Estimation of selectivity, growth, and natural mortality in the assessment for EBS snow crab

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CPT and SSC comments

The CPT had several comments and questions related to formatting and presentation from the September 2016 meeting:

- Review SAFE guidelines to make sure required tables and figures are present
- Plot the relative proportion of new to old shell males to see how important the lack of fit to old shell males really is
- Plot Bayesian posterior intervals for growth parameters
- Model 0 has to be last year's accepted model

These issues will be corrected in the SAFE document presented at the September meeting. The CPT also had several suggestions for potential model runs and expanded analyses, including:

- Estimate M for mature females
- Document rationale for prior on M for immature crab
- Try starting the assessment in 1982 to check the behavior of the survey qs when the first survey stanza is excluded
- Apply priors to the survey qs so they are somewhat constrained
- Provide more detailed MCMC chain diagnostics
- Extract bycatch mortality from the Tanner crab directed fisheries that is currently lumped into the groundfish trawl bycatch (in a table in the assessment chapter, not necessarily in the model)

Overview

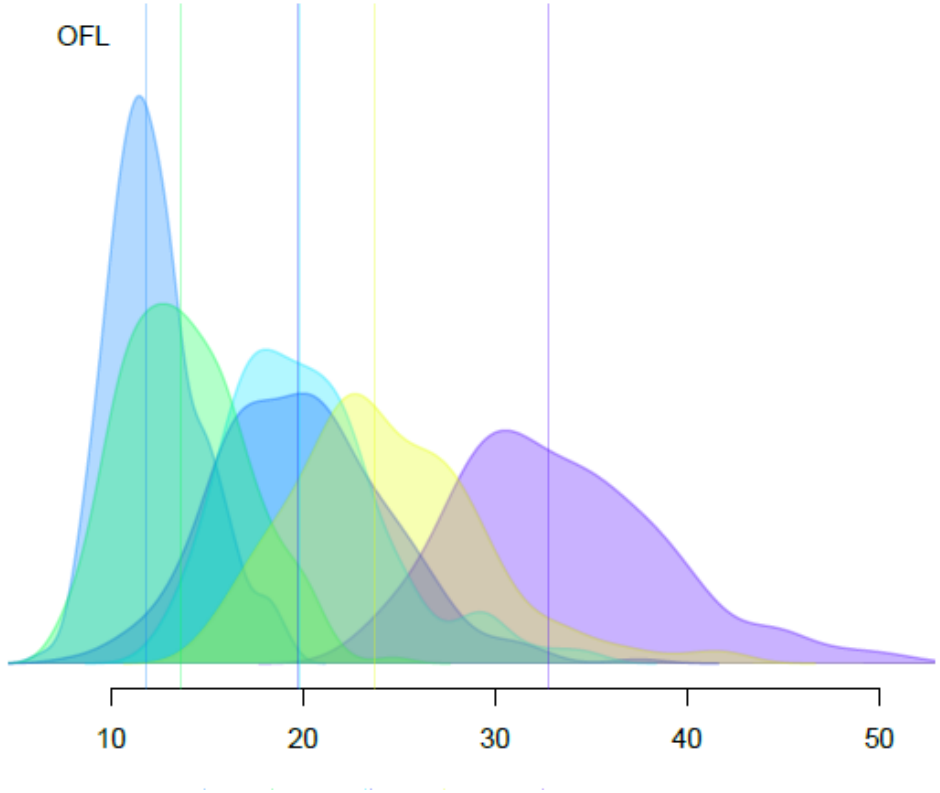
1. MCMC diagnostics and Bayesian vs. maximum likelihood
    1. Bayesian methods designed to produce distributions
    2. Diagnostics suggests some problematic population processes
2. Survey selectivity
    1. Eliminate the first 4 years of data
    2. Think about how to use BSFRF data
3. Growth
    1. Piece-wise models causes problems, but contributes little to the model
    2. Unclear what the best model is
4. Natural mortality
    1. Mature female natural mortality should be estimated
    2. Priors for immature natural mortality should be revisited

Bayesian methods vs. maximum likelihood

Goal: set a TAC that accounts for scientific uncertainty

Historical methods:

- estimate parameters via ML
- input parameters into projection script
- Input numbers at length for the final year in the projection script with error
- Calculate a distribution of the OFL based on the error added to the numbers at length

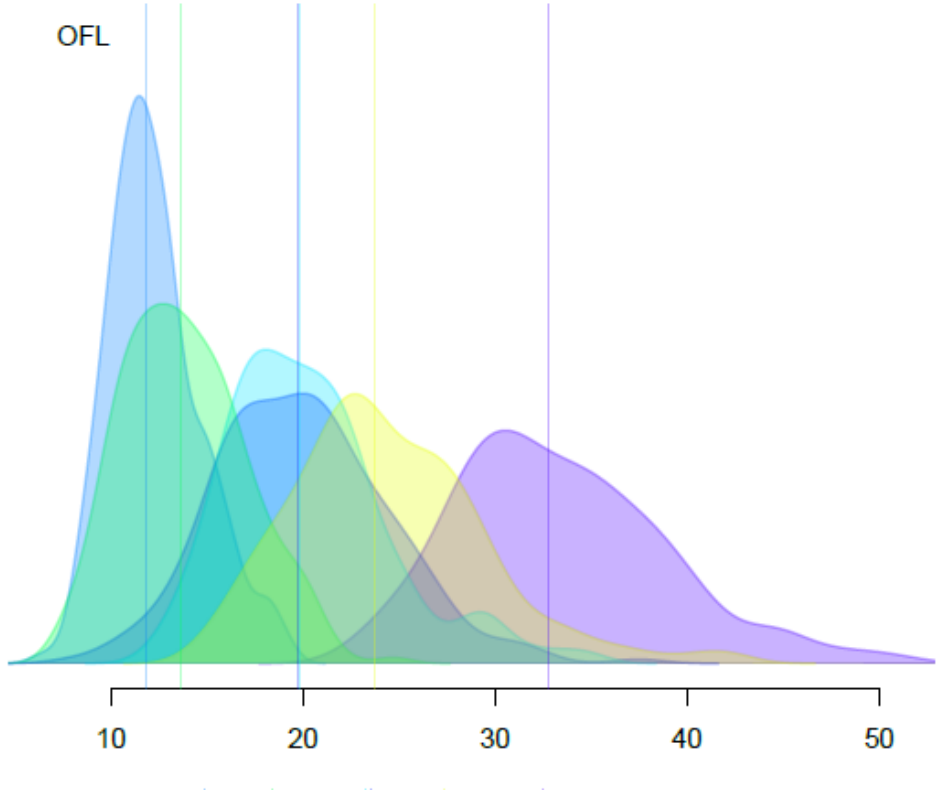


Problems with historical methods:

- Parameter values are not perfectly know, but are assumed so.
- Error added to numbers at length is arbitrary, but determines the distribution of the OFL.
- Jittering was required to ensure MLEs were found

Bayesian methods vs. maximum likelihood

Goal: set a TAC that accounts for scientific uncertainty



Bayesian methods:

- Assume a distribution for each parameter
- Do not require copying and pasting model output
- Posterior distributions of the OFL are a result of the uncertainty in parameter estimates

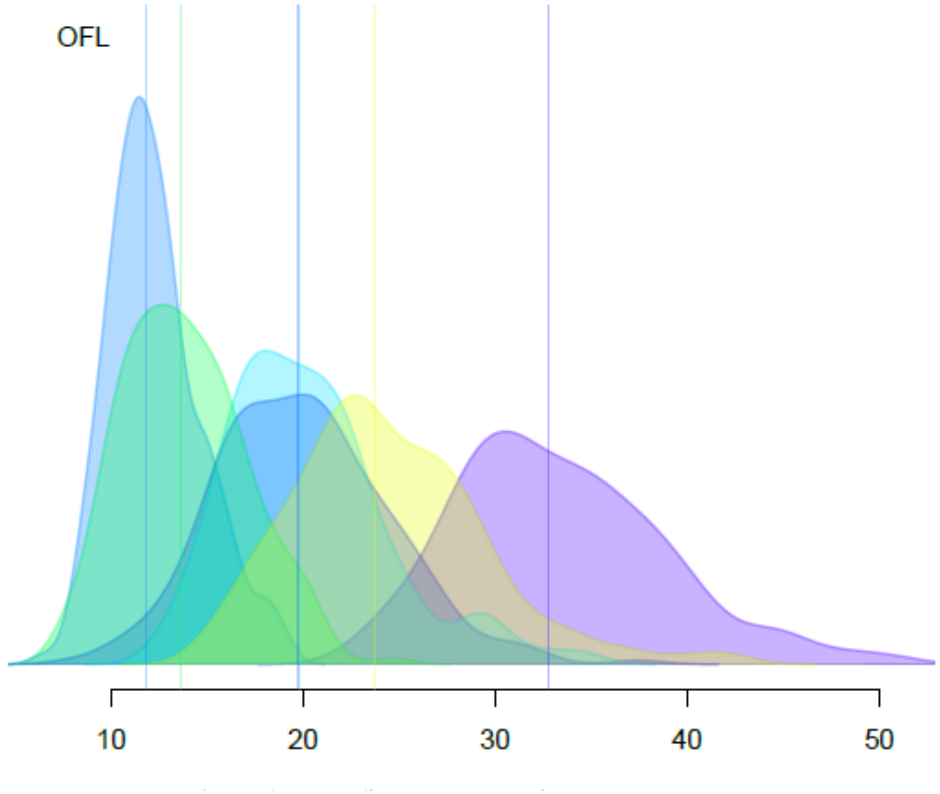
Issues with Bayesian methods:

- Priors must be specified
- Time-consuming
- Knowing the model has converged is difficult (though there are many diagnostics to identify non-convergence)
- Reliant on the var/covar matrix; therefore reliant on an appropriately specified model

Bayesian methods vs. maximum likelihood

A possible modification of historical methods that avoids Bayesian methods:

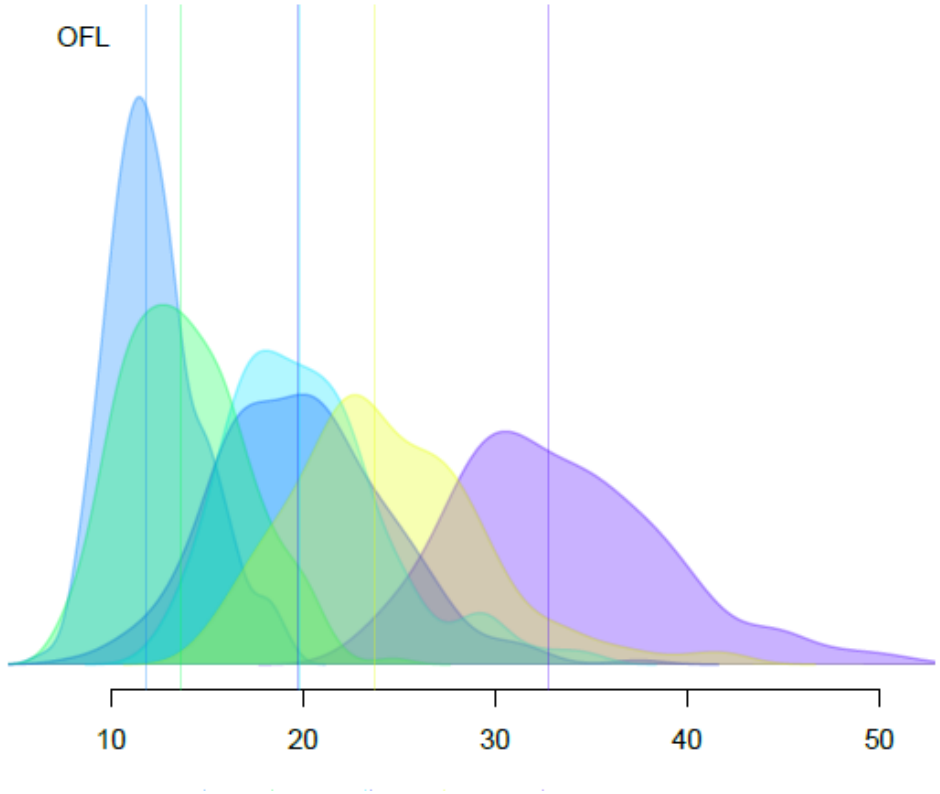
- Calculate the OFL during the fitting of the model instead of in the report section and include the OFL as a sd_report variable
- Then produce a distribution of the OFL with its calculated standard deviation
- I tried this once with the ‘Trim data’ model, but the model blew up.
- It takes forever to fit the model because reference points and the OFL have to be calculated in every step.

