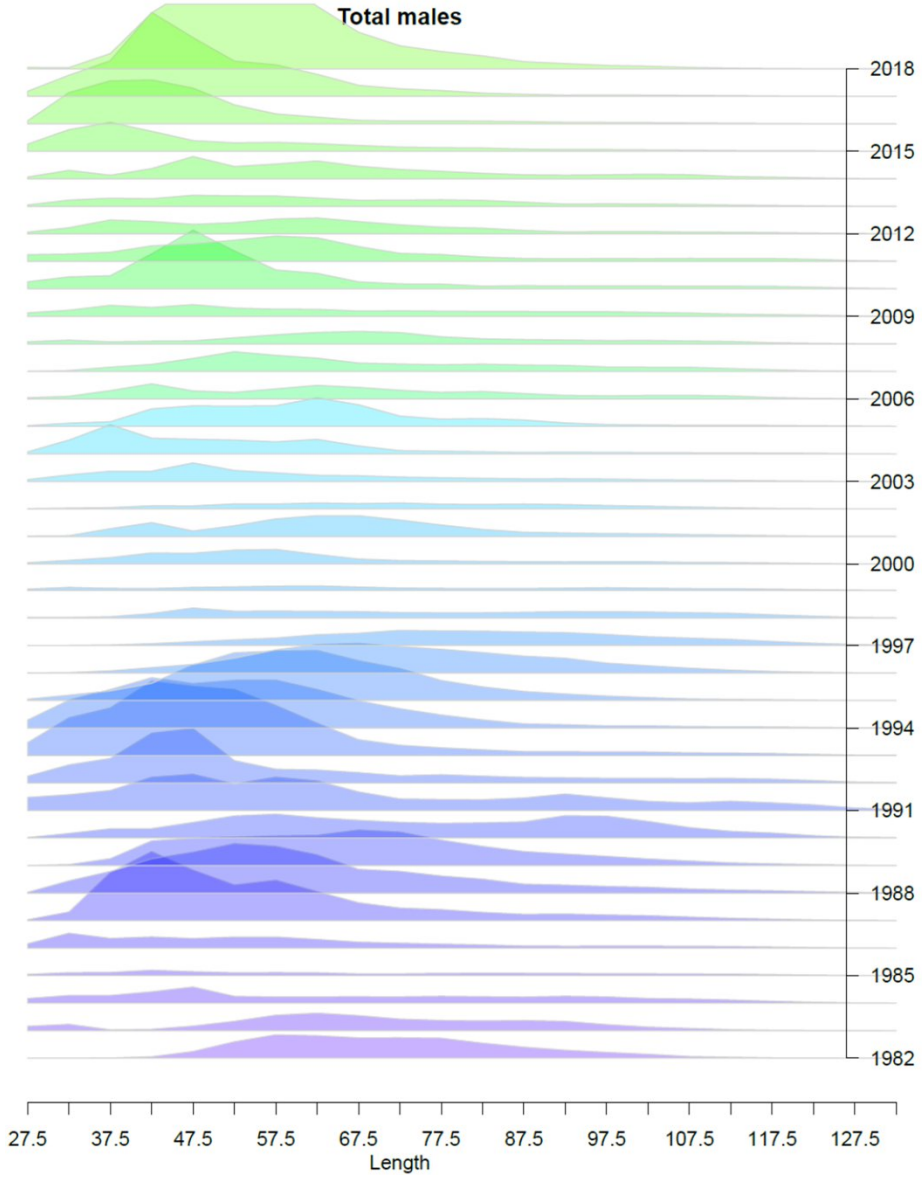
Density of all males (blue) and females (red)
2018 survey



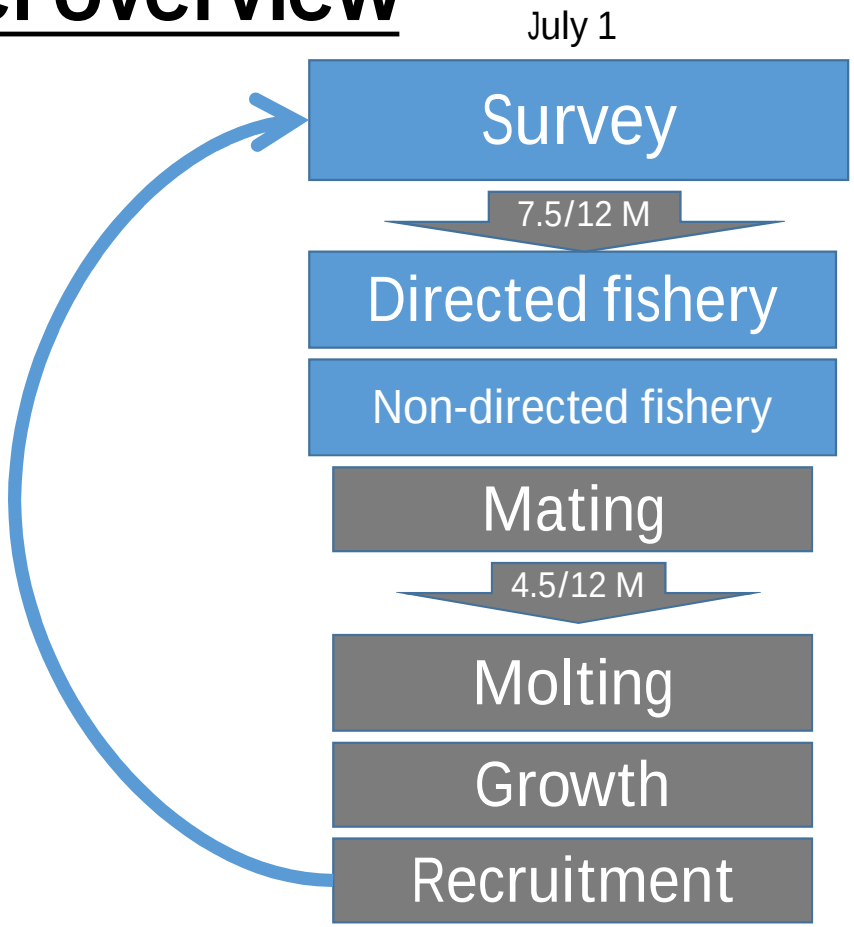
Density of males >101mm 2018 survey


Density mature females 2018 survey


Total females
27.5
32.5
37.5
42.5
47.5
52.5
57.5
62.5
67.5
72.5
77.5
82.5
Length

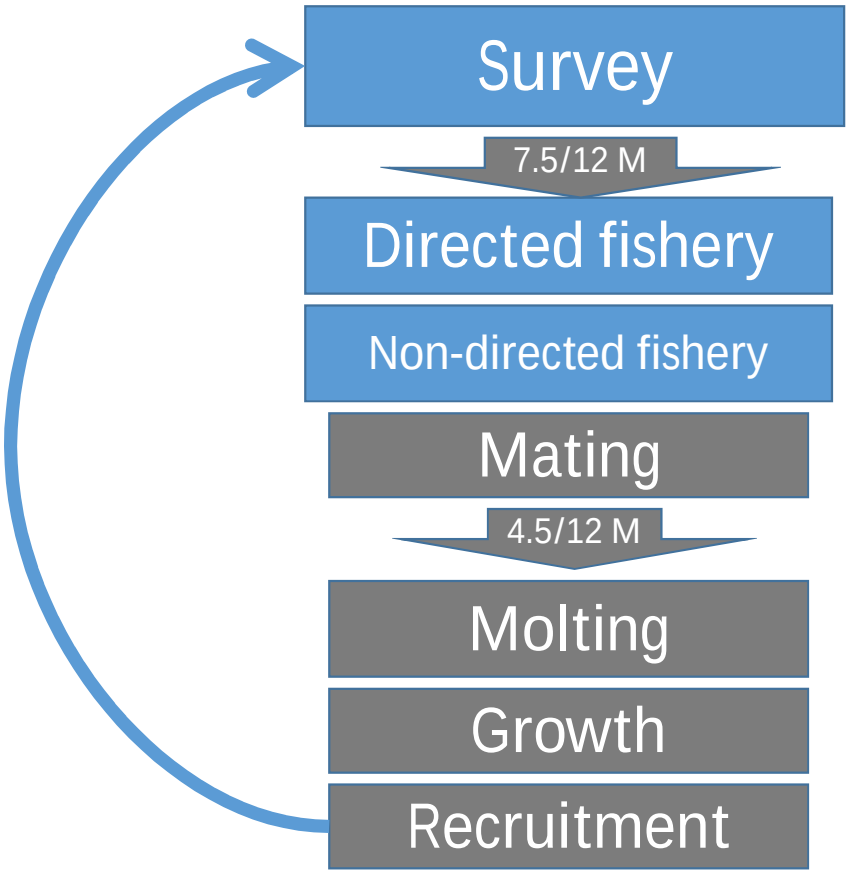

Total males
2018
2015
2012
2009
2006
2003
2000
1997
1994
1991
1988
1985
1982
27.5
37.5
47.5
57.5
67.5
77.5
87.5
97.5
107.5
117.5
127.5
Length

Model overview



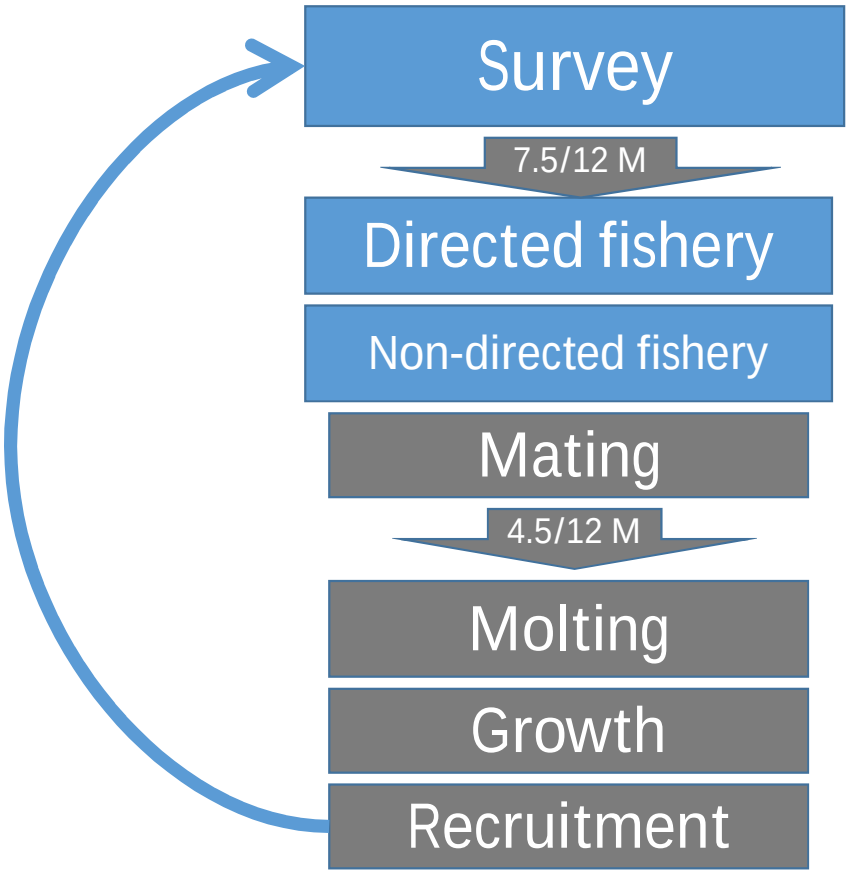
1. Logistic selectivity in 2 ‘eras’
2. Linked to BSFRF data
3. Size composition and biomass index

Model overview



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

Model overview



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

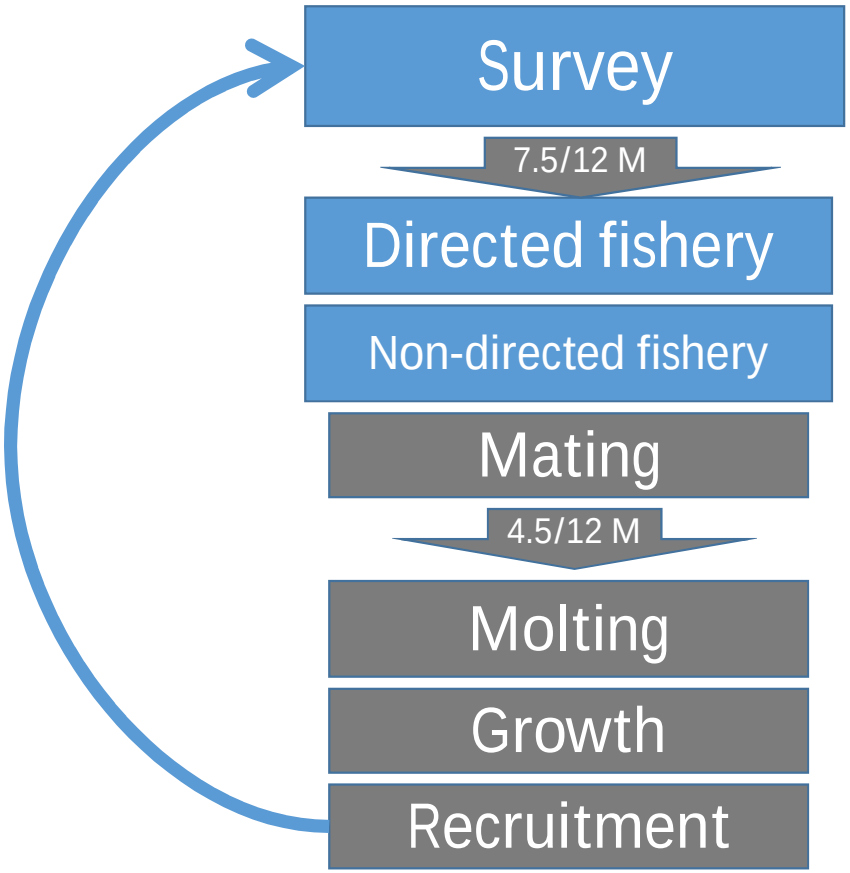
Data in:

Retained catch in t and #s

Discard numbers

Retained catch length comps

Model overview

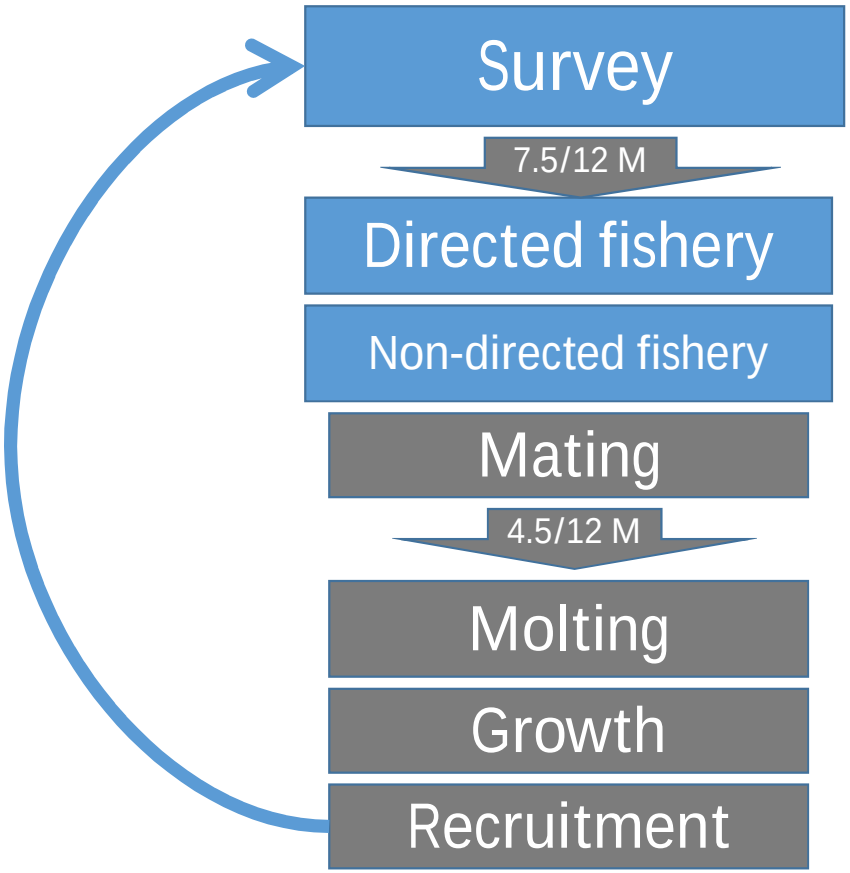


1. Logistic selectivity
2. Retention selectivity
3. Discard mortality equal to 30%

Fit to:

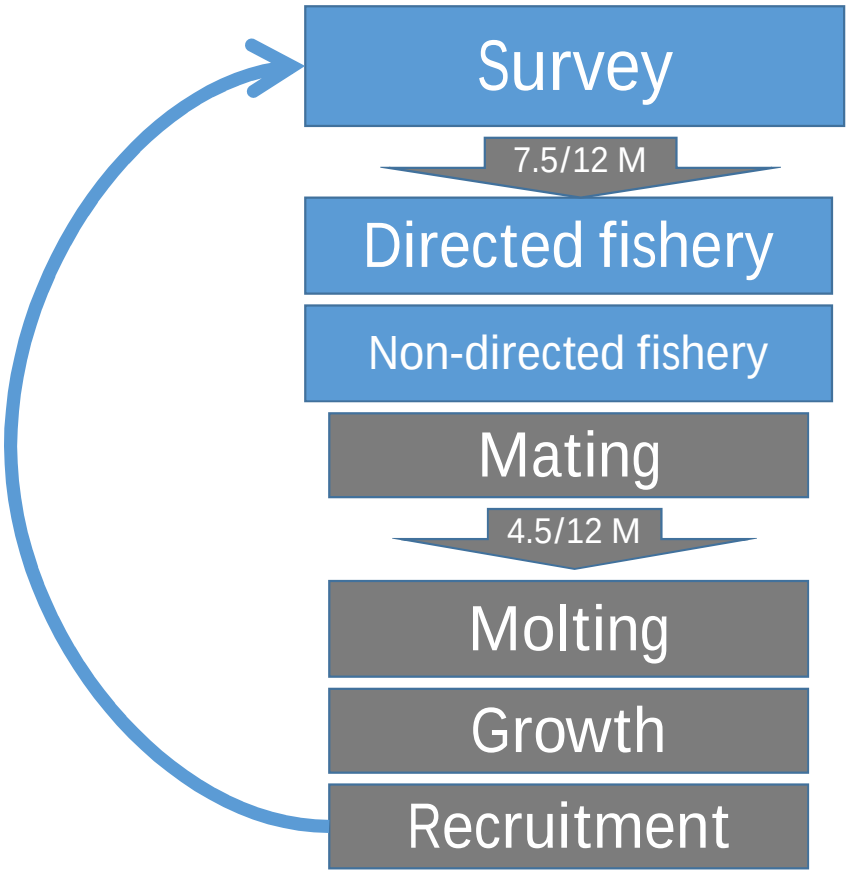
Retained length comps
Total length comps
Retained biomass
Male and female discard biomass

Model overview



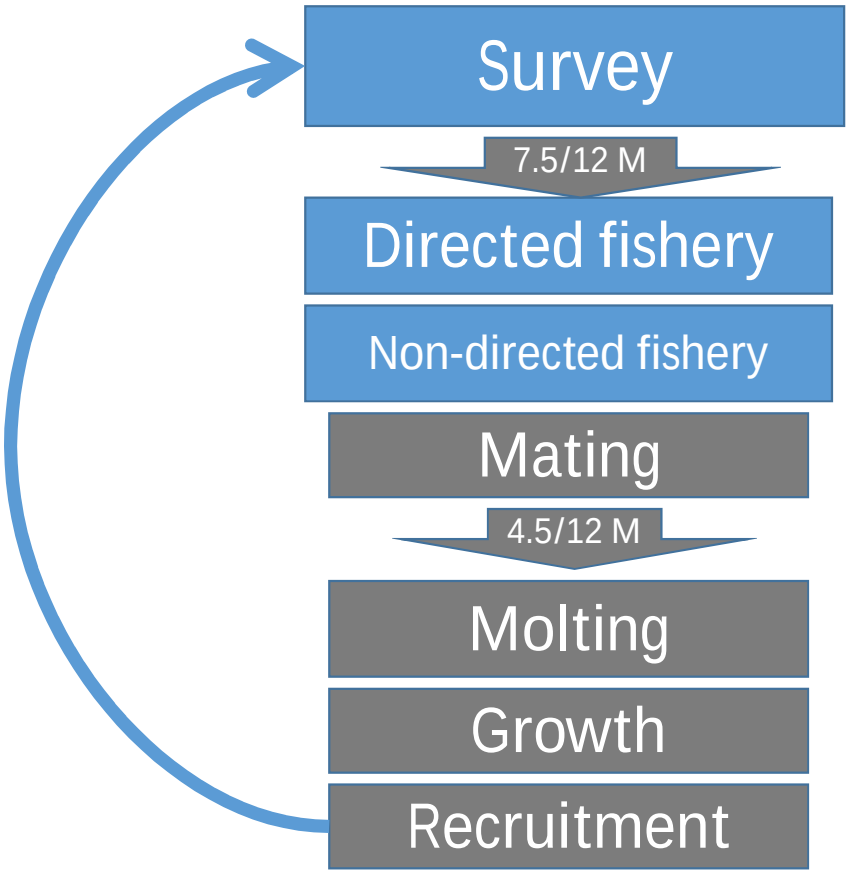
1. Logistic selectivity
2. Discard mortality equal to 80%

Model overview



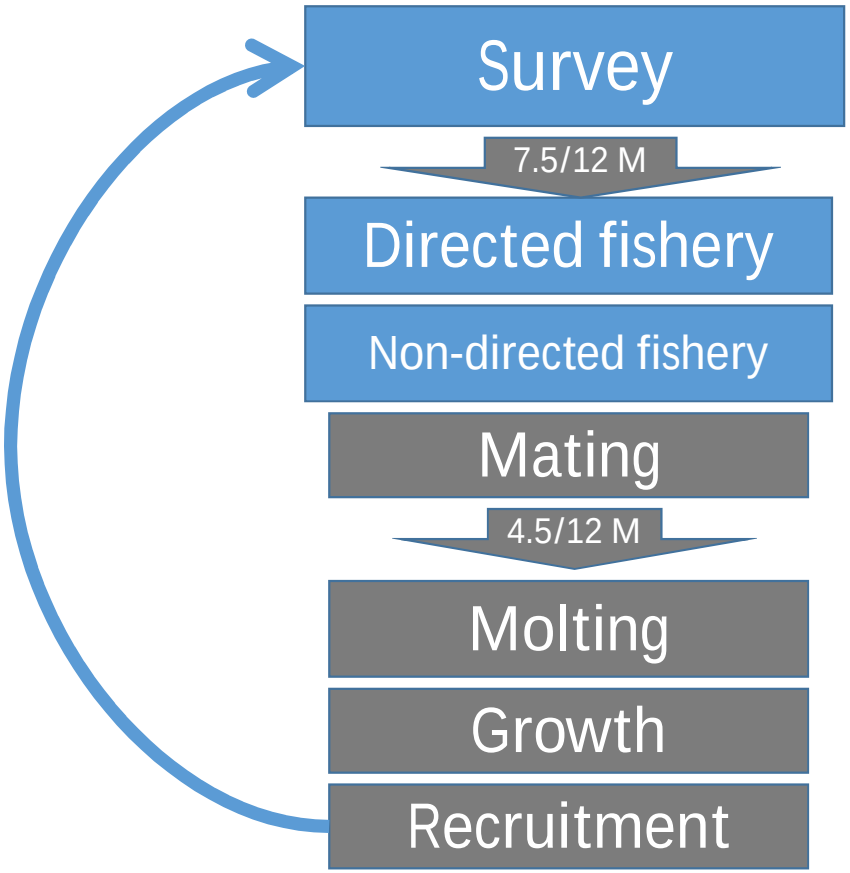
1. Freely estimated maturity curves
2. Priors and smoothing penalties
3. February 15

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 (except 1 model)

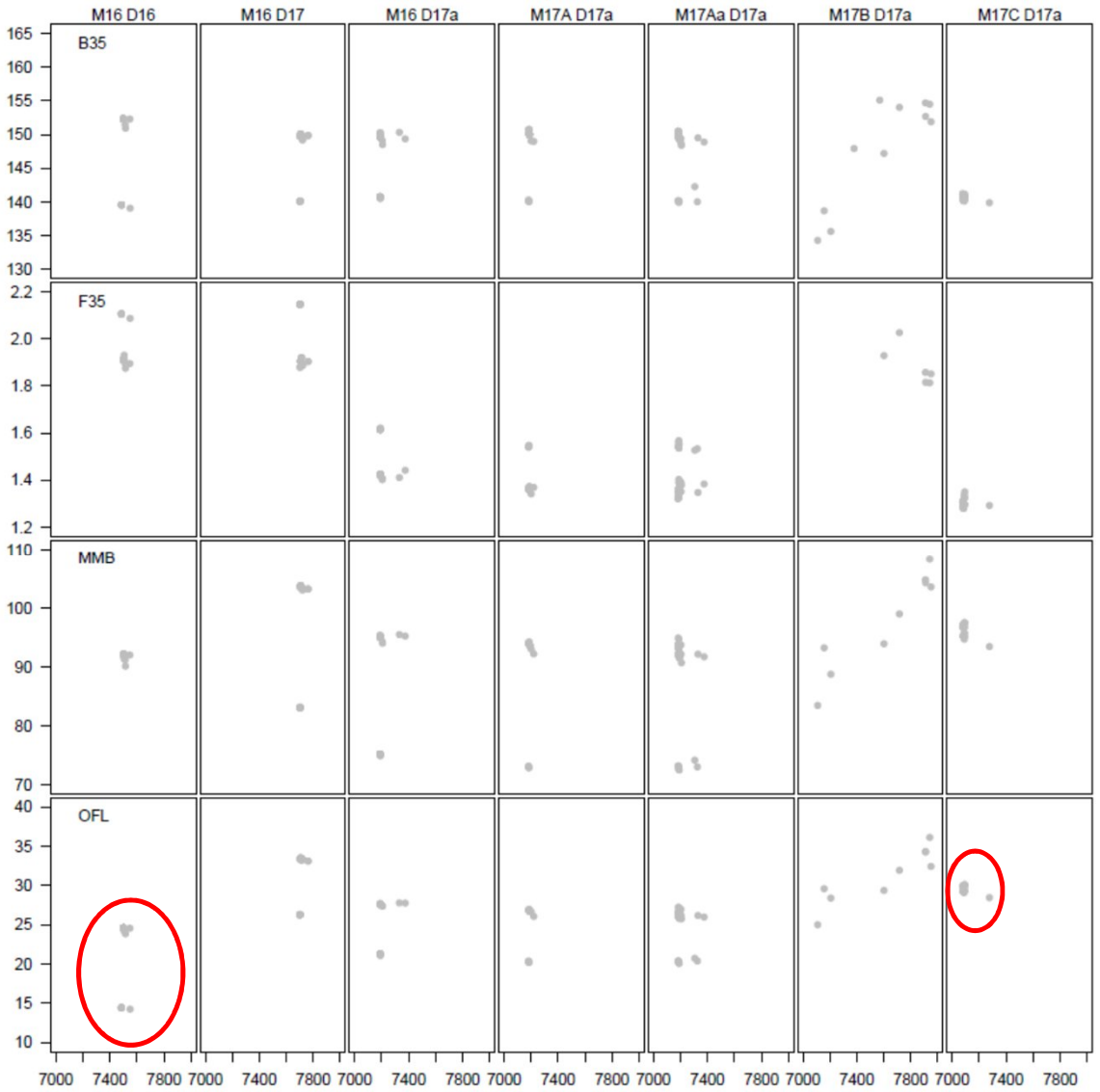
Goal: Find a stable model configuration to calculate the OFL

Plan of attack

- Jitter and use maximum likelihood estimates
  - Model less stable with new data