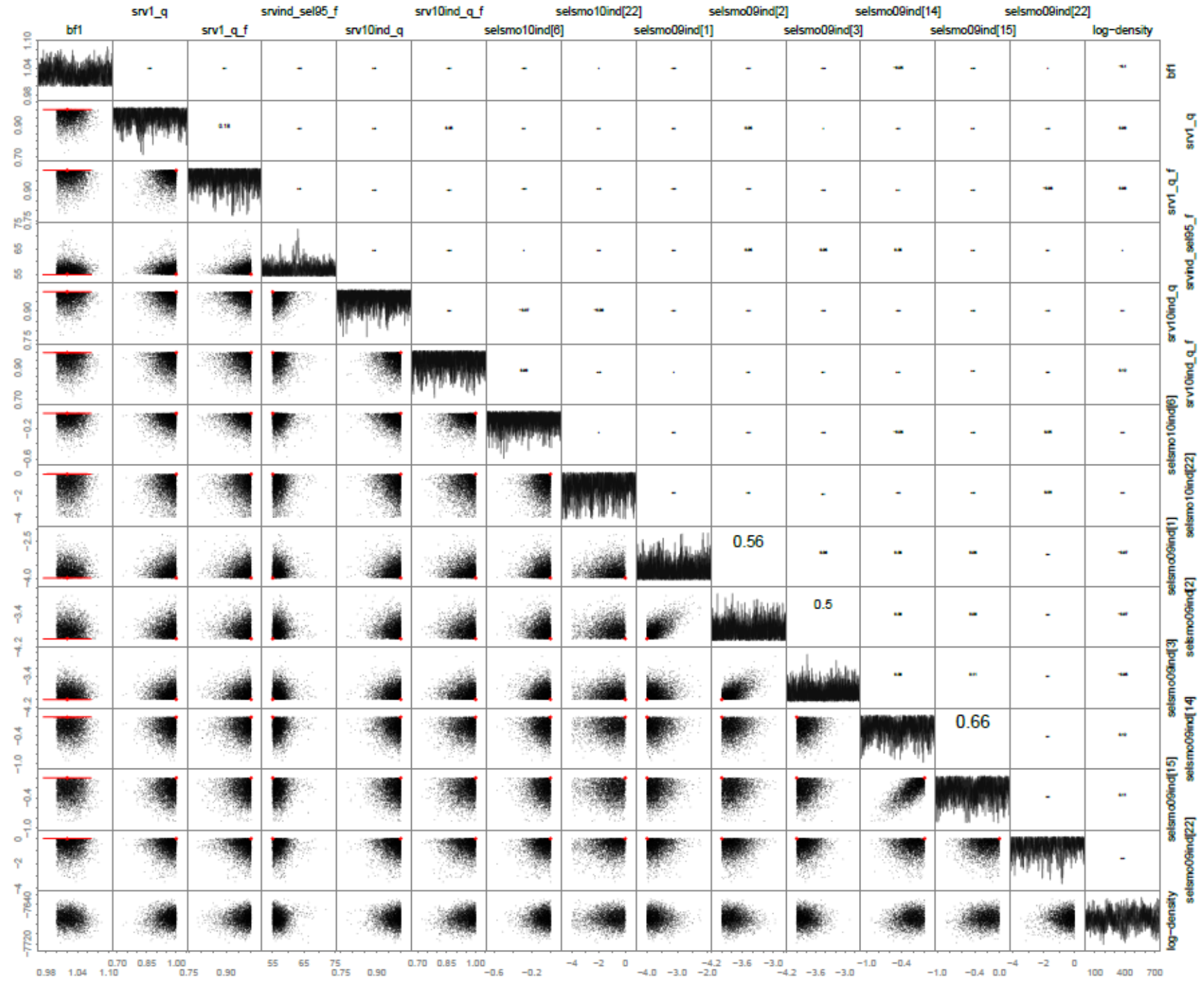


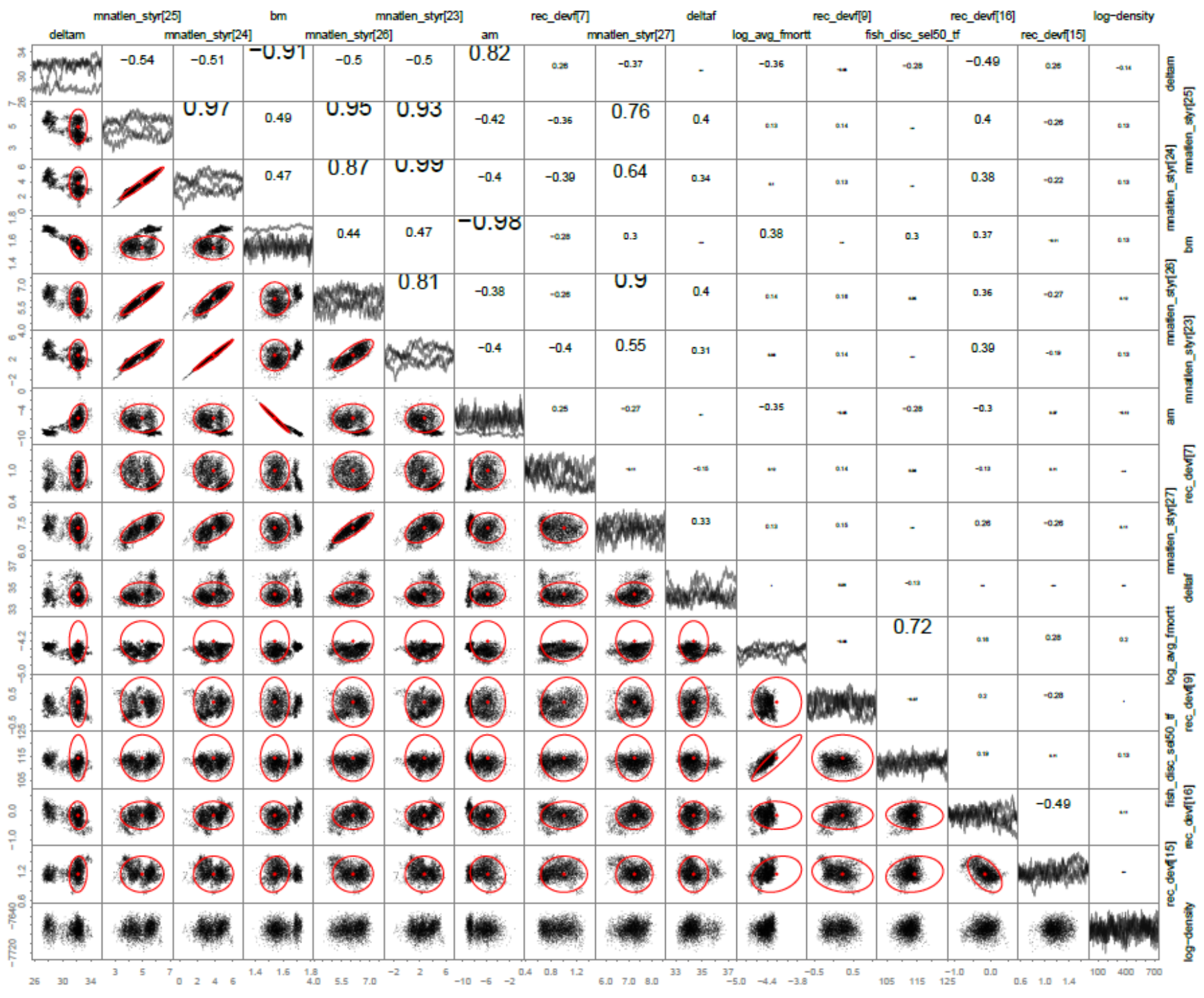
MCMC diagnostics

MCMC is used to ‘build’ the distributions of parameters and derived quantities

- Diagnostics check for appropriate specification of the model and var/covar matrix (used to explore the posterior)
- Stationarity in the traces for parameters and the objective function (mixing)
- No parameters hitting bounds
- If there are problems in these diagnostics, be cautious about inference from the model




bf1
srv1_q
srv1_q_f
srvind_sel95_f
srv10ind_q
srv10ind_q_f
selsmo10ind[6]
selsmo10ind[22]
selsmo09ind[1]
selsmo09ind[2]
selsmo09ind[3]
selsmo09ind[14]
selsmo09ind[15]
selsmo09ind[22]
log−density
0.56
0.5
0.66


deltam
mnatlen_styr[24]
mnatlen_styr[25]
mnatlen_styr[26]
bm
am
mnatlen_styr[23]
mnatlen_styr[27]
rec_devf[7]
deltaf
log_avg_fmortt
rec_devf[9]
fish_disc_sel50_tf
rec_devf[16]
rec_devf[15]
log−density
−0.54 −0.51 −0.91 −0.5 −0.5 0.82 0.26 −0.37 −0.36 −0.28 −0.49 0.26 −0.14
0.97 0.49 0.95 0.93 −0.42 −0.36 0.76 0.4 0.4 −0.26 0.13
0.47 0.87 0.99 −0.4 −0.39 0.64 0.34 0.38 −0.22 0.13
0.44 0.47 −0.98 −0.28 0.3 0.38 0.3 0.37 0.13
0.81 −0.38 −0.26 0.9 0.4 0.36 −0.27
−0.4 −0.4 0.55 0.31 0.39 −0.19 0.13
0.25 −0.27 −0.35 −0.28 −0.3
0.33 0.26 −0.26
0.72

Diagnostic summary

- Several processes have problem parameters
- Slow mixing:
  - Growth parameters
  - Rec devs
  - Initial numbers at length
- Bound hitting
  - Growth parameters
  - Survey selectivity (NMFS) during era 1
  - Industry survey selectivity parameters
- Dealt with slow mixing by using really long chains last year, but this takes a very long time
- Methods for adjustment
  - Priors on parameters hitting their bounds
  - Reformulating the model
  - Excluding problematic periods of data