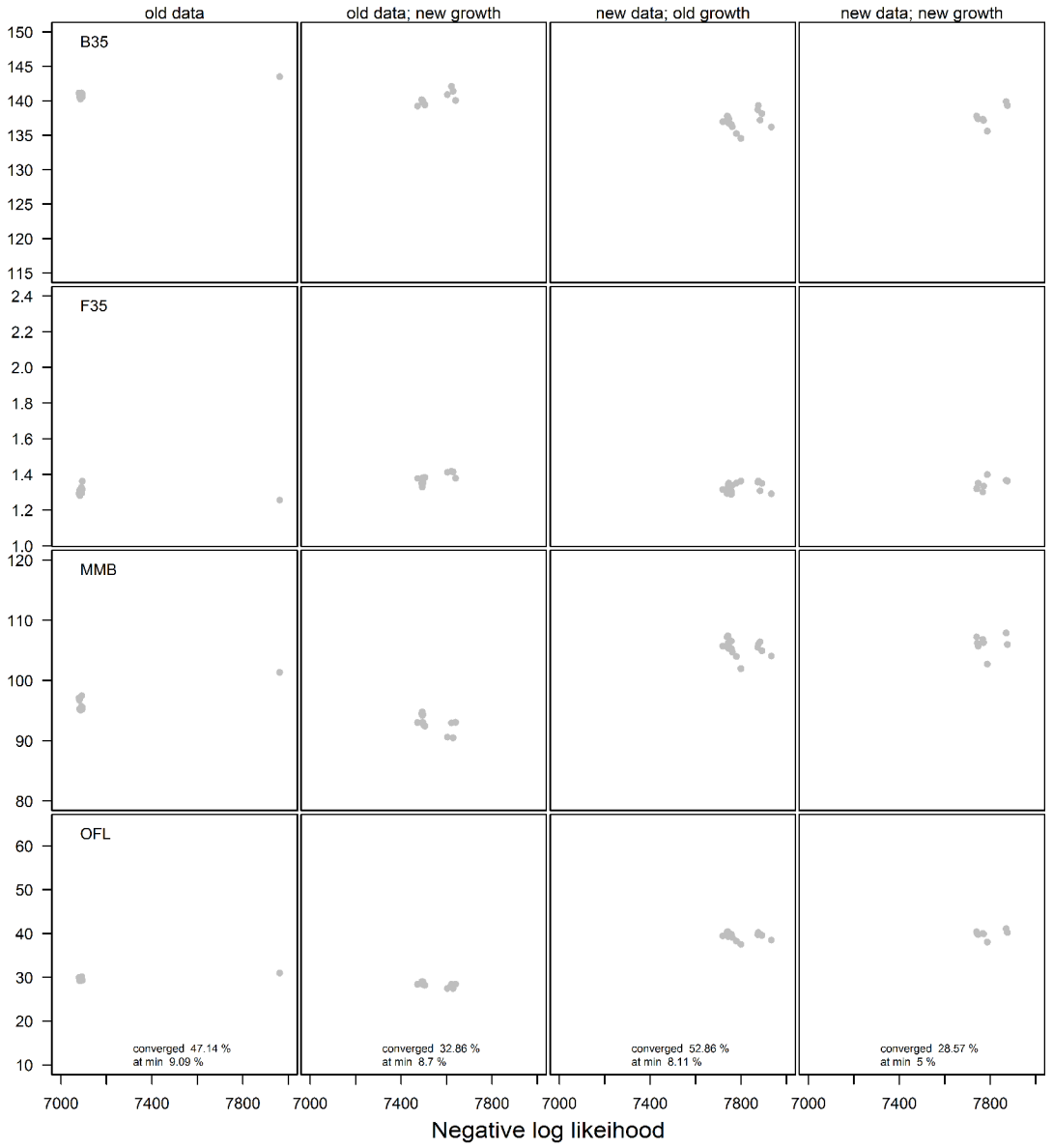
Last year

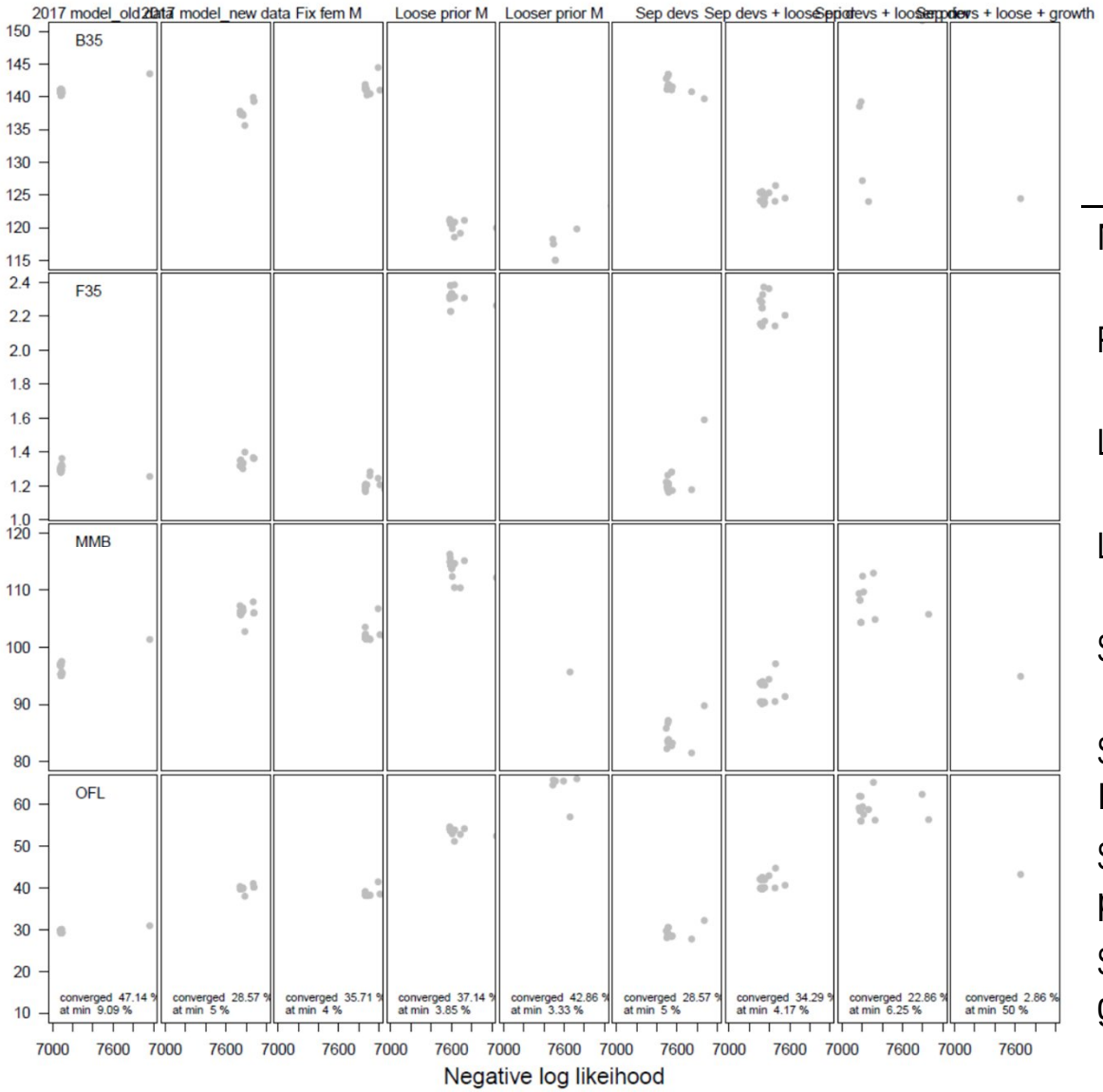
- Bimodality
- Estimating mature female M ‘fixed’ the problem



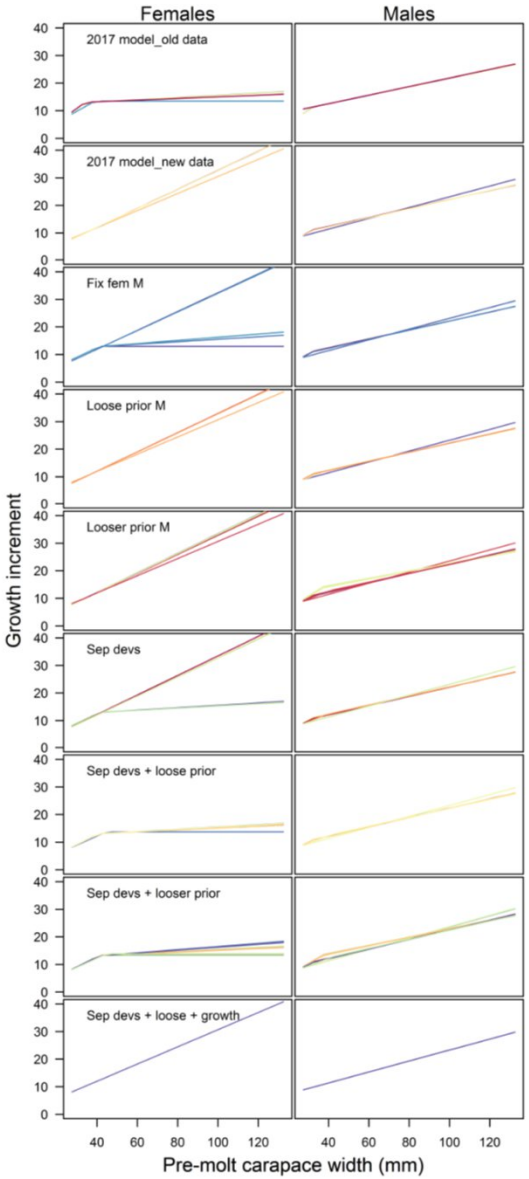
This year

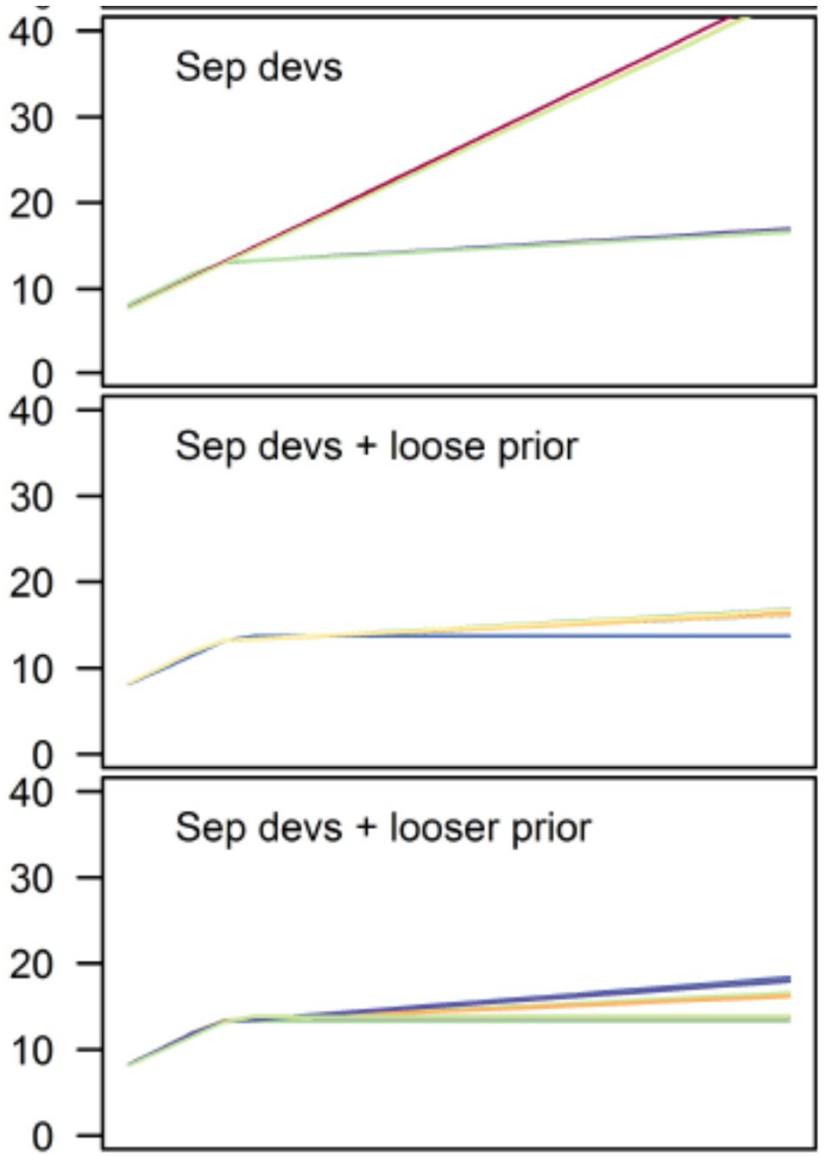
- Step-wise addition of data
- New survey data introduces more instability than new growth data
- Not as serious of bimodality with last year's model, but less stable estimates





Model	% converge	% at minium
New Data	27	5
Fix fem M	36	4
Loose prior M	37	4
Looser prior M	43	3
Sep devs	27	5
Sep devs + loose prior M	34	4
Sep devs + looser prior M	23	6
Sep devs + loose + growth	3	50


Females
Males
2017 model_old data
2017 model_new data
Fix fem M
Loose prior M
Looser prior M
Sep devs
Sep devs + loose prior
Sep devs + looser prior
Sep devs + loose + growth
Growth increment
Pre-molt carapace width (mm)


Sep devs
Sep devs + loose prior
Sep devs + looser prior

Plan of attack

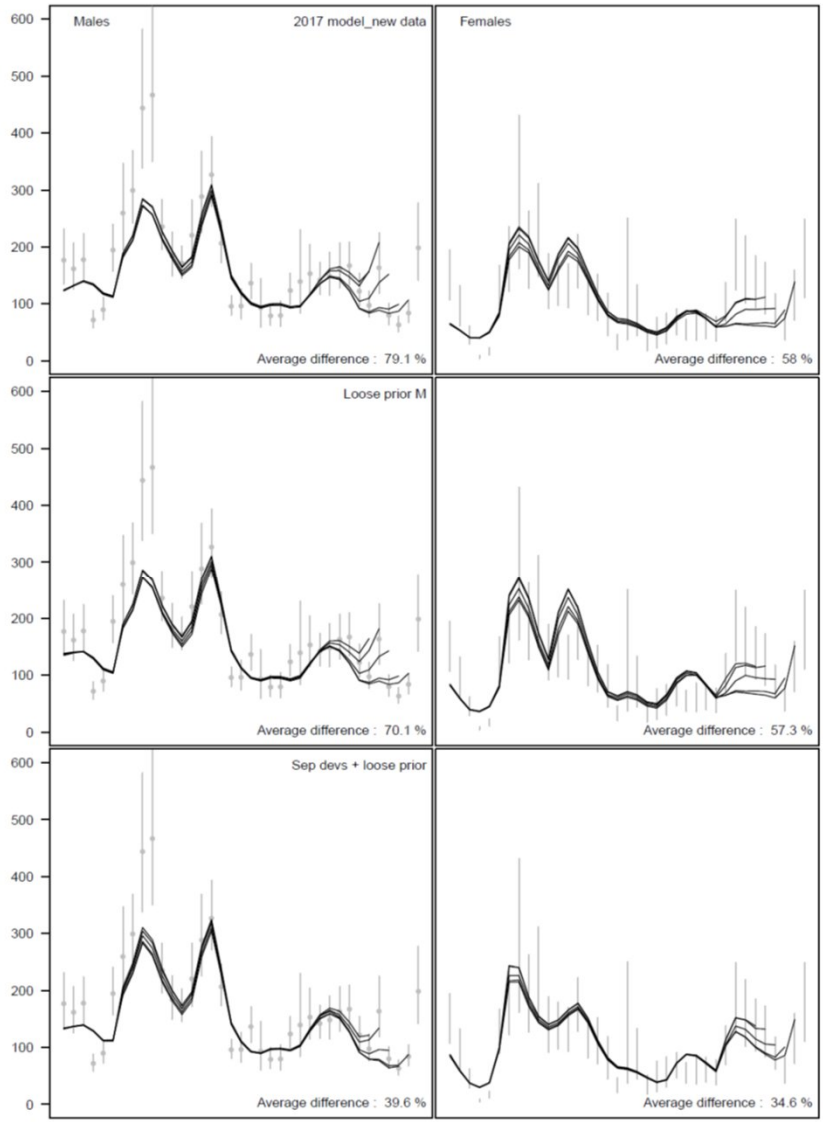
- Jitter and use maximum likelihood estimates
  - All models (except 1) were unstable
- Bayes?
  - Given the observed instability, can MCMC be useful?
  - Two runs, one failed (after ~3 days); the other was for a model that I didn't think was worth exploring