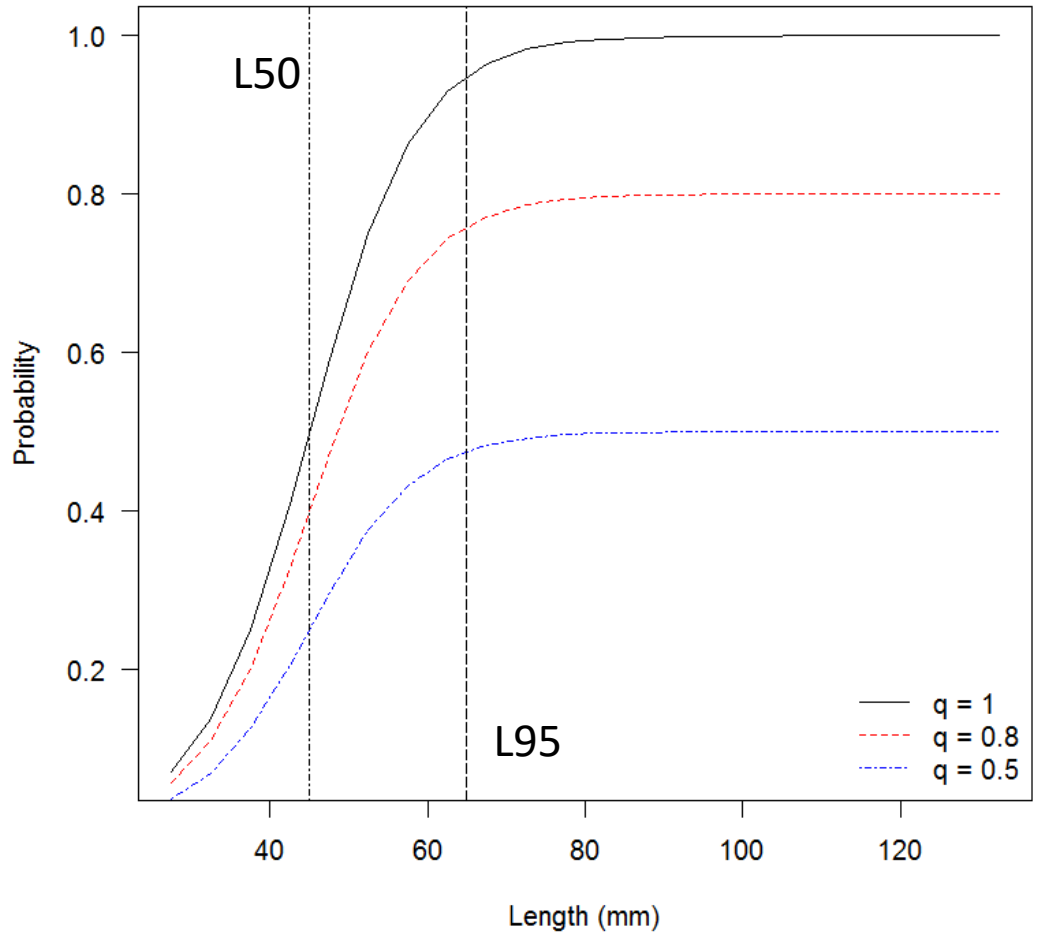
Estimating survey selectivity

- Historical methods
- Data
- Model runs
- Model results
  - Fits
  - OFL and reference points
  - Processes influenced
- Recommendations

Historical methods

- Logistic selectivity
- Three eras
  - 1978-1981: different gear
  - 1982-1988: different area
  - 1989-present: current
- Catchability coefficient (q)
  - Changes in estimates over time
  - Era 1 has always been fixed at 1
- Issues
  - Q modulates the impact of catch on the survey index
  - Foreign fleets were excluded starting 1980, so it's not clear if the catches are fully represented in era 1
  - Q in the first era is consistently estimated on its bounds and anchors the catchability in the other era
- Are the survey eras appropriately chosen?
- Are there alternate sensible configurations?

$$S_l = \frac{q}{1 + e^{(-\ln(19)\frac{L_l - L_{50}}{L_{95} - L_{50}})}}$$



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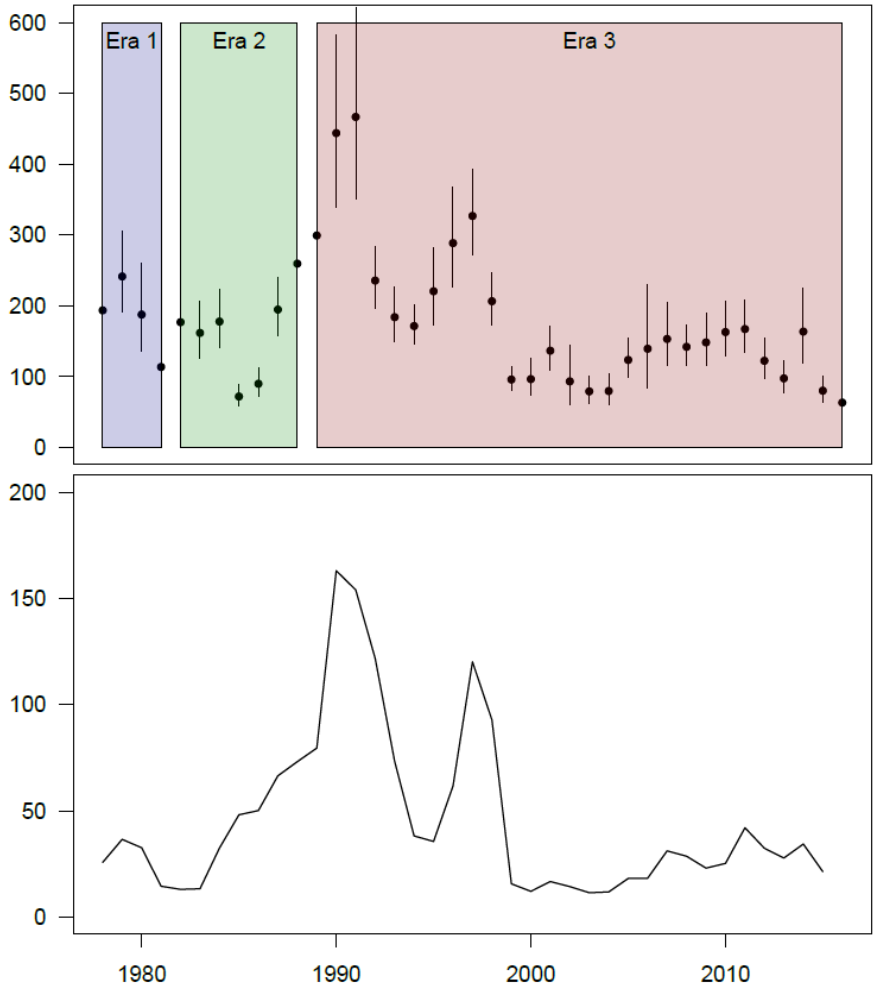

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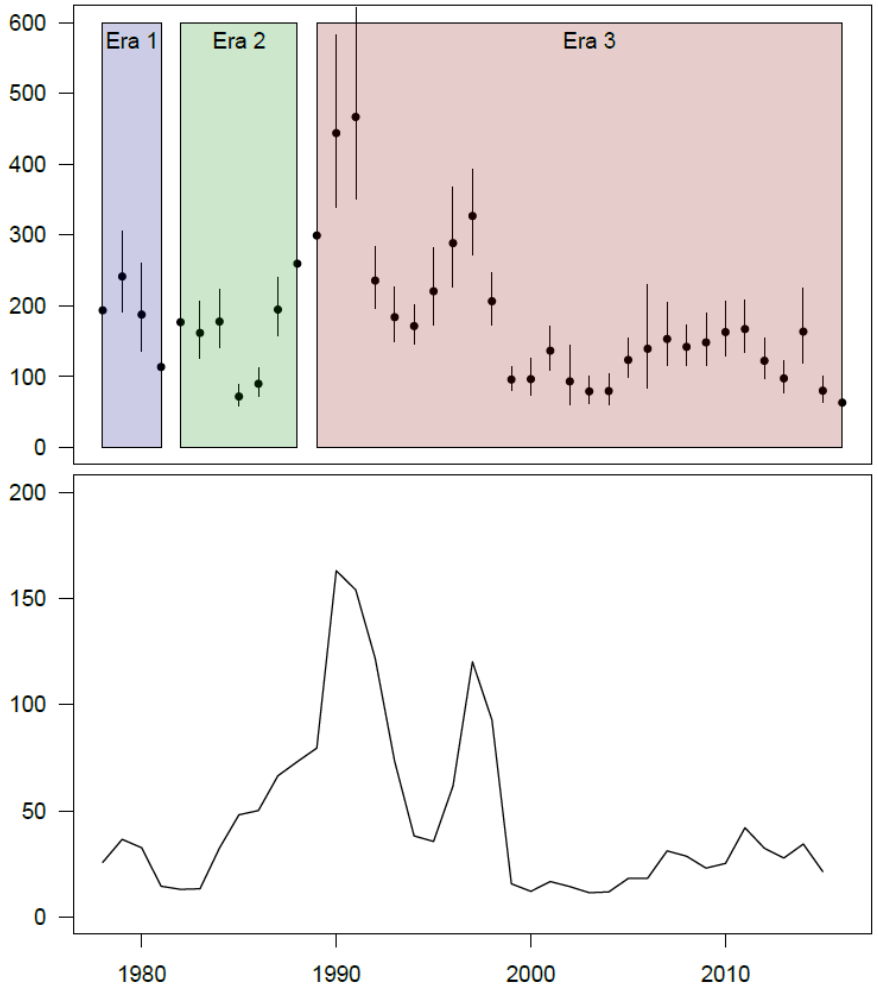