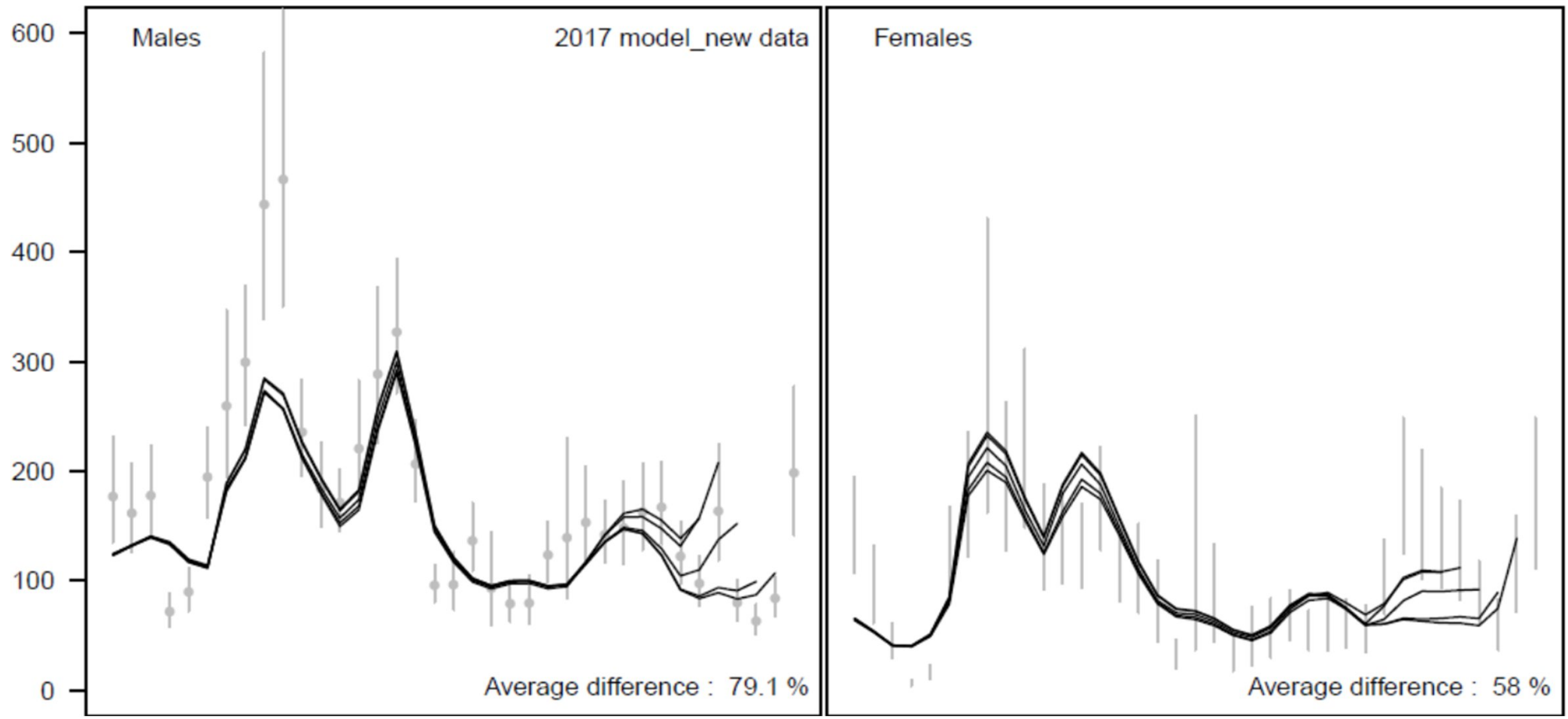
Plan of attack

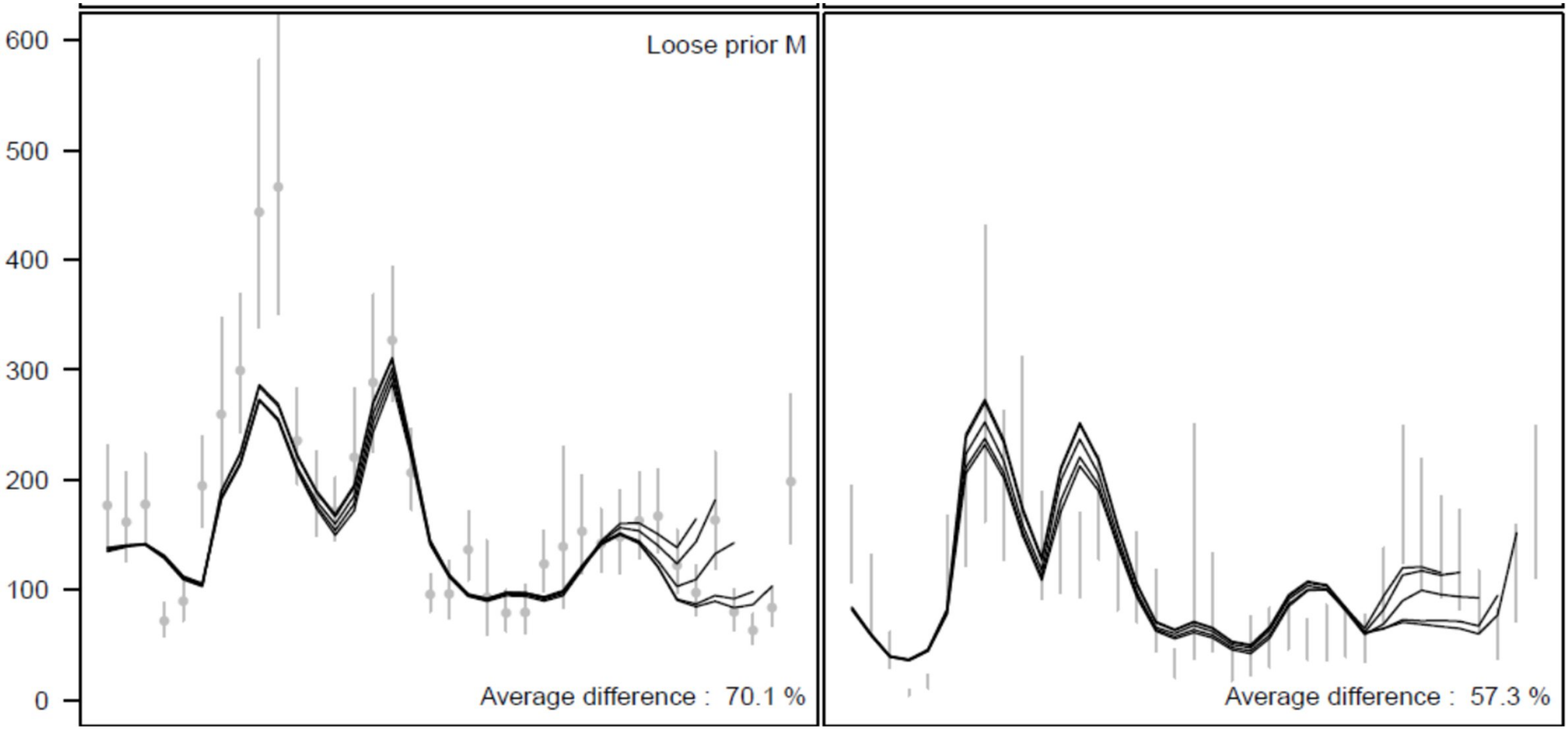
- Jitter and use maximum likelihood estimates
  - All models (except 1) were unstable
- Bayes?
  - Given the observed instability, can MCMC be useful?
  - Two runs, one failed (after ~3 days); the other was for a model that I didn't think was worth exploring
- Retrospective patterns

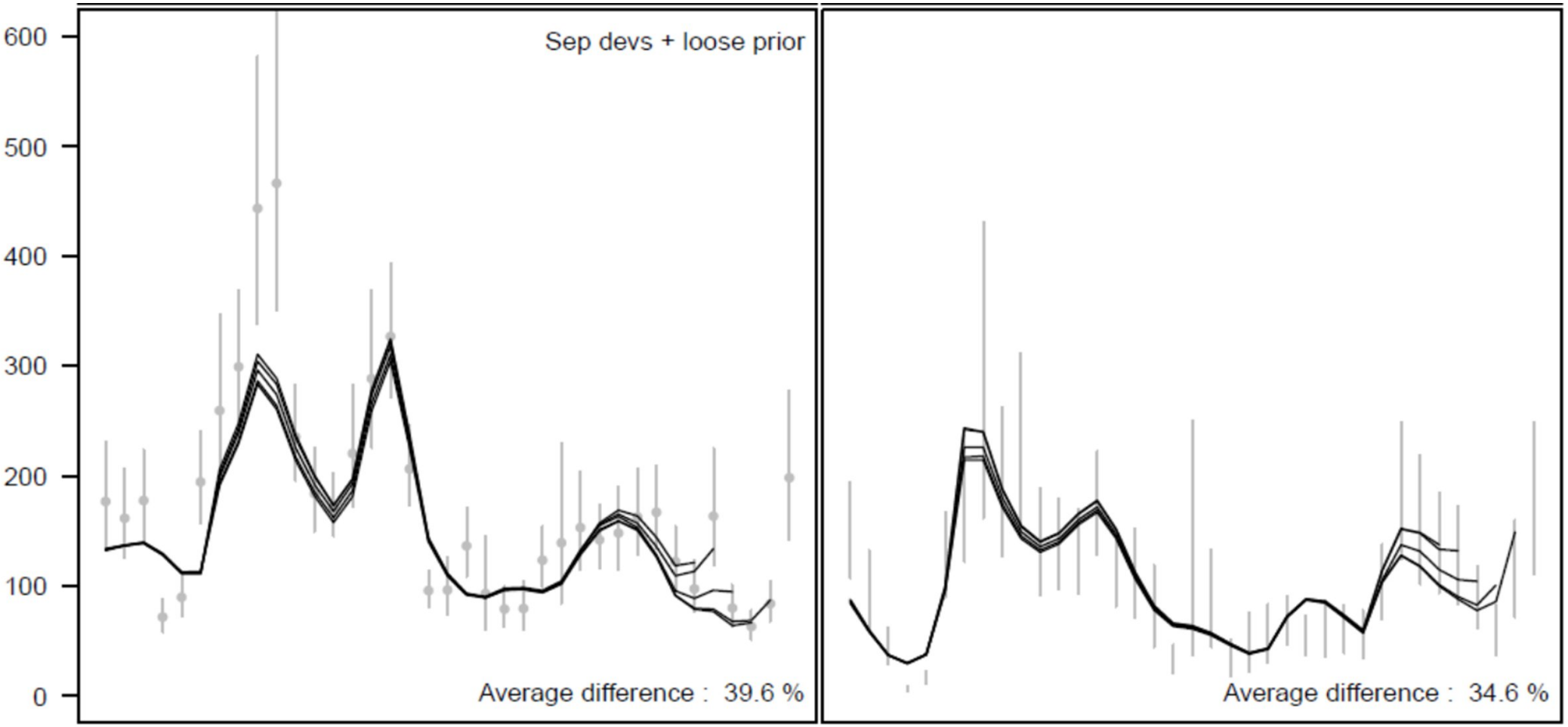
Retrospective patterns

- A retrospective pattern is a consistent directional change in assessment estimates of management quantities (e.g. MMB) in a given year when additional years of data are added to an assessment.




Males
2017 model_new data
Average difference : 79.1 %
Females
Average difference : 58 %
600
500
400
300
200
100
0


Loose prior M
600
500
400
300
200
100
0
Average difference : 70.1 %
Average difference : 57.3 %


Sep devs + loose prior
Average difference : 39.6 %
Average difference : 34.6 %
600
500
400
300
200
100
0

Likelihood component	2017 model_old data	2017 model_new data	Fix fem M	Loose prior M	Looser prior M	Sep devs	Sep devs + loose prior	Sep devs + looser prior	Sep devs + loose + growth
Total	7083.27	7740.18	7862.9	7583.52	7480.17	7493.83	7305.5	7169.93	7652.66

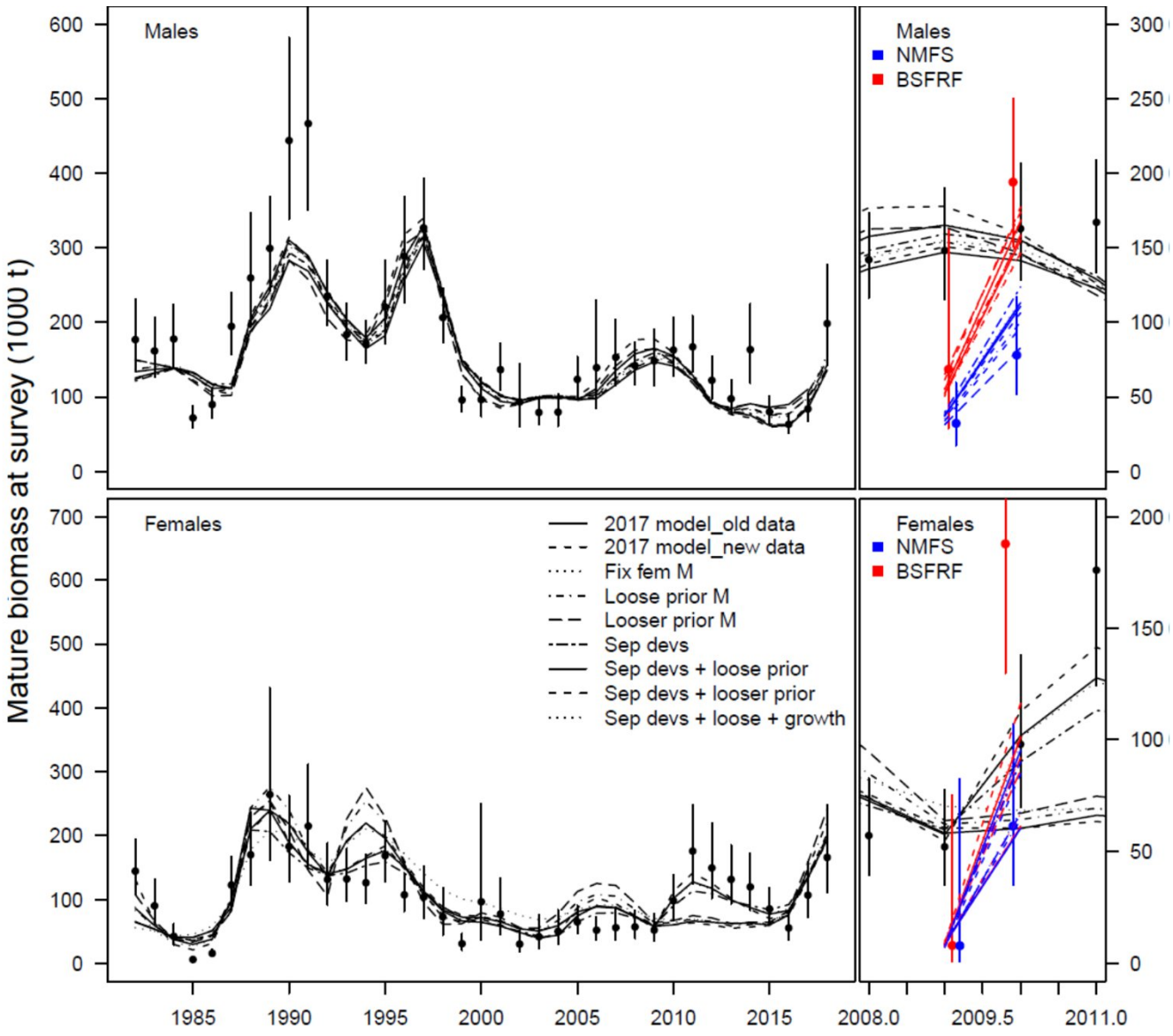
Long story short:

All models were less stable than last year

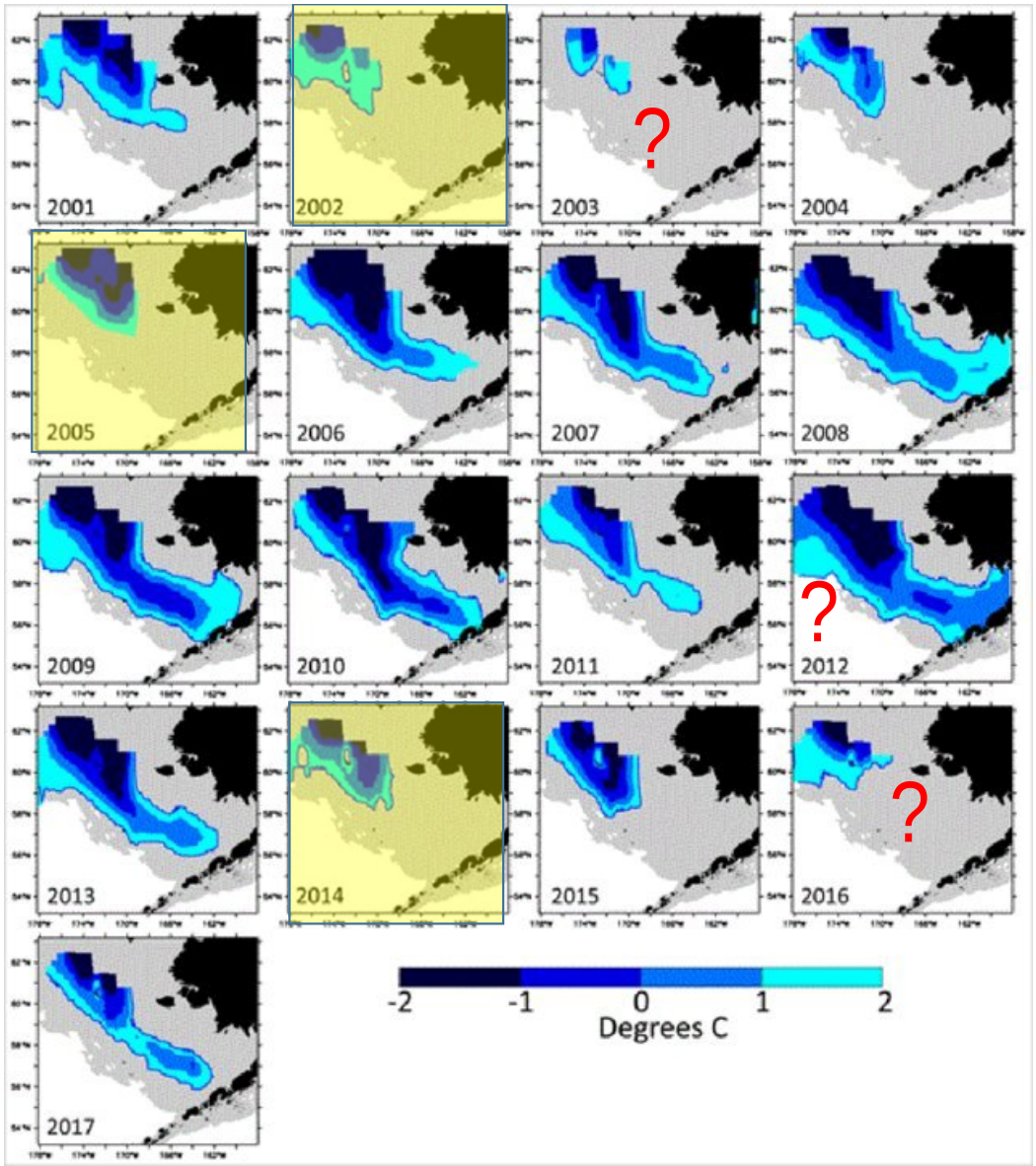
All tested models had retrospective patterns; separate rec devs lessened these patterns

There were still issues with some population processes

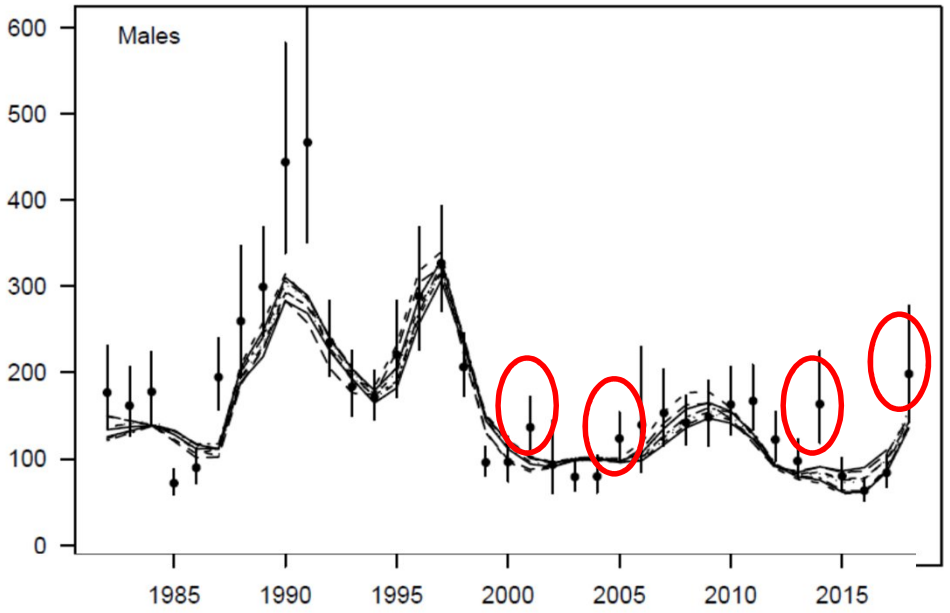
Model fits



Note: NMFS and BSFRF female biomass equal in 2009



Why does the model not match the terminal year survey estimate?