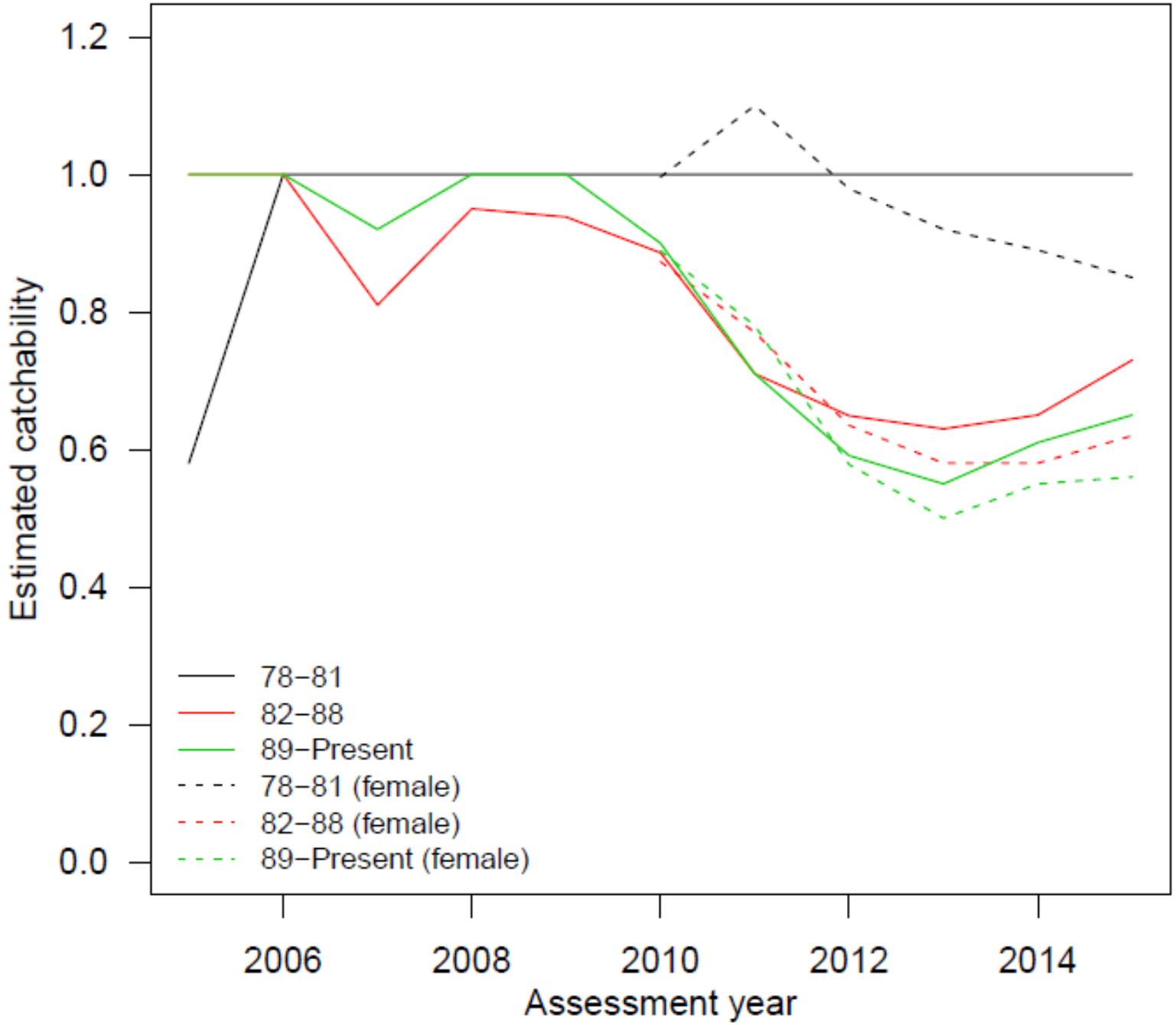
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Estimated catchability
78–81
82–88
89–Present
78–81 (female)
82–88 (female)
89–Present (female)
2006
2008
2010
2012
2014
Assessment year

Historical methods

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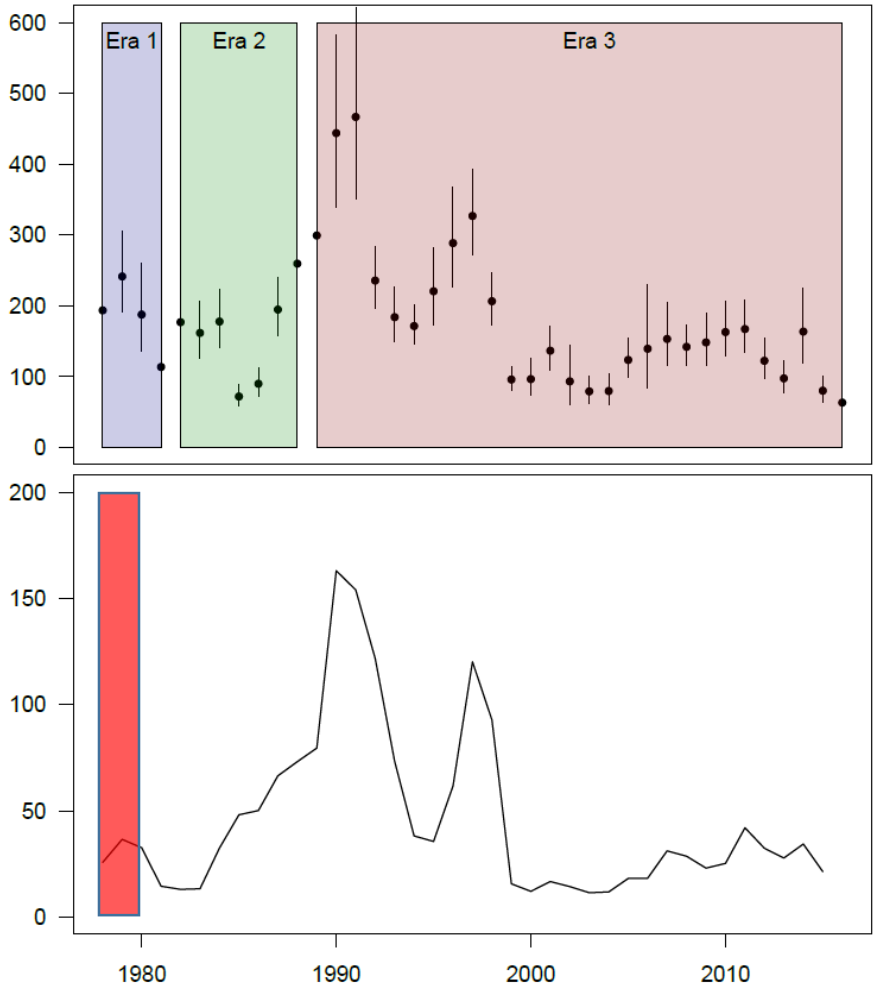
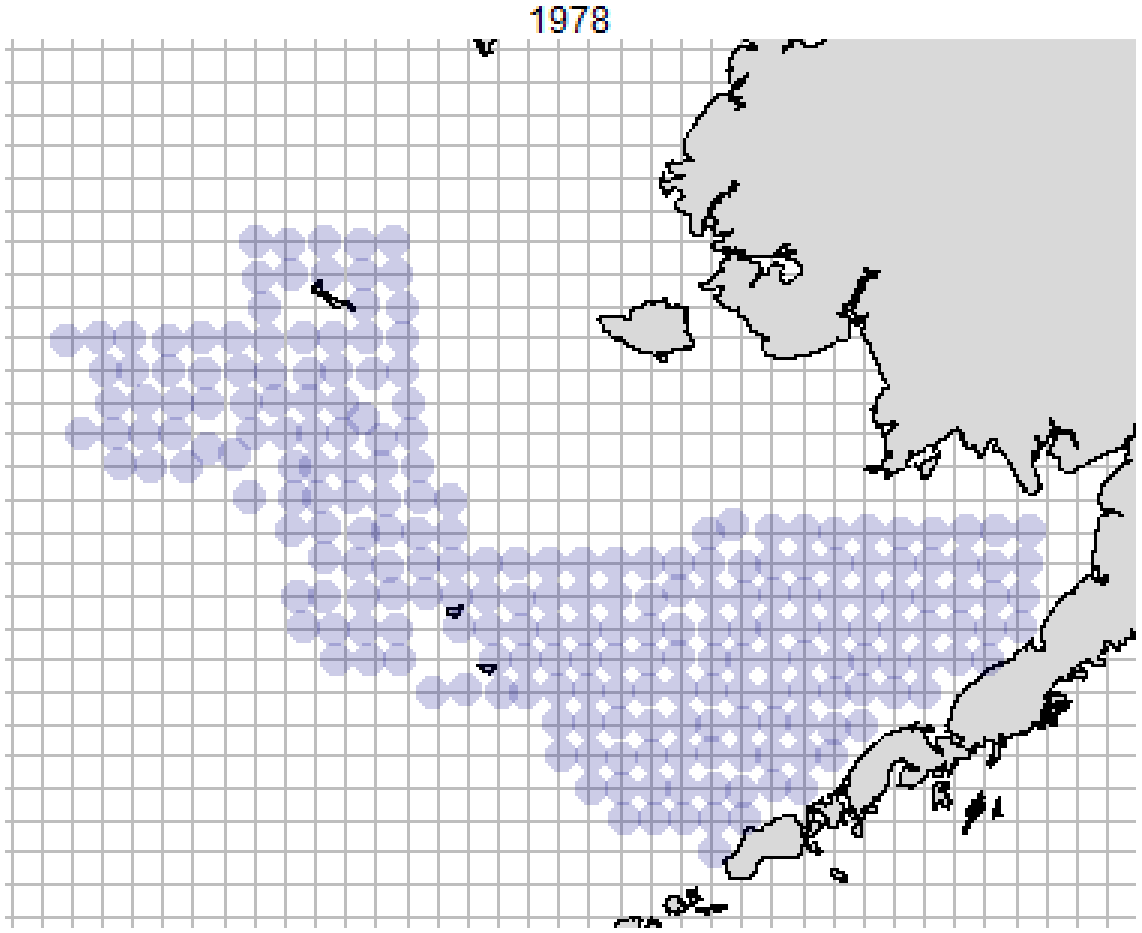
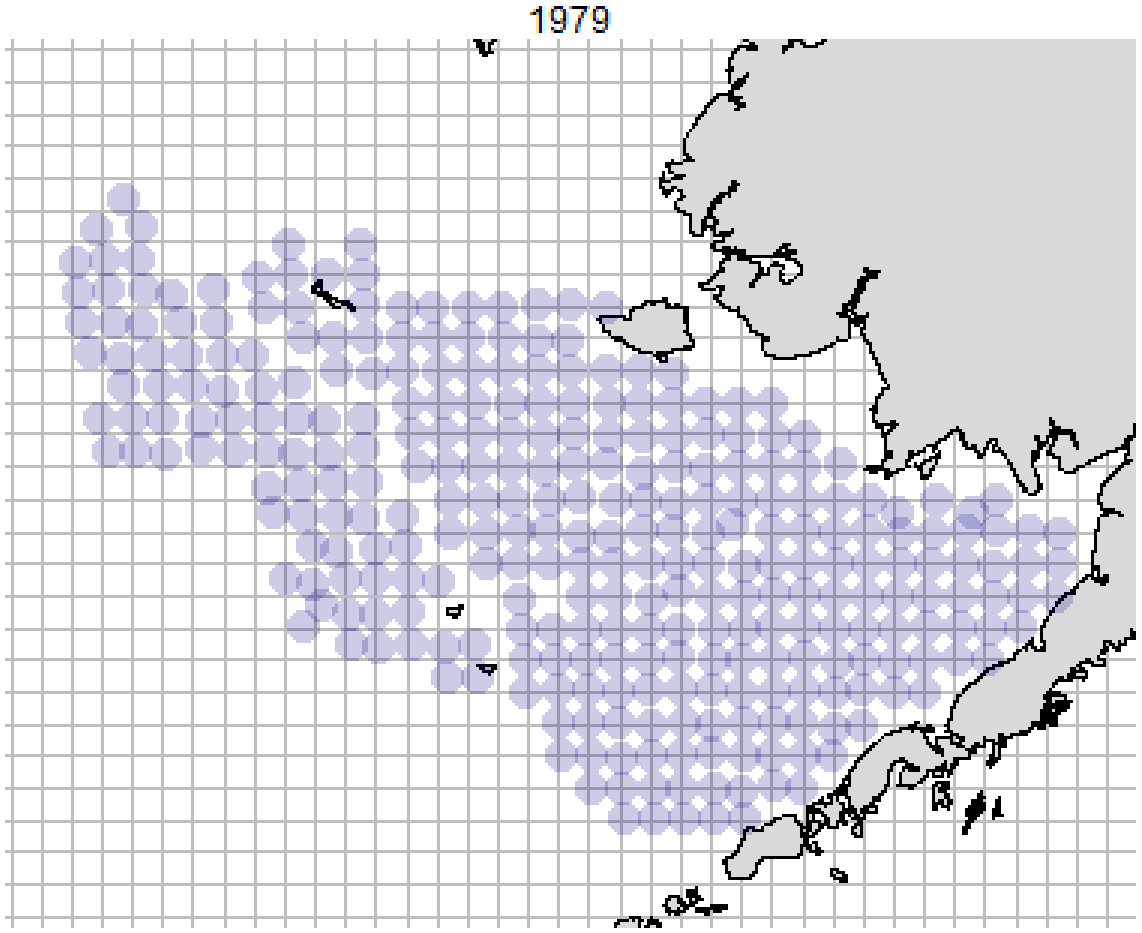