Survey

7.5/12 M

Directed fishery

Non-directed fishery

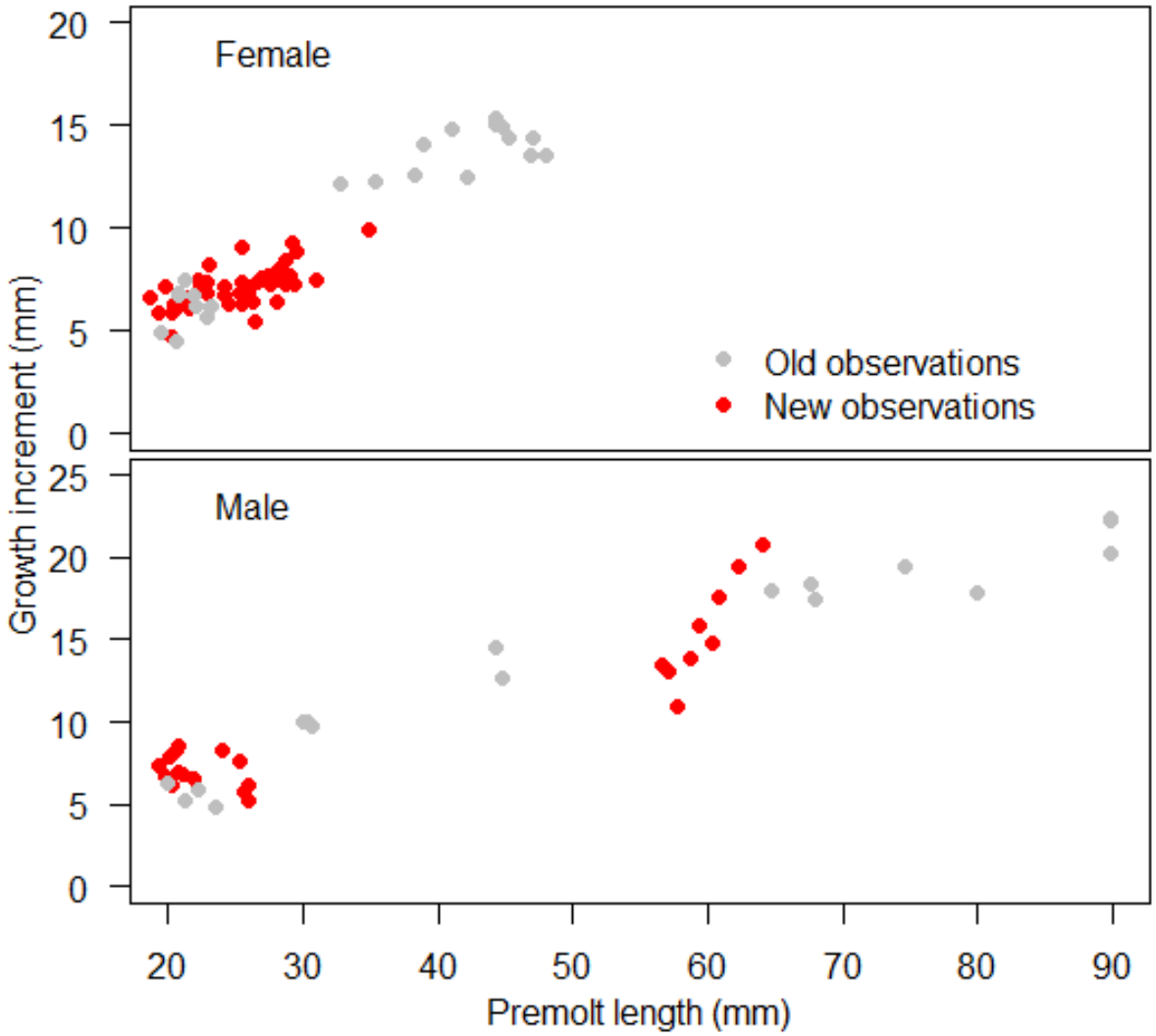
Mating

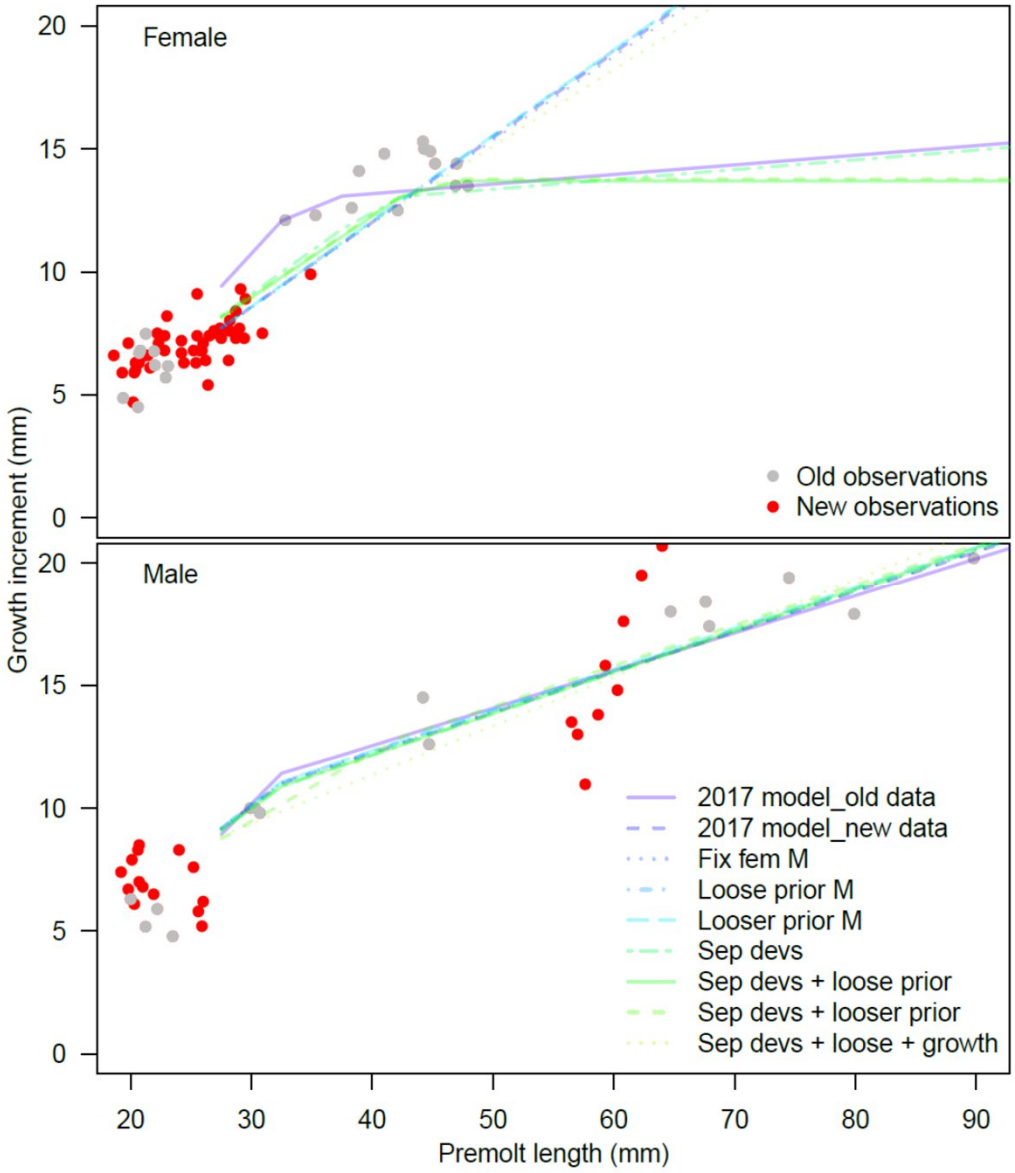
4.5/12 M

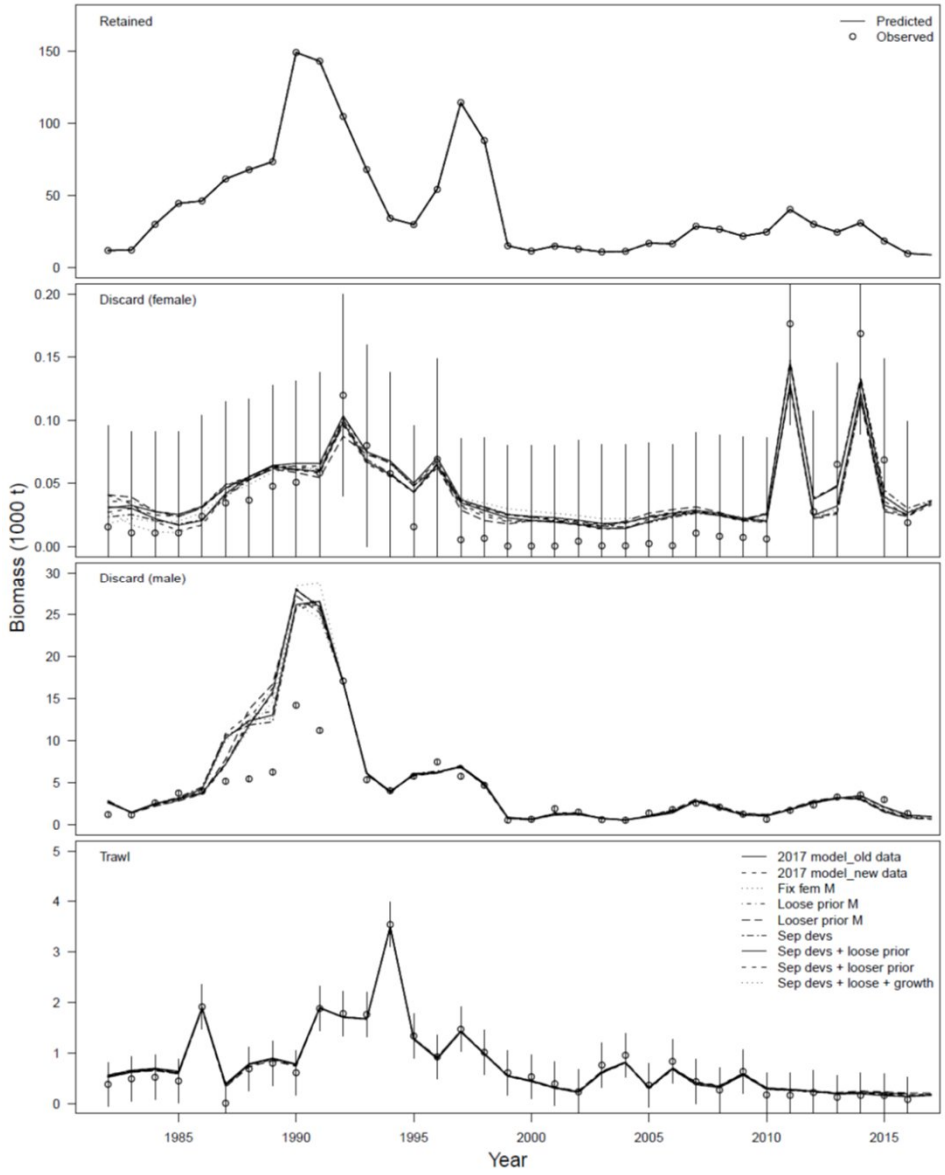
Molting

Growth

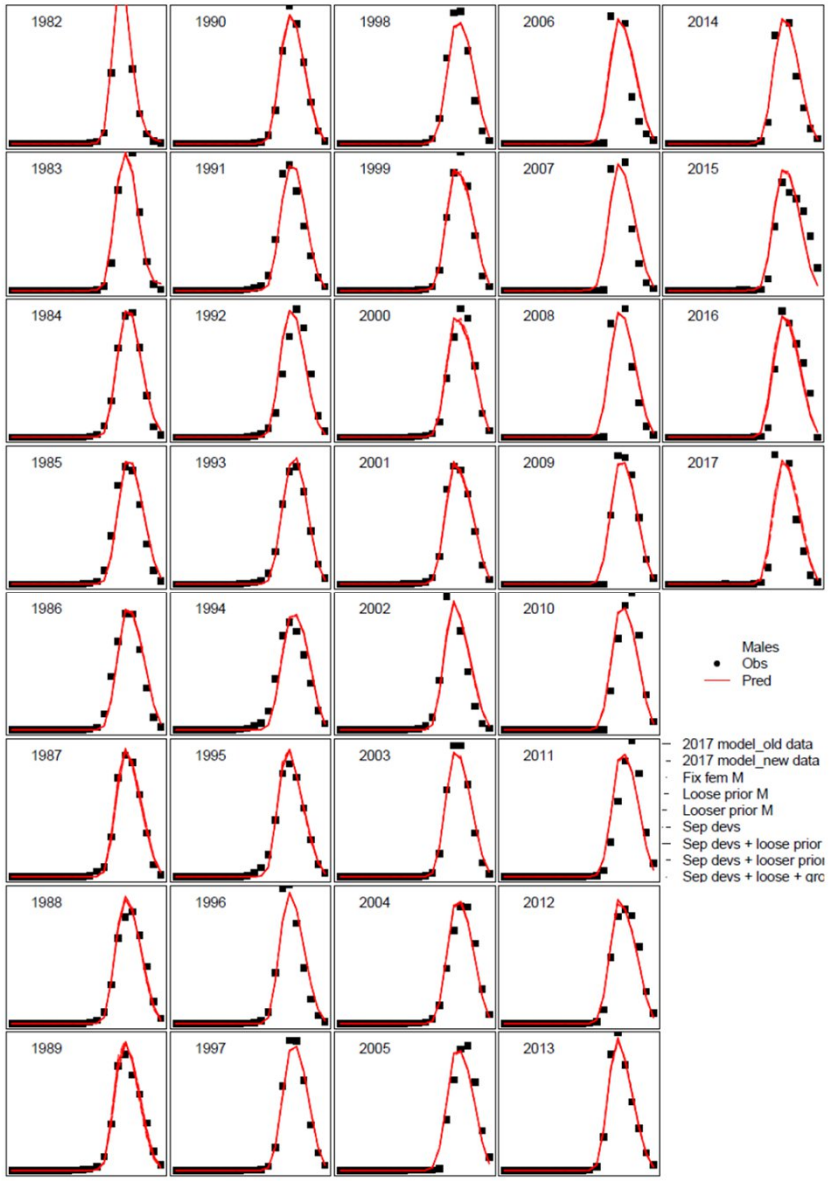
Recruitment



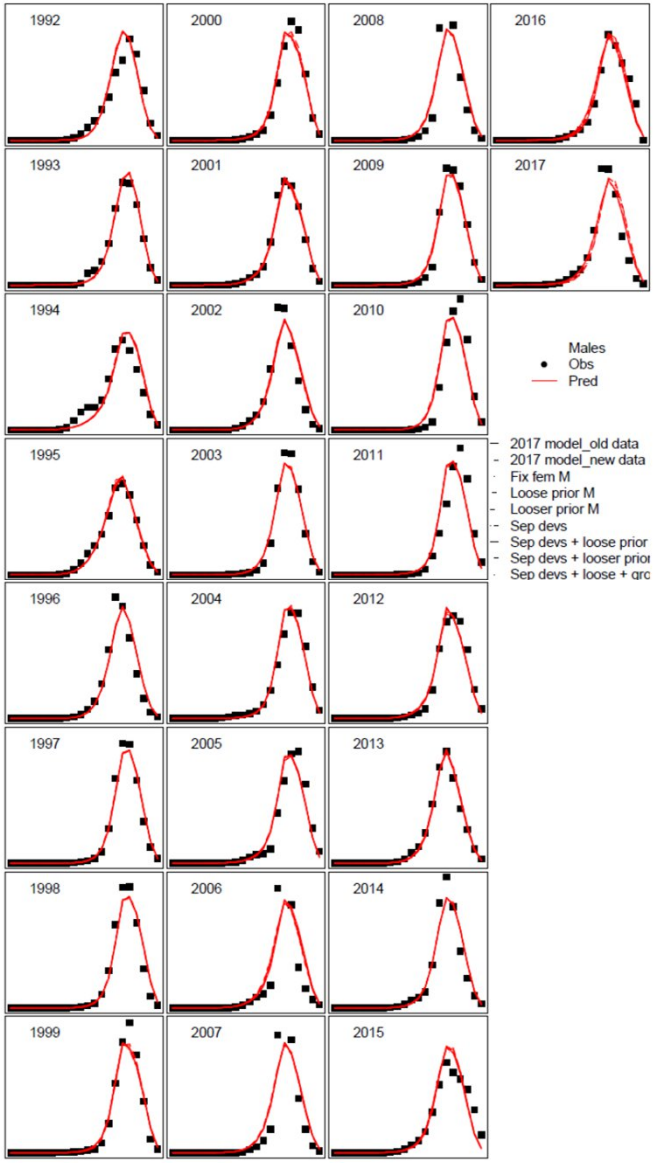

Female
Male
Old observations
New observations
2017 model_old data
2017 model_new data
Fix fem M
Loose prior M
Looser prior M
Sep devs
Sep devs + loose prior
Sep devs + looser prior
Sep devs + loose + growth
Growth increment (mm)
Premolt length (mm)
0
5
10
15
20
20
30
40
50
60
70
80
90

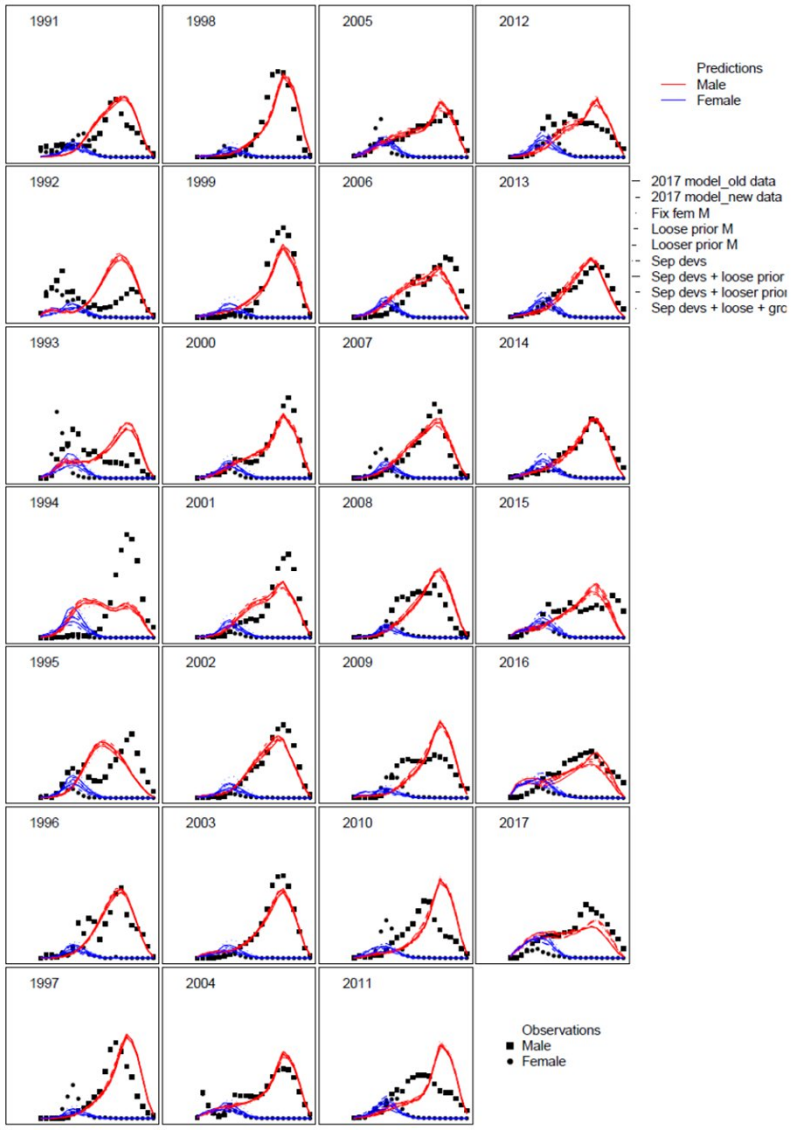

Retained
Predicted
Observed
Discard (female)
Discard (male)
Trawl
2017 model_old data
2017 model_new data
Fix fem M
Loose prior M
Looser prior M
Sep devs
Sep devs + loose prior
Sep devs + looser prior
Sep devs + loose + growth
Biomass (1000 t)
Year

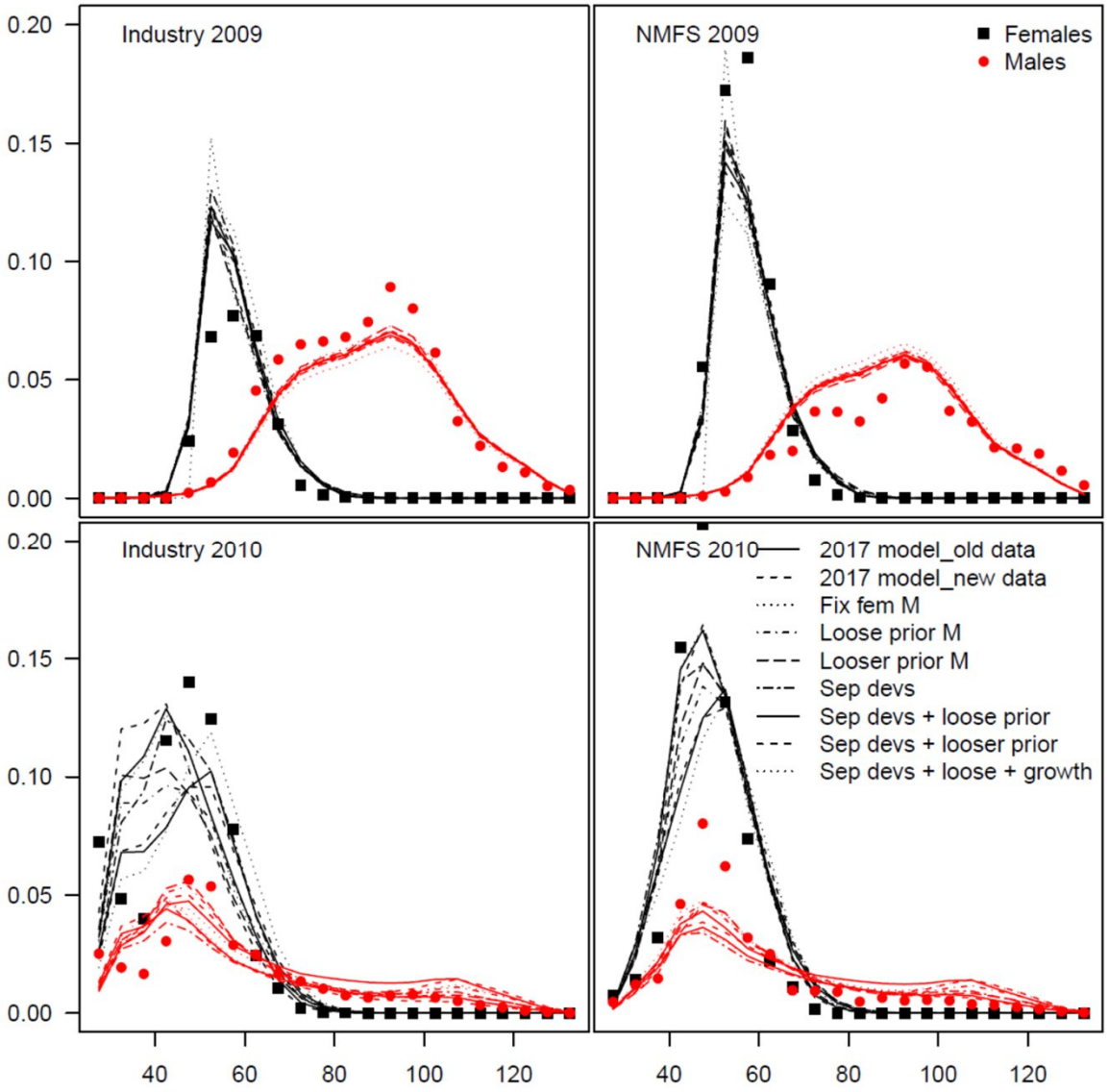
Retained catch



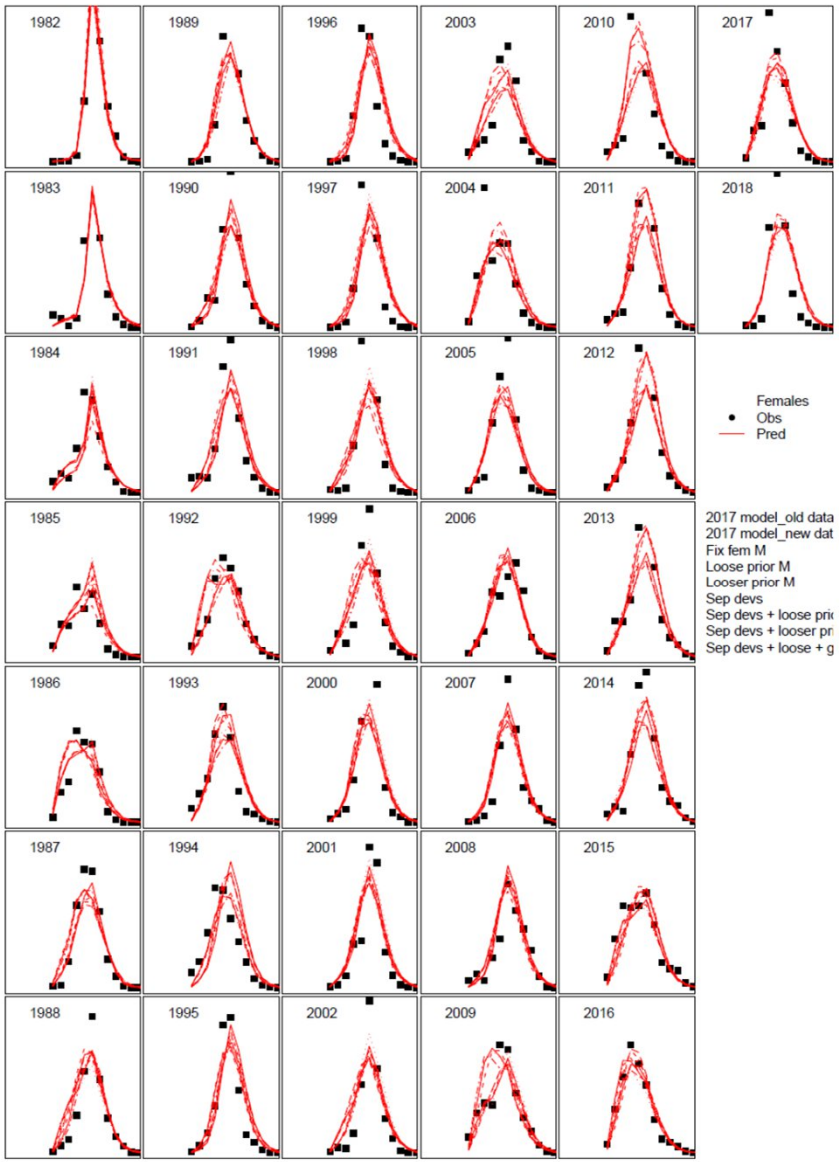
Total catch

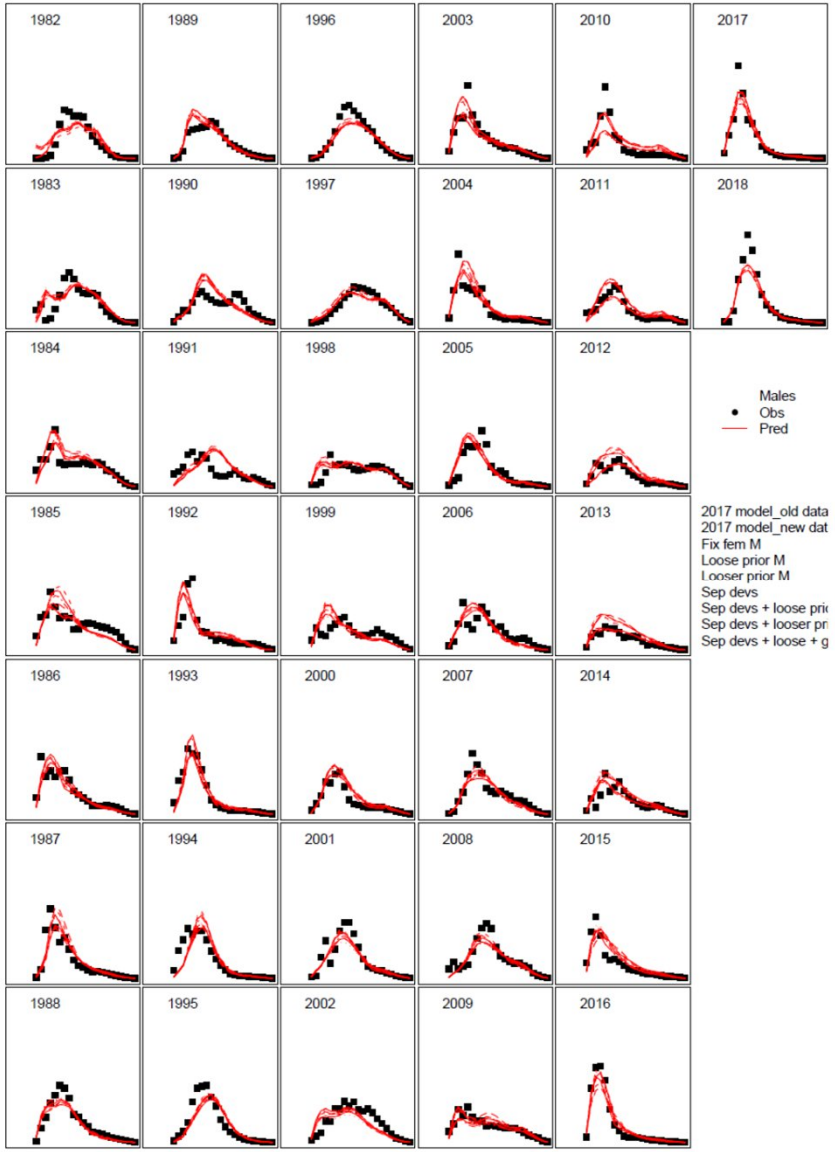

1992
2000
2008
2016
1993
2001
2009
2017
1994
2002
2010
1995
2003
2011
1996
2004
2012
1997
2005
2013
1998
2006
2014
1999
2007
2015
Males
Obs
Pred
2017 model_old data
2017 model_new data
Fix fem M
Loose prior M
Looser prior M
Sep devs
Sep devs + loose prior
Sep devs + looser prior
Sep devs + loose + qrc


1991
1998
2005
2012
1992
1999
2006
2013
1993
2000
2007
2014
1994
2001
2008
2015
1995
2002
2009
2016
1996
2003
2010
2017
1997
2004
2011
Predictions
Male
Female
2017 model_old data
2017 model_new data
Fix fem M
Loose prior M
Looser prior M
Sep devs
Sep devs + loose prior
Sep devs + looser prior
Sep devs + loose + grc
Observations
Male
Female


Industry 2009
NMFS 2009
Females
Males
Industry 2010
NMFS 2010
2017 model_old data
2017 model_new data
Fix fem M
Loose prior M
Looser prior M
Sep devs
Sep devs + loose prior
Sep devs + looser prior
Sep devs + loose + growth
0.20
0.15
0.10
0.05
0.00
40
60
80
100
120

SURVEY


1982
1989
1996
2003
2010
2017
1983
1990
1997
2004
2011
2018
1984
1991
1998
2005
2012
1985
1992
1999
2006
2013
1986
1993
2000
2007
2014
1987
1994
2001
2008
2015
1988
1995
2002
2009
2016
Females
Obs
Pred
2017 model_old data
2017 model_new dat
Fix fem M
Loose prior M
Looser prior M
Sep devs
Sep devs + loose pri
Sep devs + looser pr
Sep devs + loose + g


1982
1989
1996
2003
2010
2017
1983
1990
1997
2004
2011
2018
1984
1991
1998
2005
2012
1985
1992
1999
2006
2013
1986
1993
2000
2007
2014
1987
1994
2001
2008
2015
1988
1995
2002
2009
2016
Males
Obs
Pred
2017 model_old data
2017 model_new dat
Fix fem M
Loose prior M
Looser prior M
Sep devs
Sep devs + loose pri
Sep devs + looser pr
Sep devs + loose + g

Model	Pro	Con
New data		Retrospective patterns; Growth data fits
Fix fem M		Retrospective patterns (assumed)
Loose prior M		Retrospective patterns
Looser prior M		Retrospective patterns (assumed)
Sep devs	Survey data fits	Growth data fits
Sep devs + loose prior M	Survey data fits	Growth data fits
Sep devs + looser prior M	Survey data fits	Growth data fits
Sep devs + loose + growth	Survey data fits; growth data fits	