1978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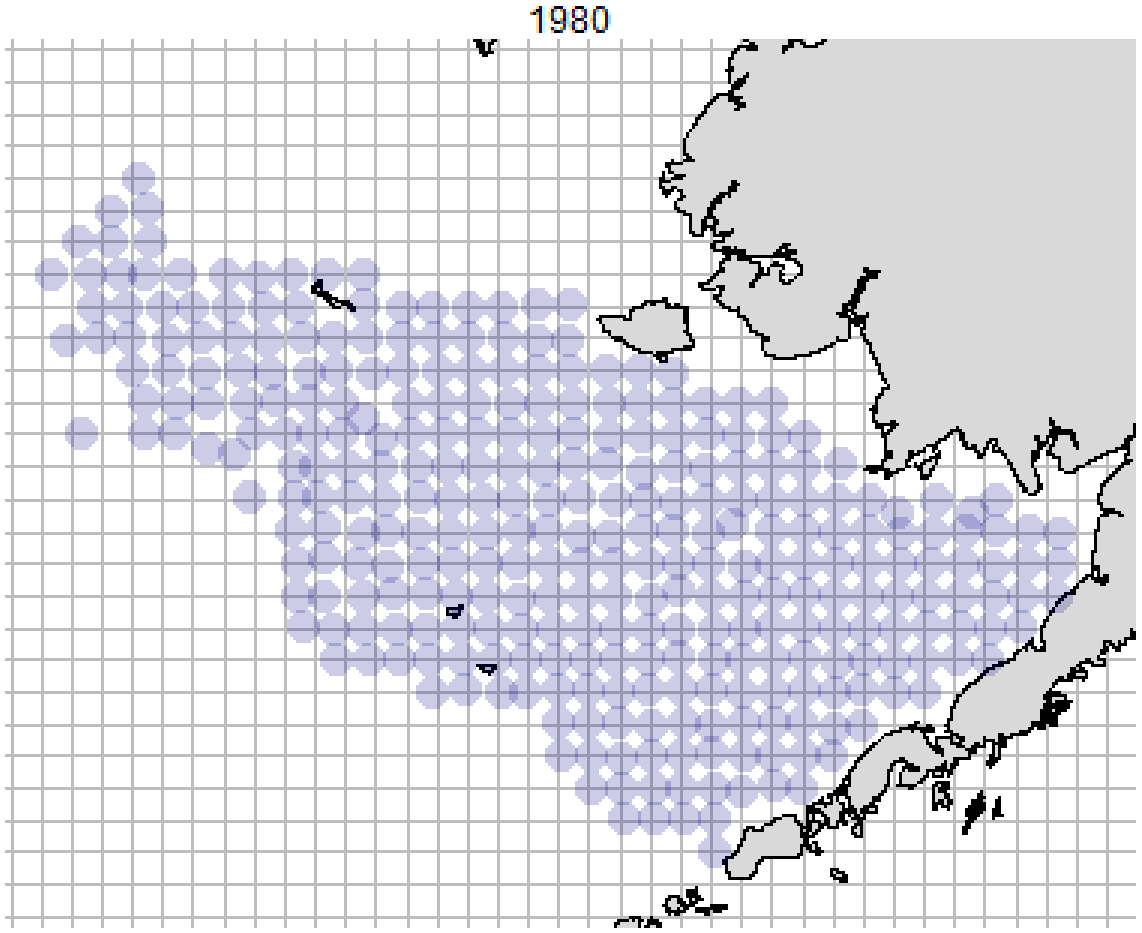
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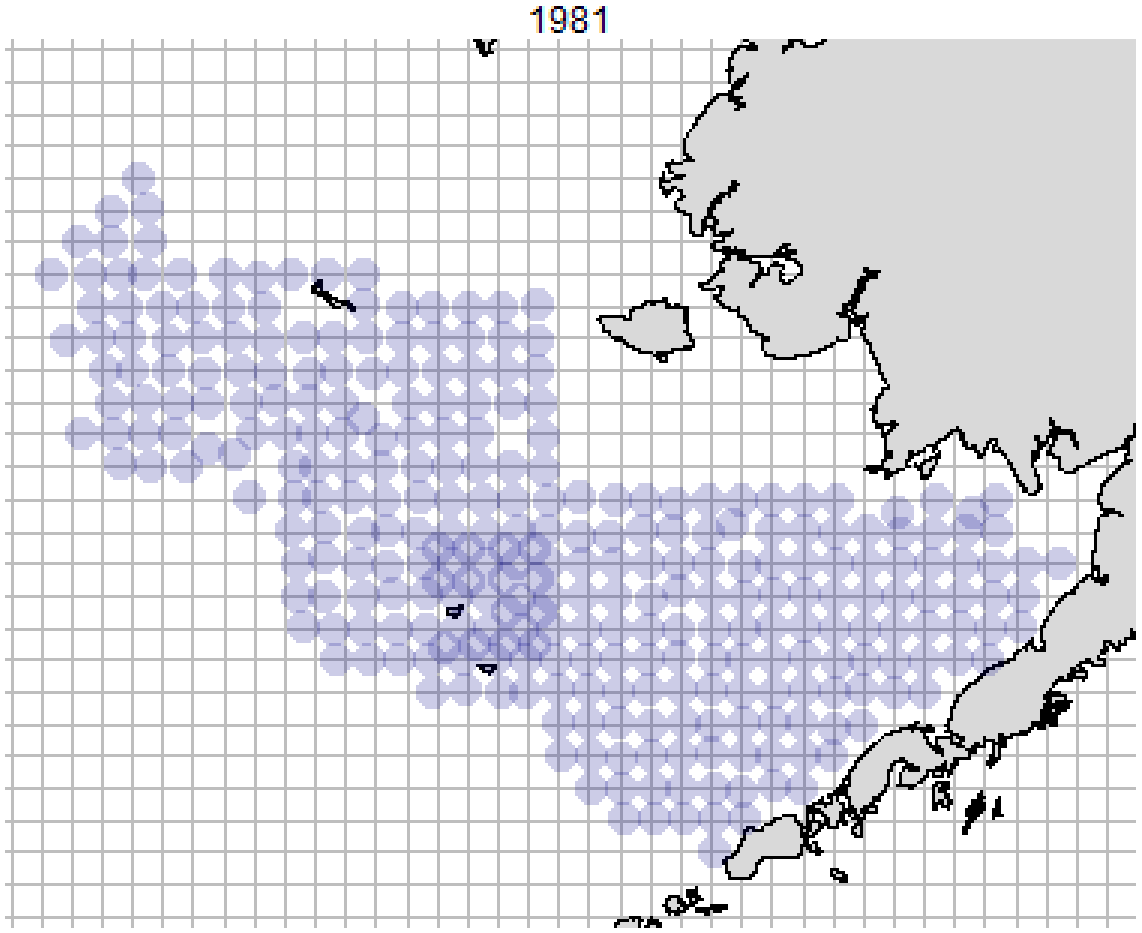
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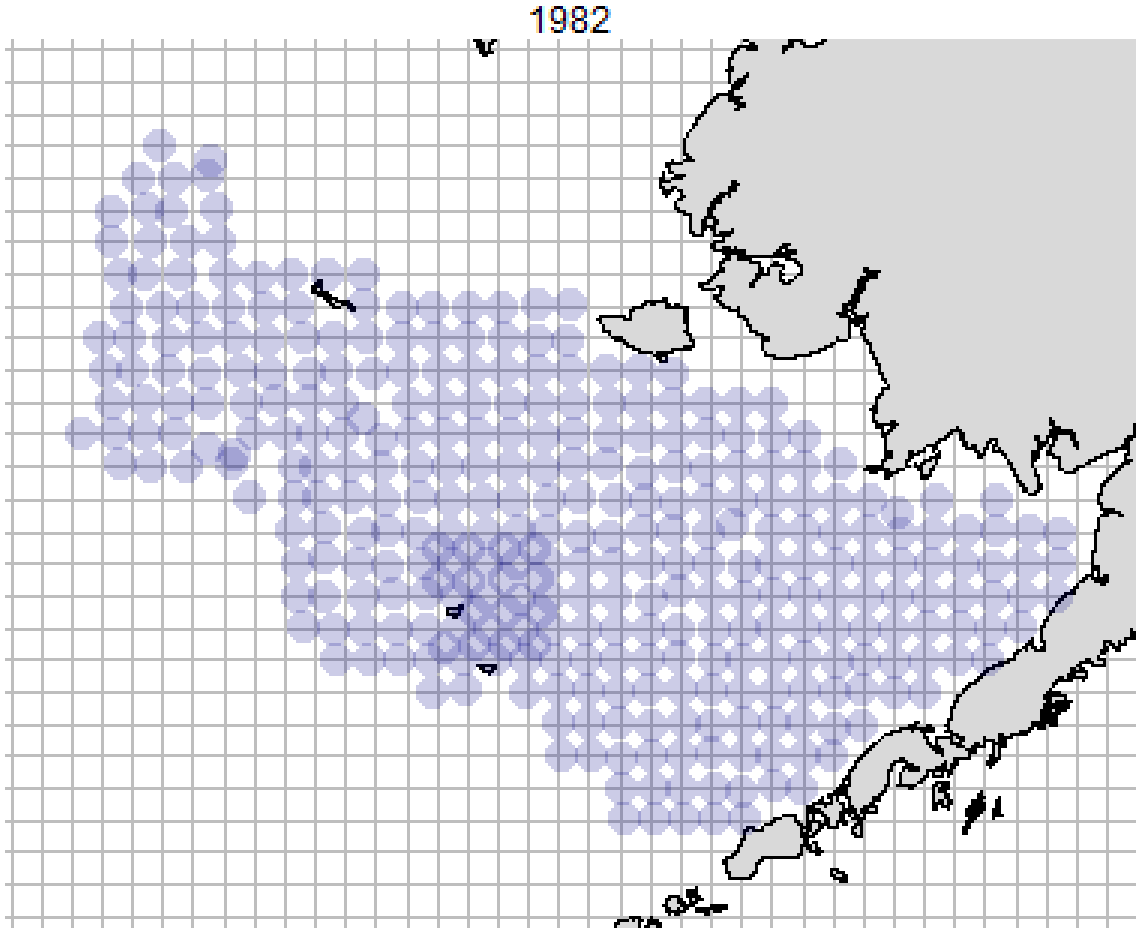