Estimated population processes

Survey

7.5/12 M

Directed fishery

Non-directed fishery

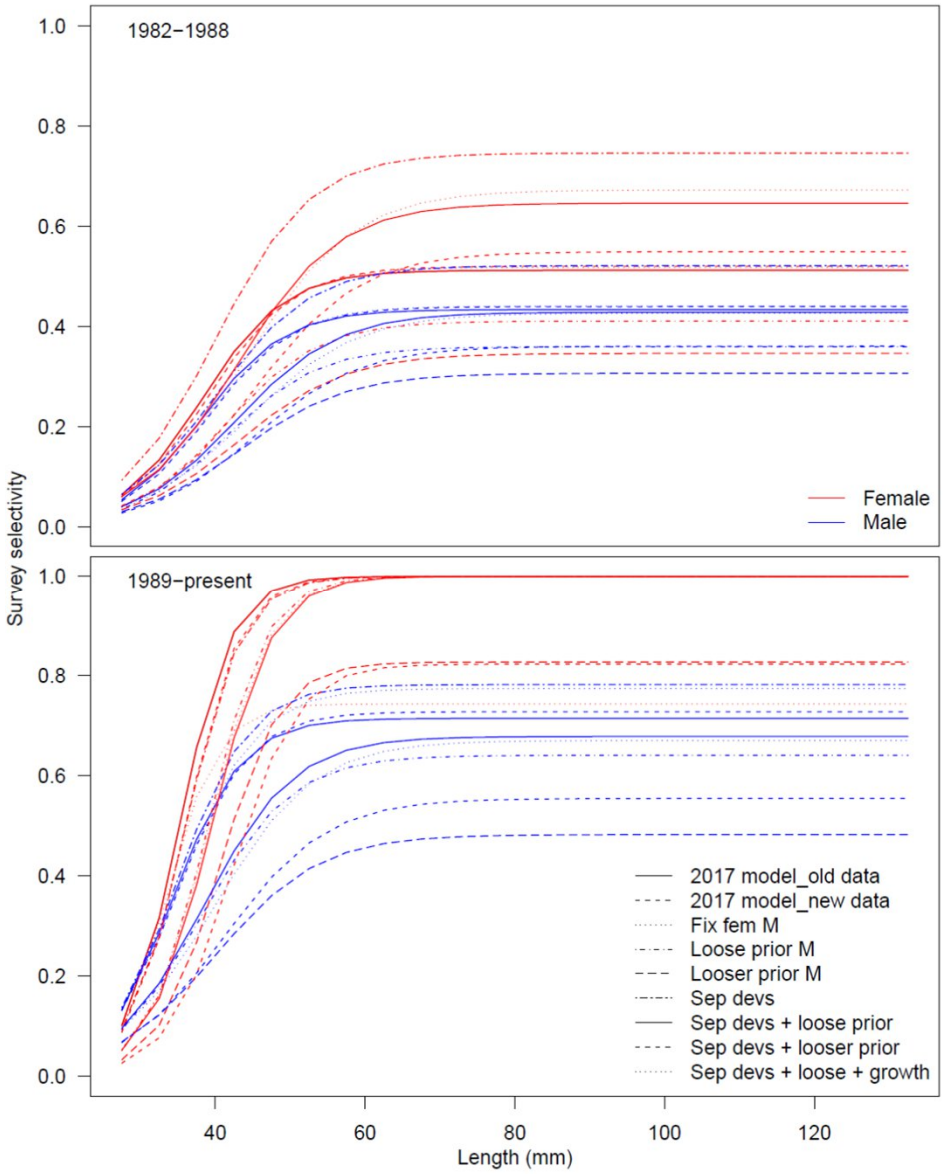
Mating

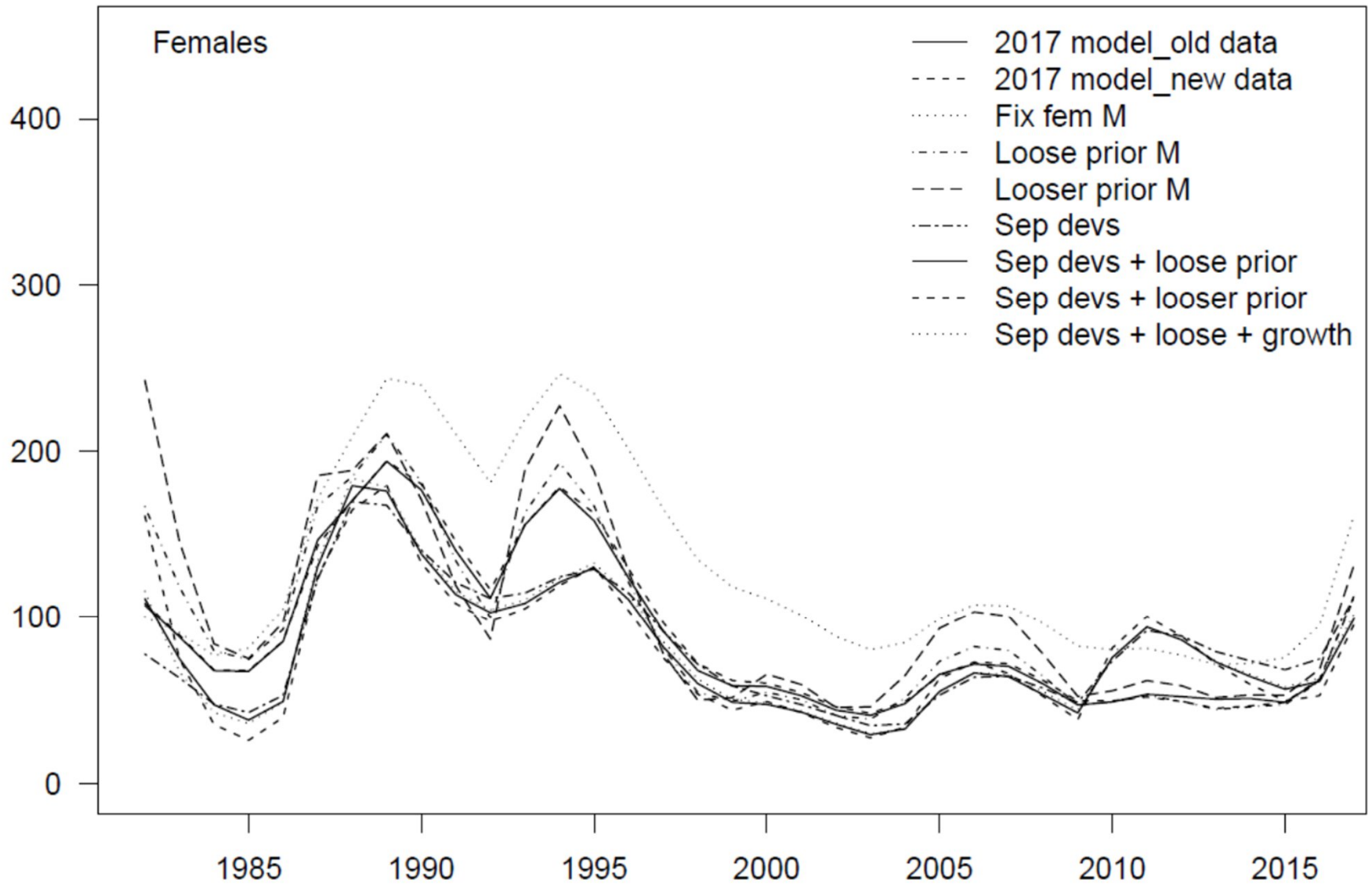
4.5/12 M

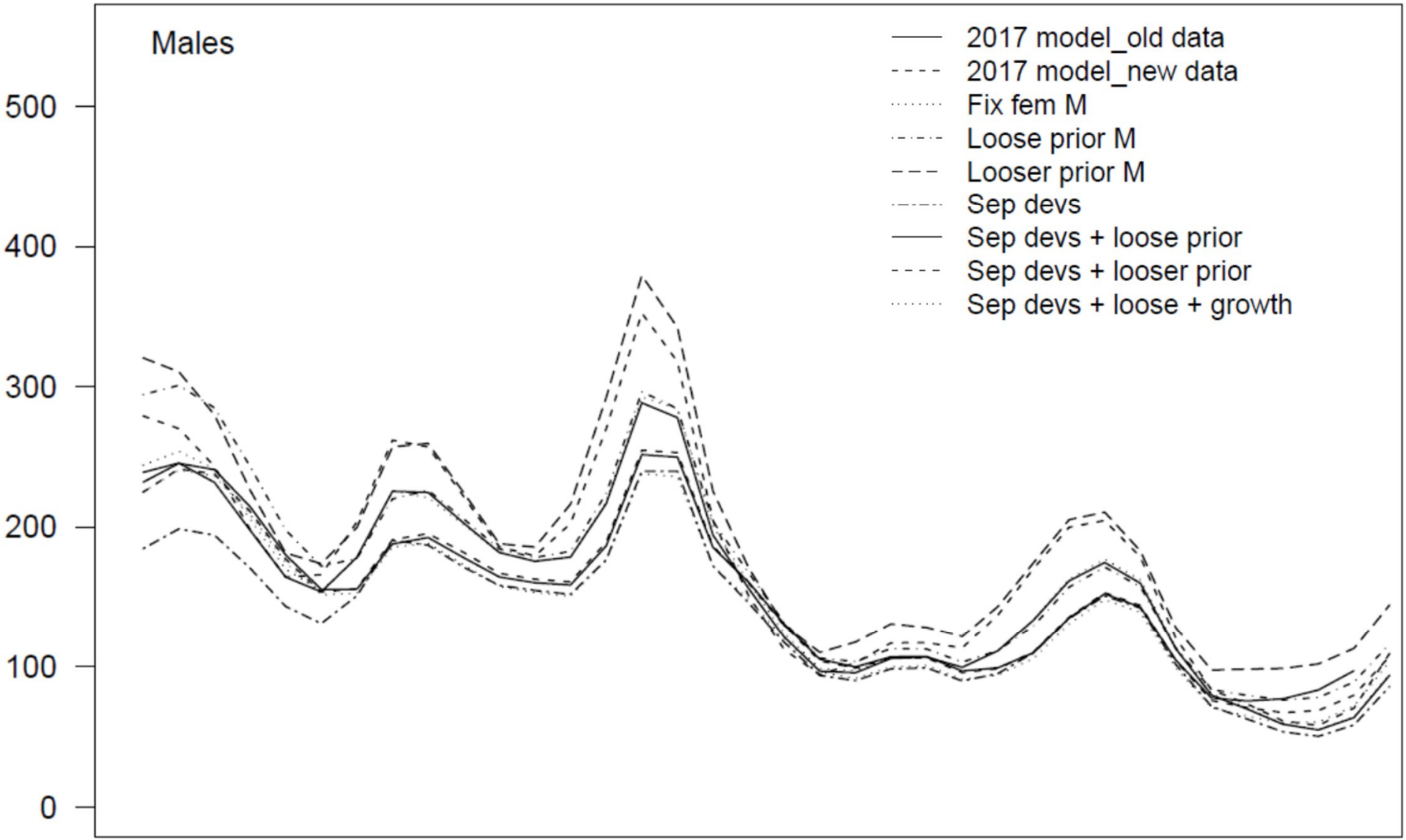
Molting

Growth

Recruitment




Females
2017 model_old data
2017 model_new data
Fix fem M
Loose prior M
Looser prior M
Sep devs
Sep devs + loose prior
Sep devs + looser prior
Sep devs + loose + growth
400
300
200
100
0
1985
1990
1995
2000
2005
2010
2015


Males
2017 model_old data
2017 model_new data
Fix fem M
Loose prior M
Looser prior M
Sep devs
Sep devs + loose prior
Sep devs + looser prior
Sep devs + loose + growth
500
400
300
200
100
0

Model	Pro	Con
New data		Retrospective patterns; Growth data fits
Fix fem M	Fem q != 1	Retrospective patterns
Loose prior M		Retrospective patterns
Looser prior M	Fem q != 1	Retrospective patterns
Sep devs	Survey data fits	Growth data fits
Sep devs + loose prior M	Survey data fits	Growth data fits
Sep devs + looser prior M	Survey data fits; Fem q != 1	Growth data fits
Sep devs + loose + growth	Survey data fits; growth data fits	

Survey

7.5/12 M

Directed fishery

Non-directed fishery

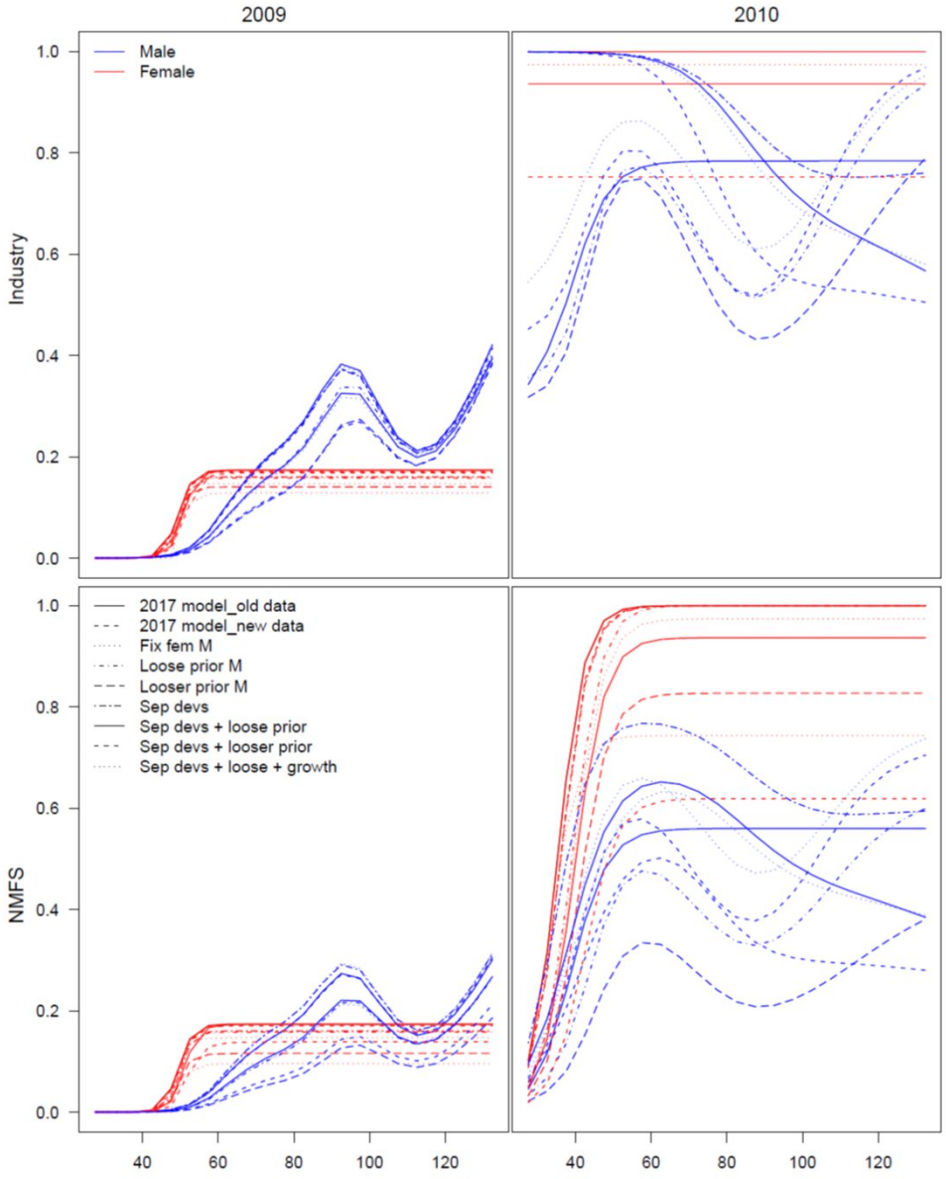
Mating

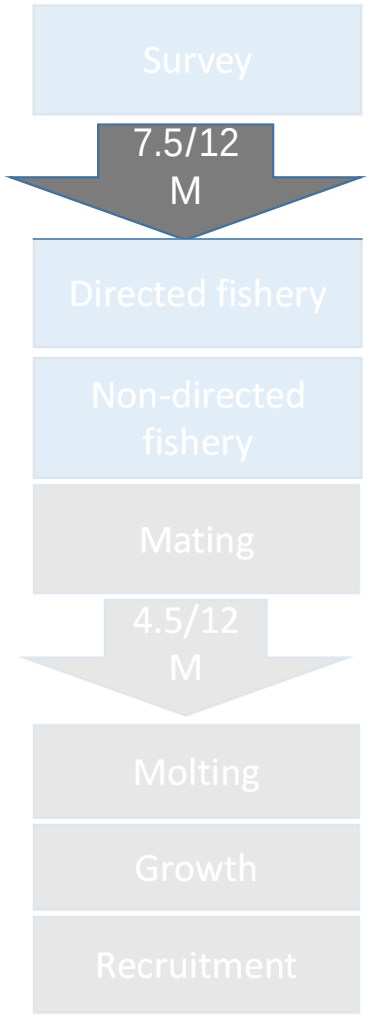
4.5/12 M

Molting

Growth

Recruitment




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

Parameter	2017 model_old data	2017 model_new data	Fix fem M	Loose prior M	Looser prior M	Sep devs	Sep devs + loose prior	Sep devs + looser prior	Sep devs + loose + growth
Mmult_imat	1.22	1.21	1.28	1.56	1.33	1.18	1.49	1.38	1.48
Mmult	1.16	1.17	1.14	1.54	2.7	1.14	1.51	2.48	1.55
Mmultf	1.55	1.51		2.19	3.08	1.57	2.48	4.48	2.38

M	2017	New data	Fix fem M	Loose prior M	Looser prior M	Sep devs	Sep devs + loose prior	Sep devs + looser prior	Sep devs + loose prior + growth
Immature	0.28	0.28	0.29	0.36	0.31	0.27	0.34	0.32	0.34
Mature males	0.27	0.27	0.26	0.35	0.62	0.26	0.35	0.57	0.36
Mature females	0.36	0.35	0.23	0.50	0.71	0.36	0.57	1.03	0.55

Model	Pro	Con
New data		Retrospective patterns; Growth data fits
Fix fem M	Fem q != 1	Retrospective patterns
Loose prior M		Retrospective patterns; Mature Ms high
Looser prior M	Fem q != 1	Retrospective patterns
Sep devs	Survey data fits	Growth data fits
Sep devs + loose prior M	Survey data fits	Growth data fits
Sep devs + looser prior M	Survey data fits; Fem q != 1	Growth data fits; mature Ms high
Sep devs + loose + growth	Survey data fits; growth data fits	

Survey

7.5/12 M

Directed fishery

Non-directed fishery

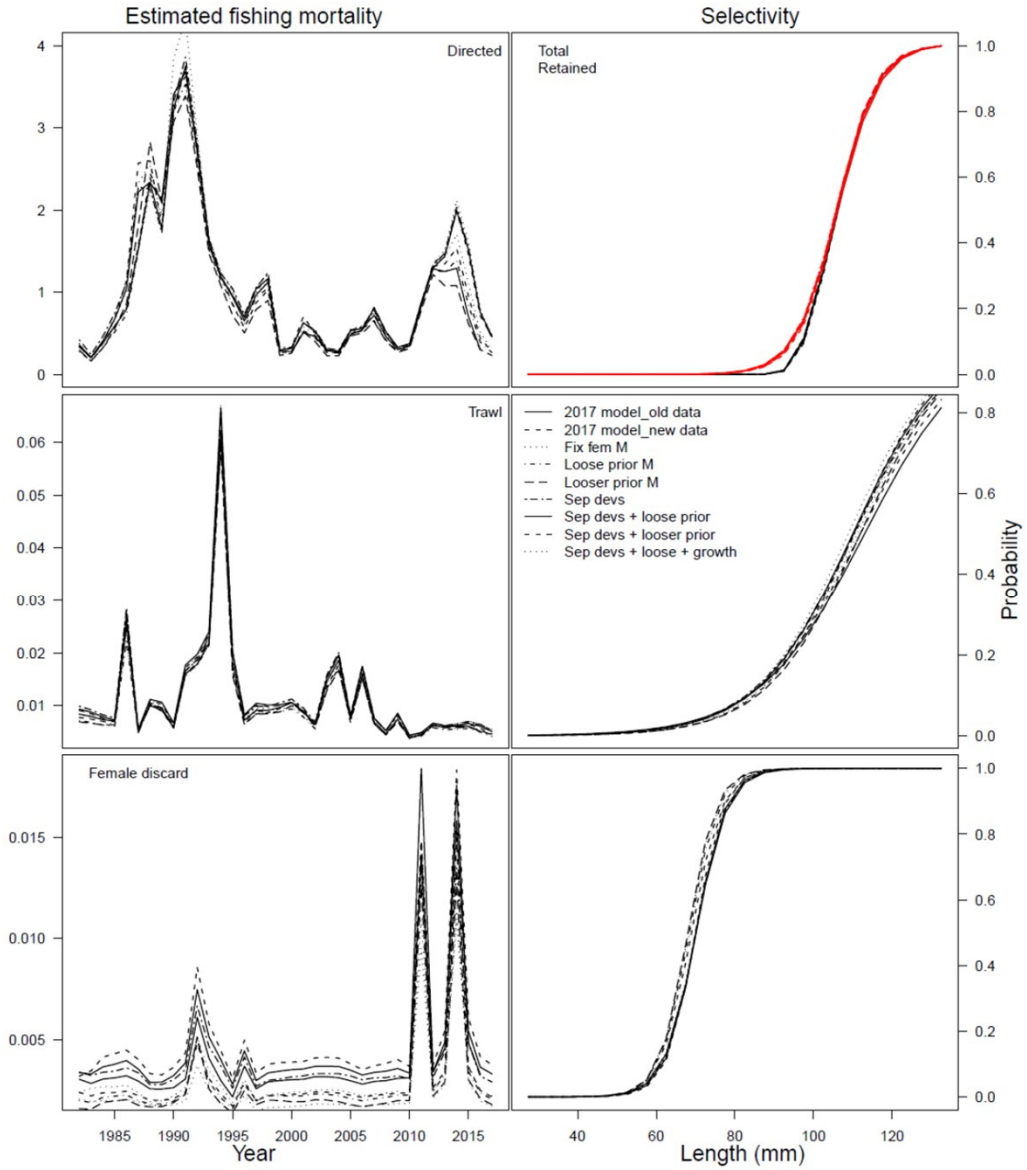
Mating

4.5/12 M

Molting

Growth

Recruitment



Survey

7.5/12 M

Directed fishery

Non-directed fishery

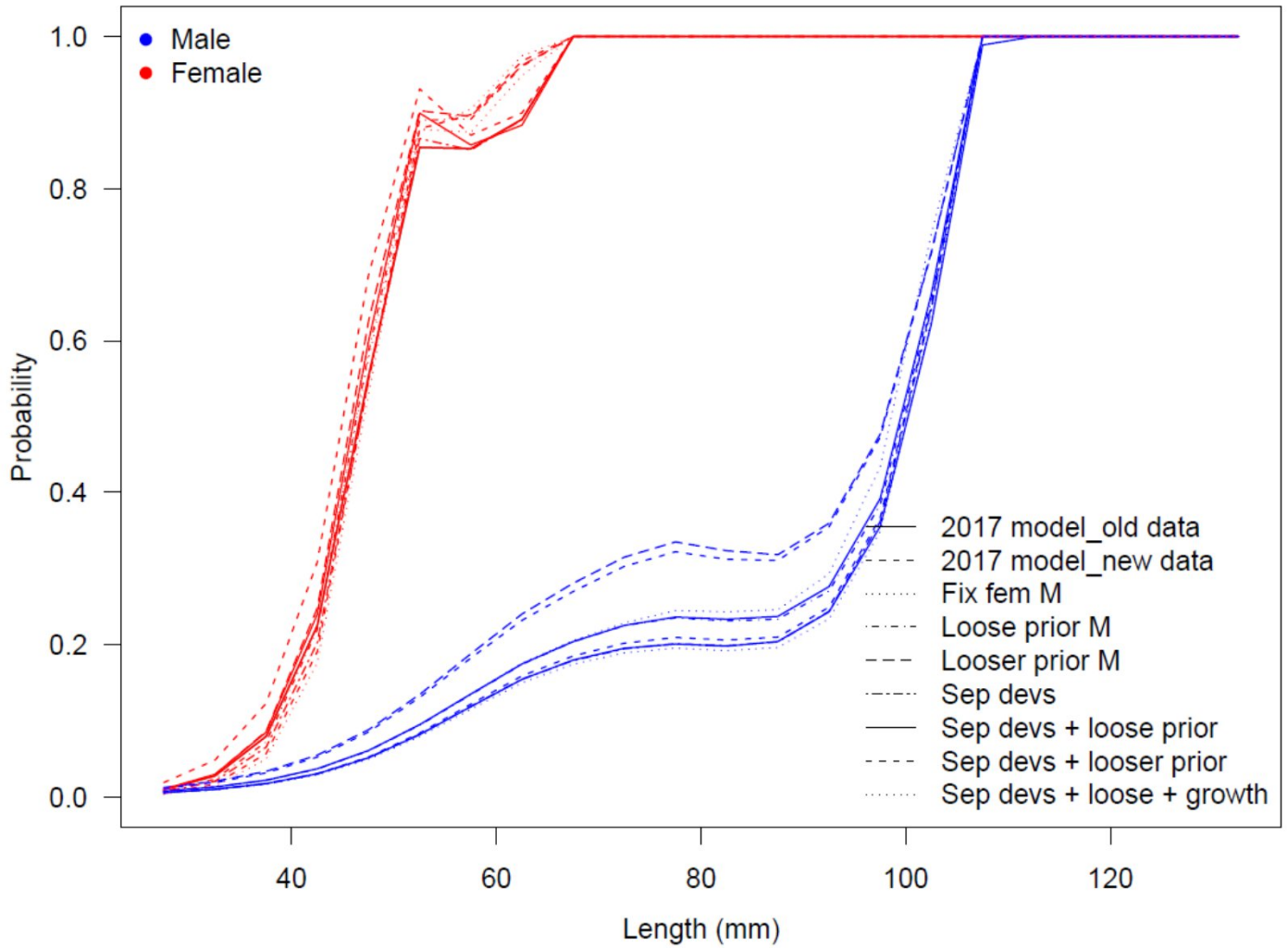
Mating

4.5/12 M

Molting

Growth

Recruitment



Model	Pro	Con
New data		Retrospective patterns; Growth data fits
Fix fem M	Fem q != 1	Retrospective patterns (assumed)
Loose prior M		Retrospective patterns; Mature Ms high
Looser prior M	Fem q != 1	Retrospective patterns (assumed); increased probability of maturing
Sep devs	Survey data fits	Growth data fits
Sep devs + loose prior M	Survey data fits	Growth data fits
Sep devs + looser prior M	Survey data fits; Fem q != 1	Growth data fits; mature Ms high; increased probability of maturing
Sep devs + loose + growth	Survey data fits; growth data fits	

Survey

7.5/12 M

Directed fishery

Non-directed fishery

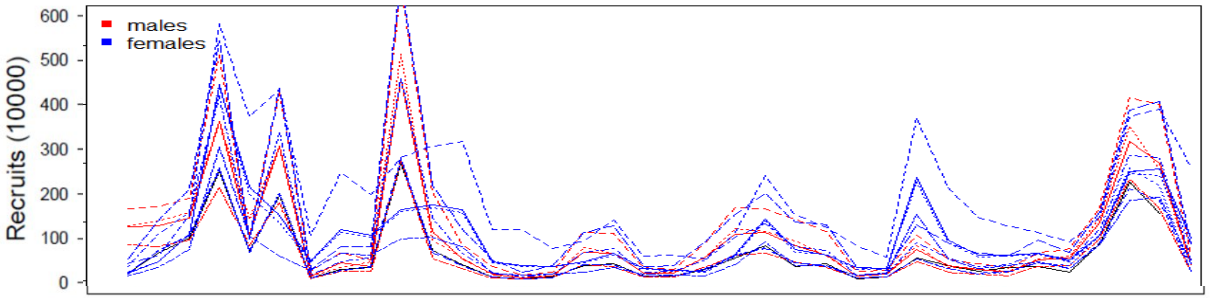
Mating

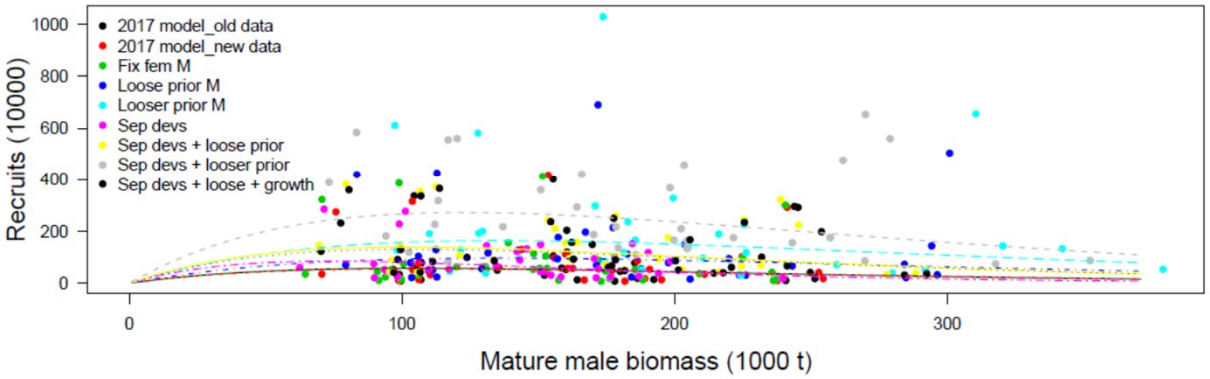
4.5/12 M

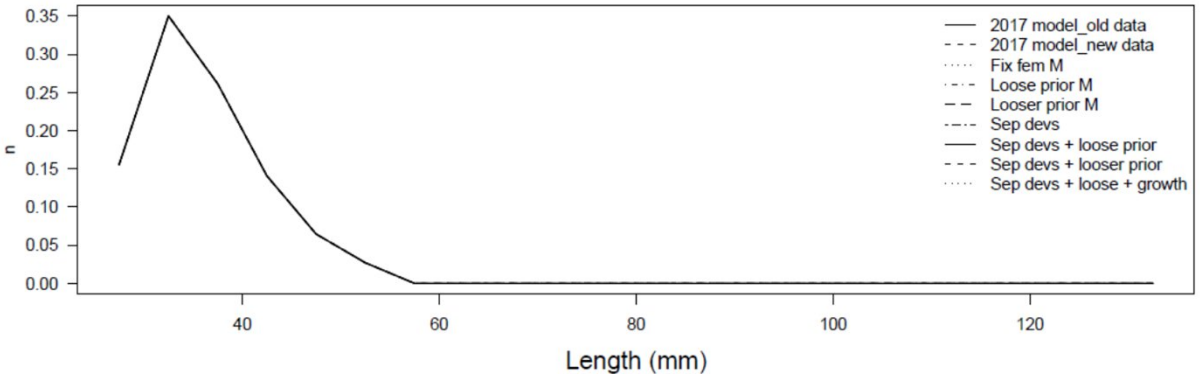
Molting

Growth

Recruitment







Model	Pro	Con
New data		Retrospective patterns; Growth data fits
Fix fem M	Fem q != 1	Retrospective patterns (assumed); Fem M low
Loose prior M		Retrospective patterns
Looser prior M	Fem q != 1	Retrospective patterns (assumed); Increased probability of maturing; Mature Ms high
Sep devs	Survey data fits	Growth data fits; strong M prior
Sep devs + loose prior M	Survey data fits	Growth data fits
Sep devs + looser prior M	Survey data fits; Fem q != 1	Growth data fits; mature Ms high; increased probability of maturing
Sep devs + loose + growth	Survey data fits; simplified growth; growth data fits	Poor convergence ?

The recommended model is 'Sep devs + loose prior'

(though I'd probably prefer 'Sep devs + loose + growth' if there weren't problems with convergence)

Recommended OFL is 42.15 kt

Model	MMB	B35	F35	FOFL	OFL
2017 model_old data	96.97	140.5	1.28	0.88	29.92
2017 model_new data	107.2	137.8	1.32	1.2	40.37
Fix fem M	103.5	141.9	1.19	1.12	39.19
Loose prior M	116.2	121.3	2.3	2.28	54.67
Looser prior M	144.4	108.9	9.42	9.42	79.54
Sep devs	85.84	142.8	1.22	1.04	29.74
Sep devs + loose prior	93.74	125.4	2.29	2.24	42.15
Sep devs + looser prior	109.3	109.5	8.13	8.13	59.21
Sep devs + loose + growth	94.89	124.4	2.57	2.52	43.28