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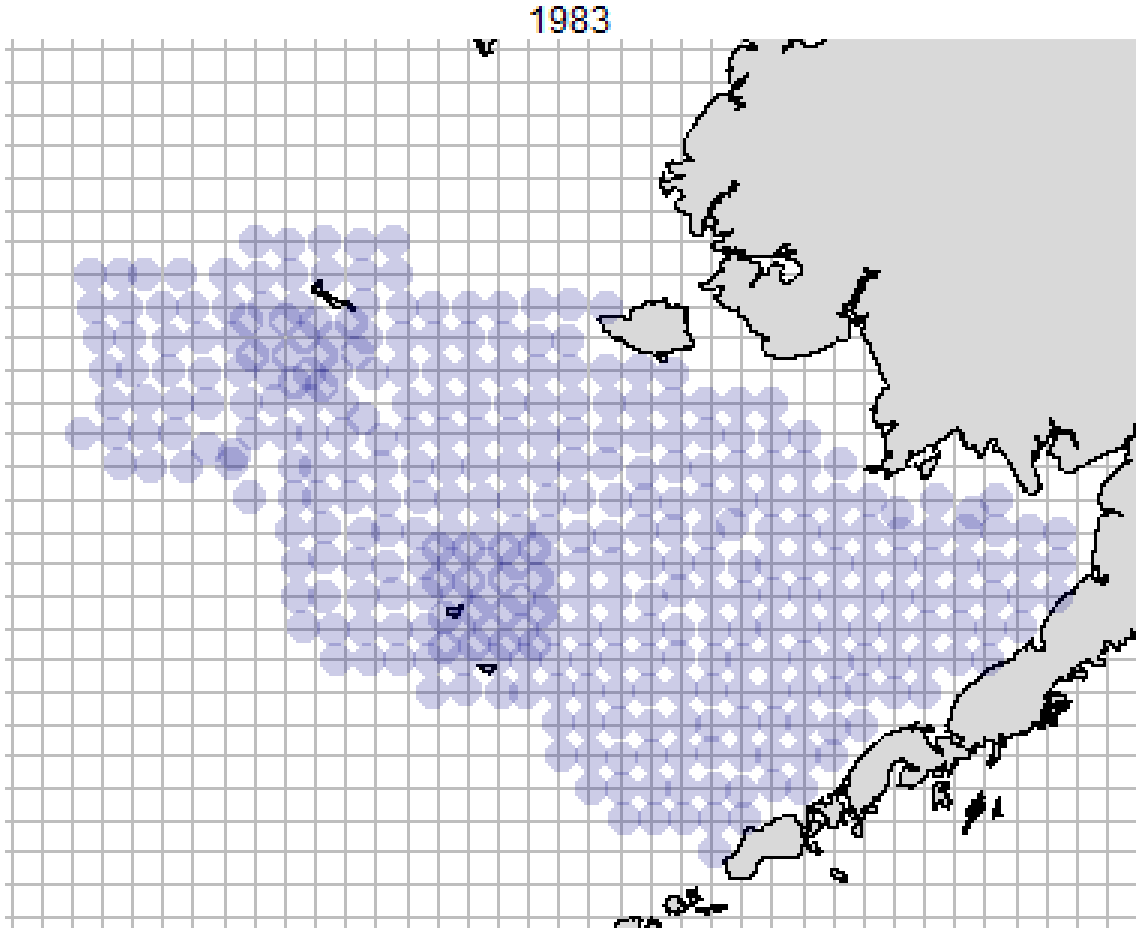
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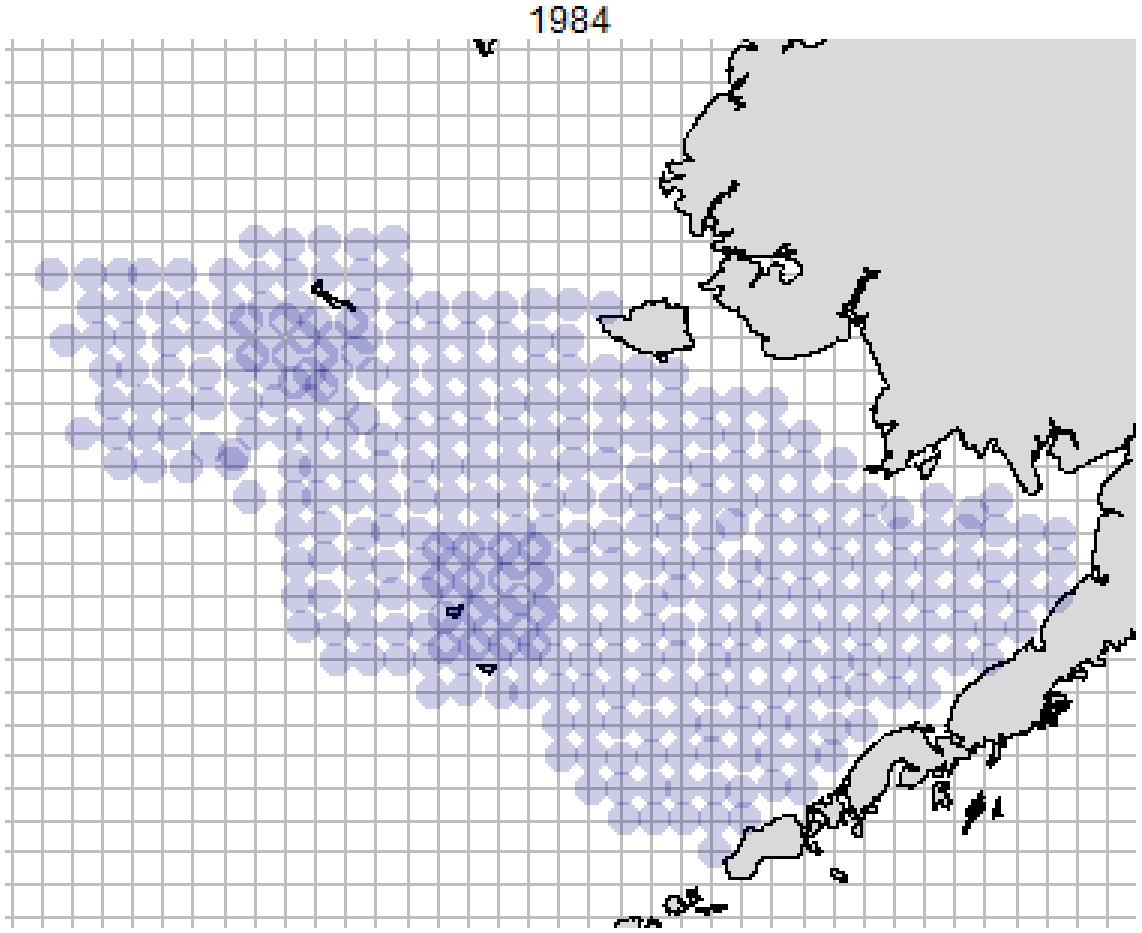
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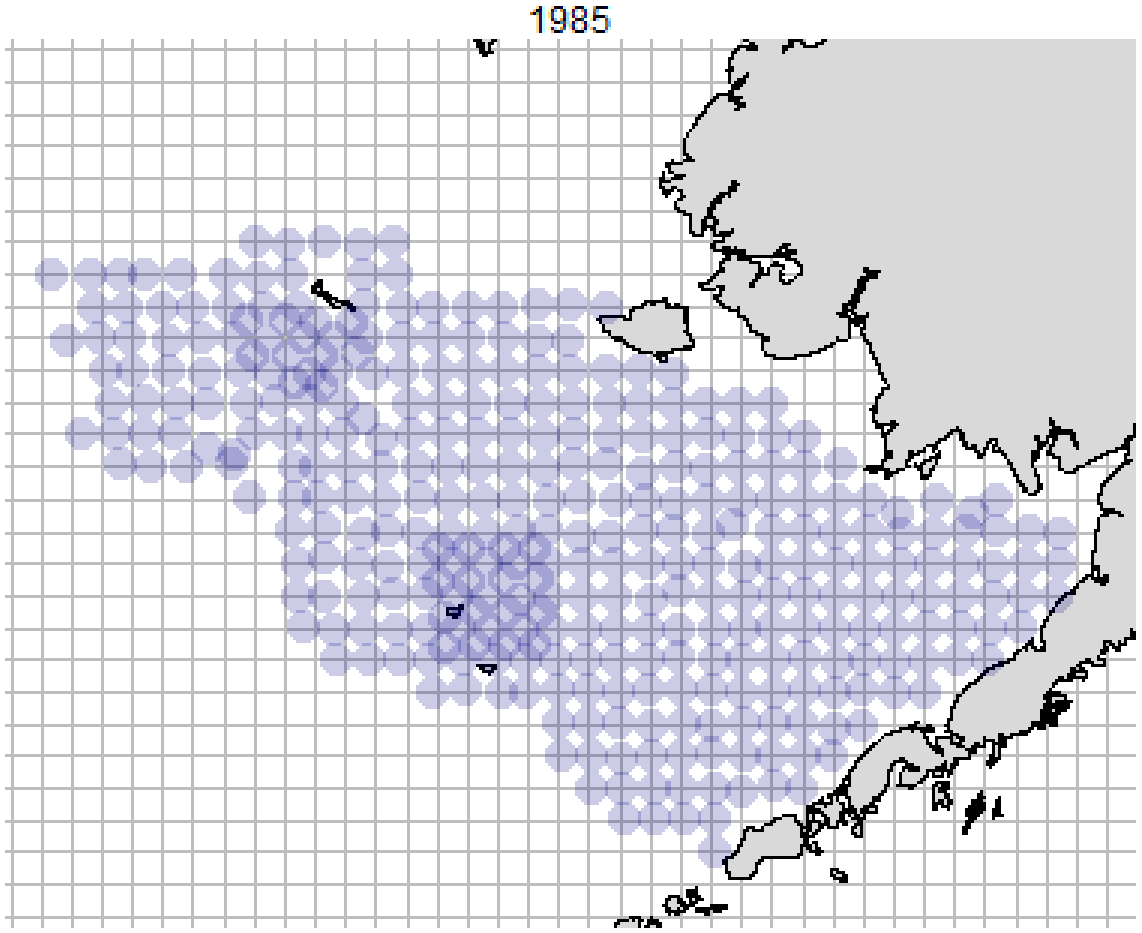
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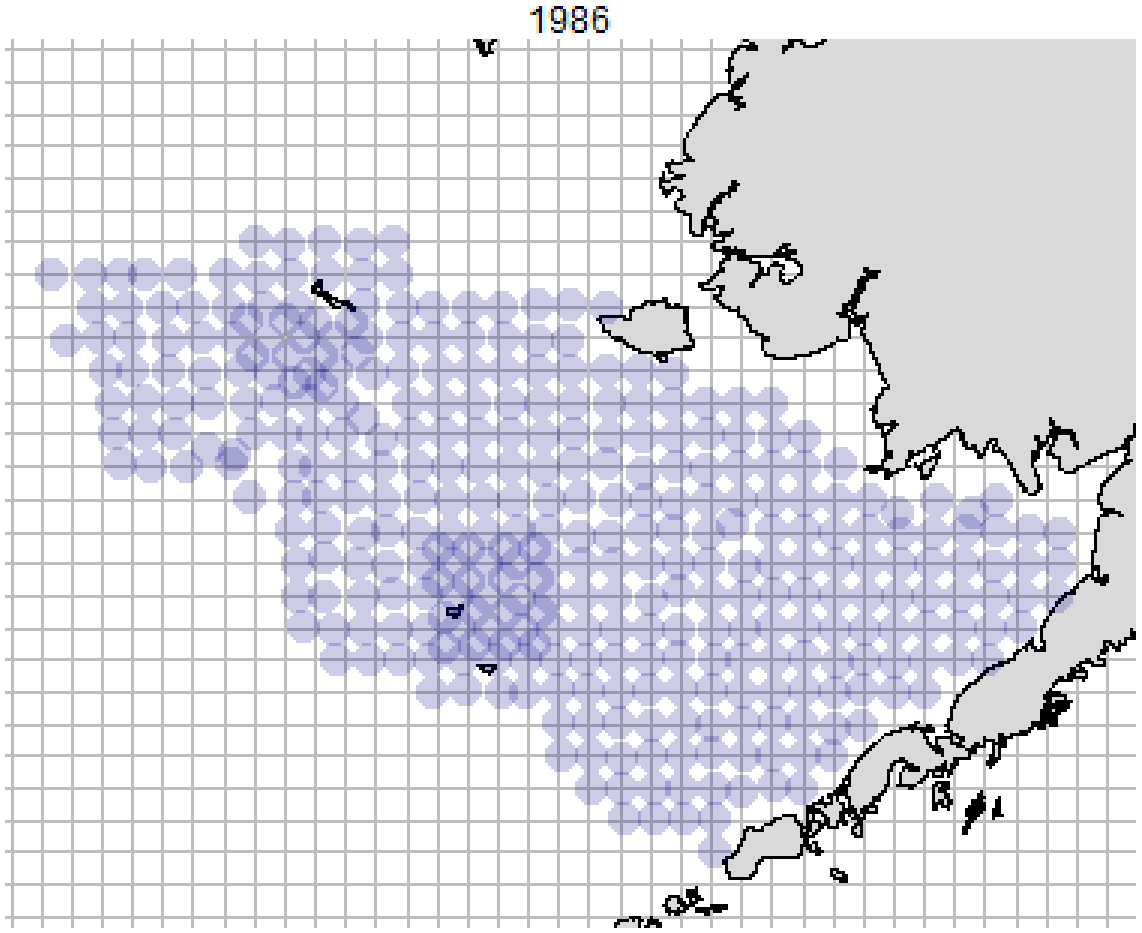
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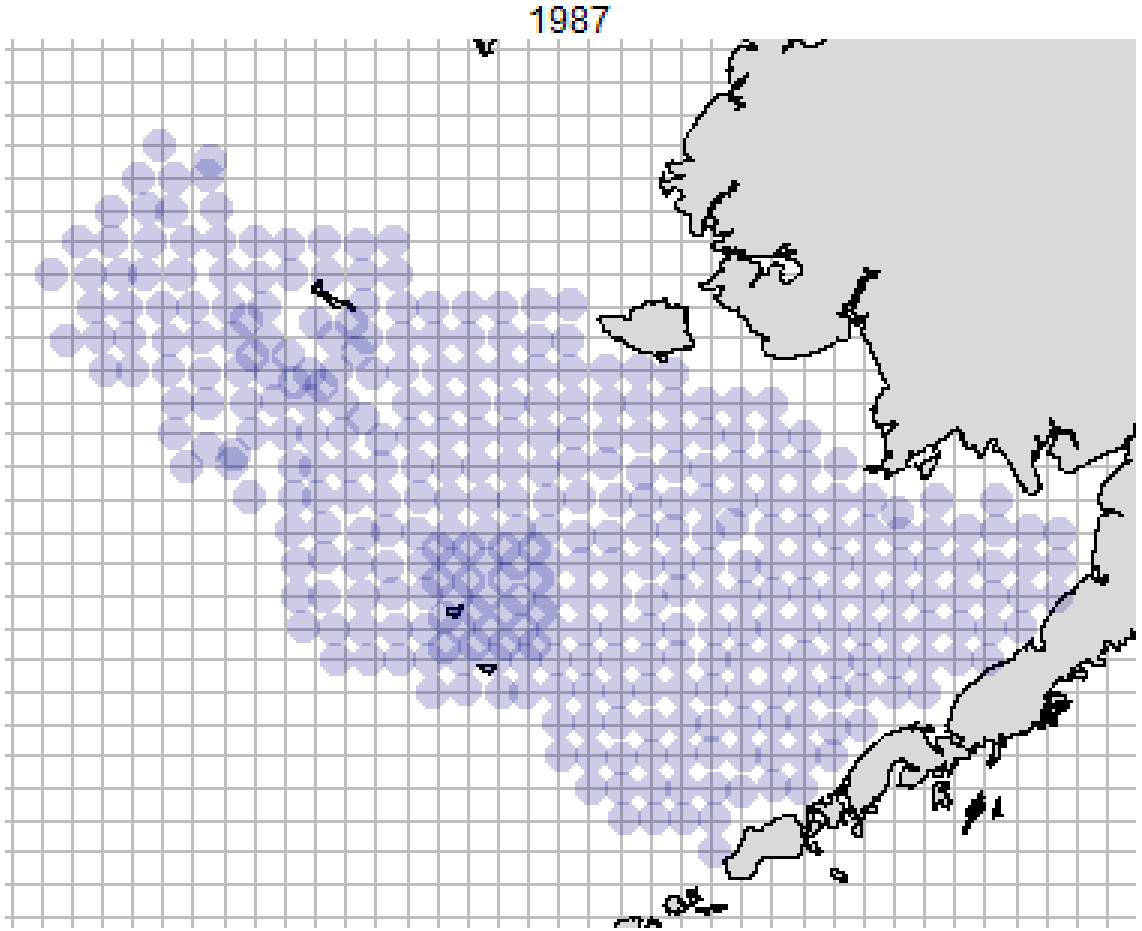
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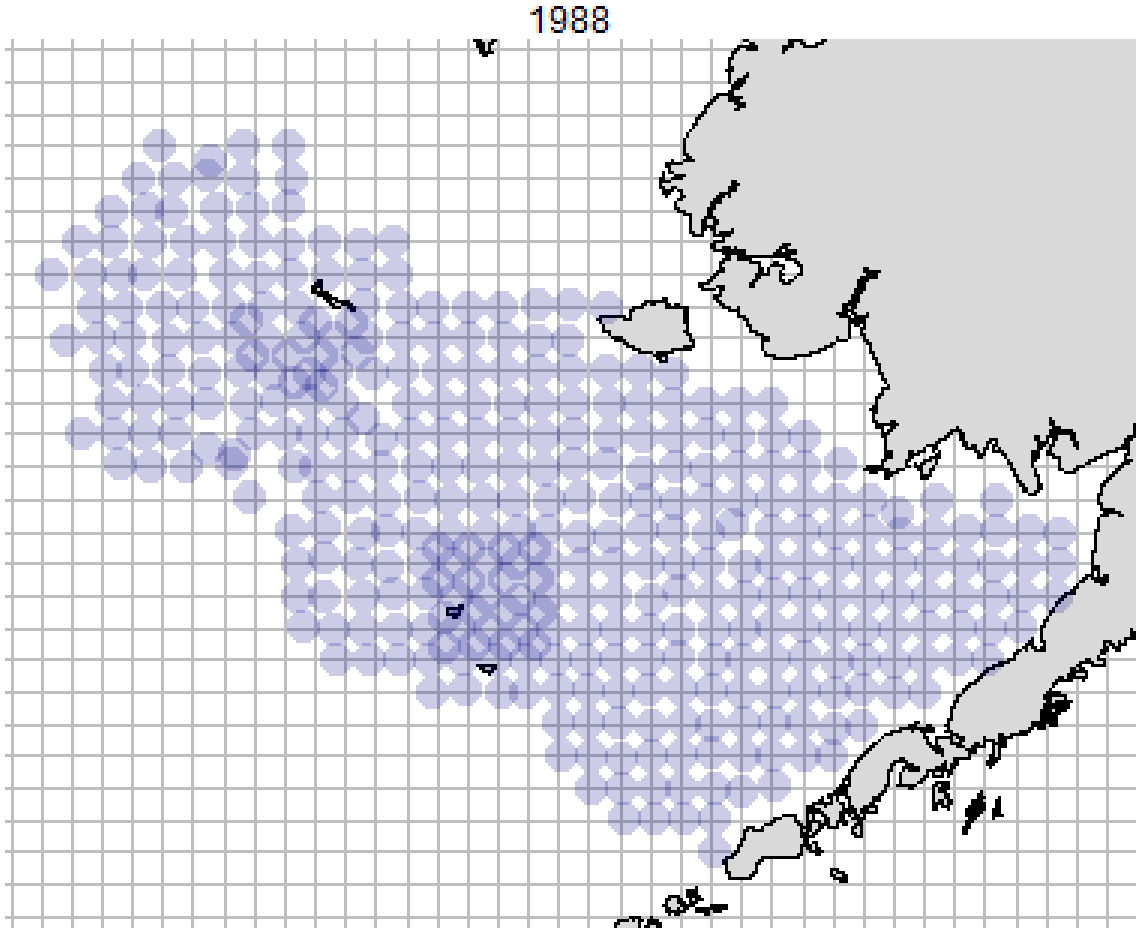
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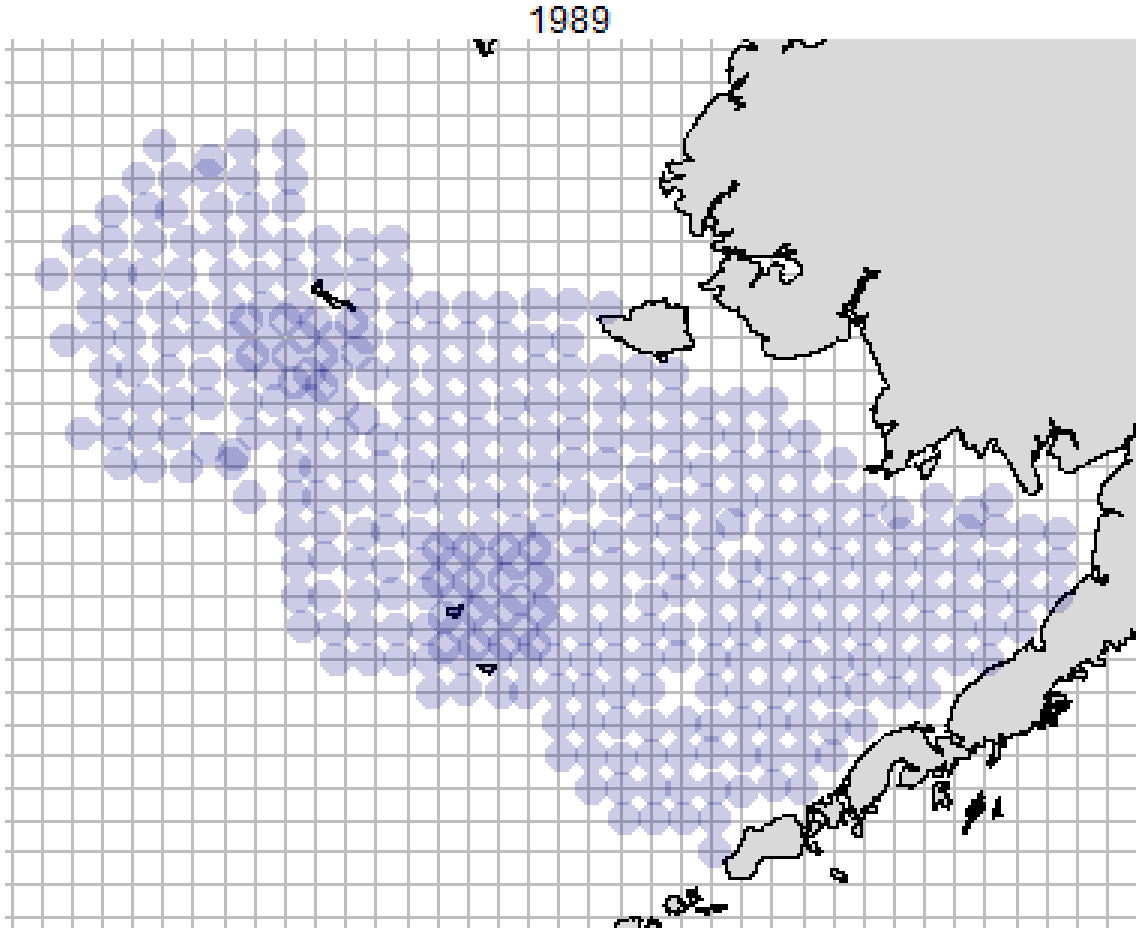
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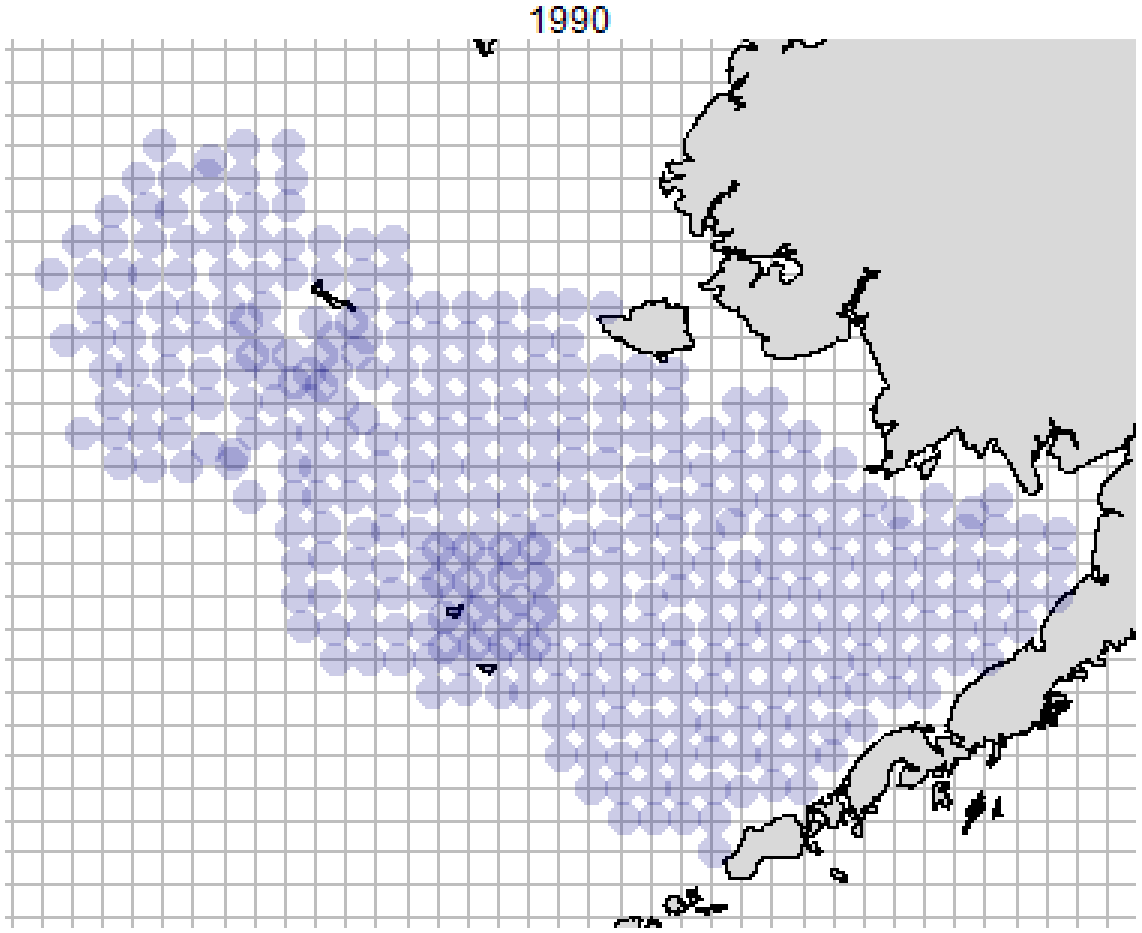
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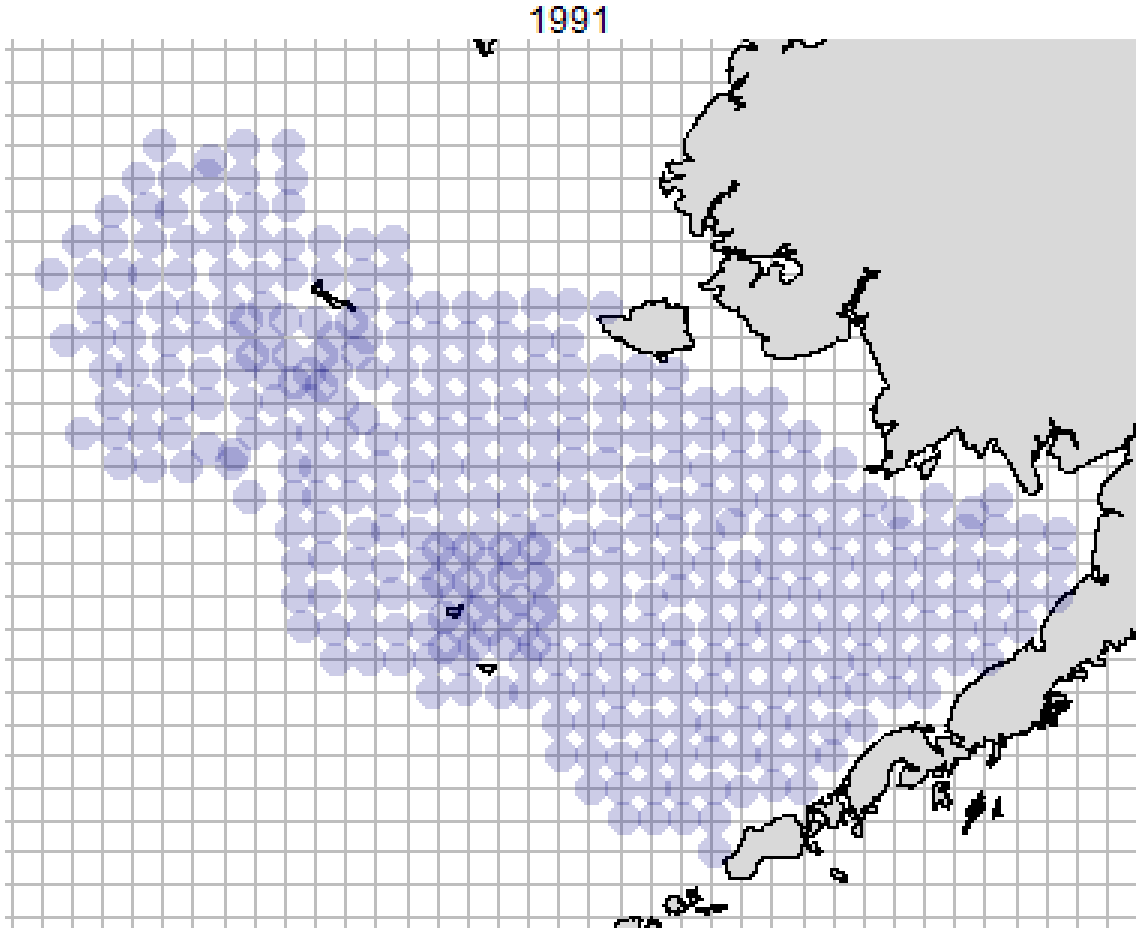
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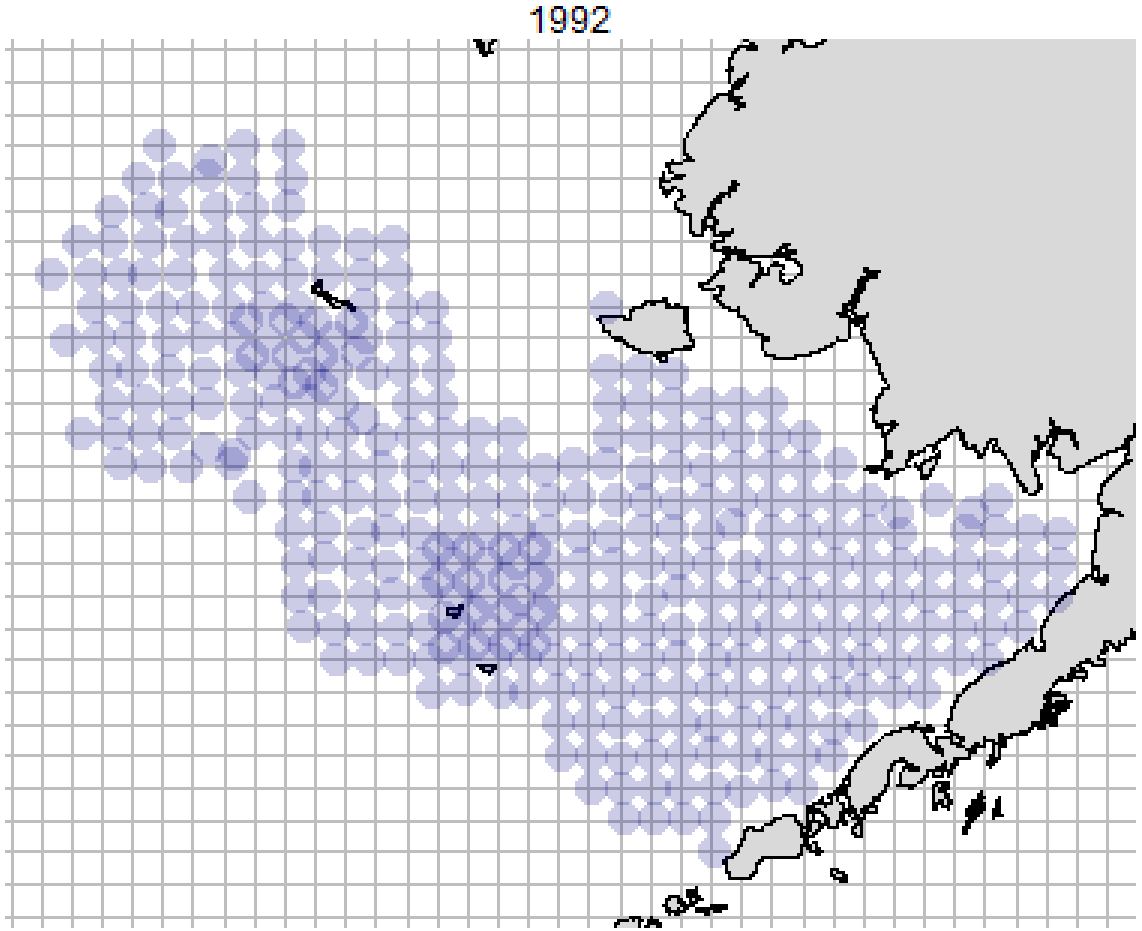
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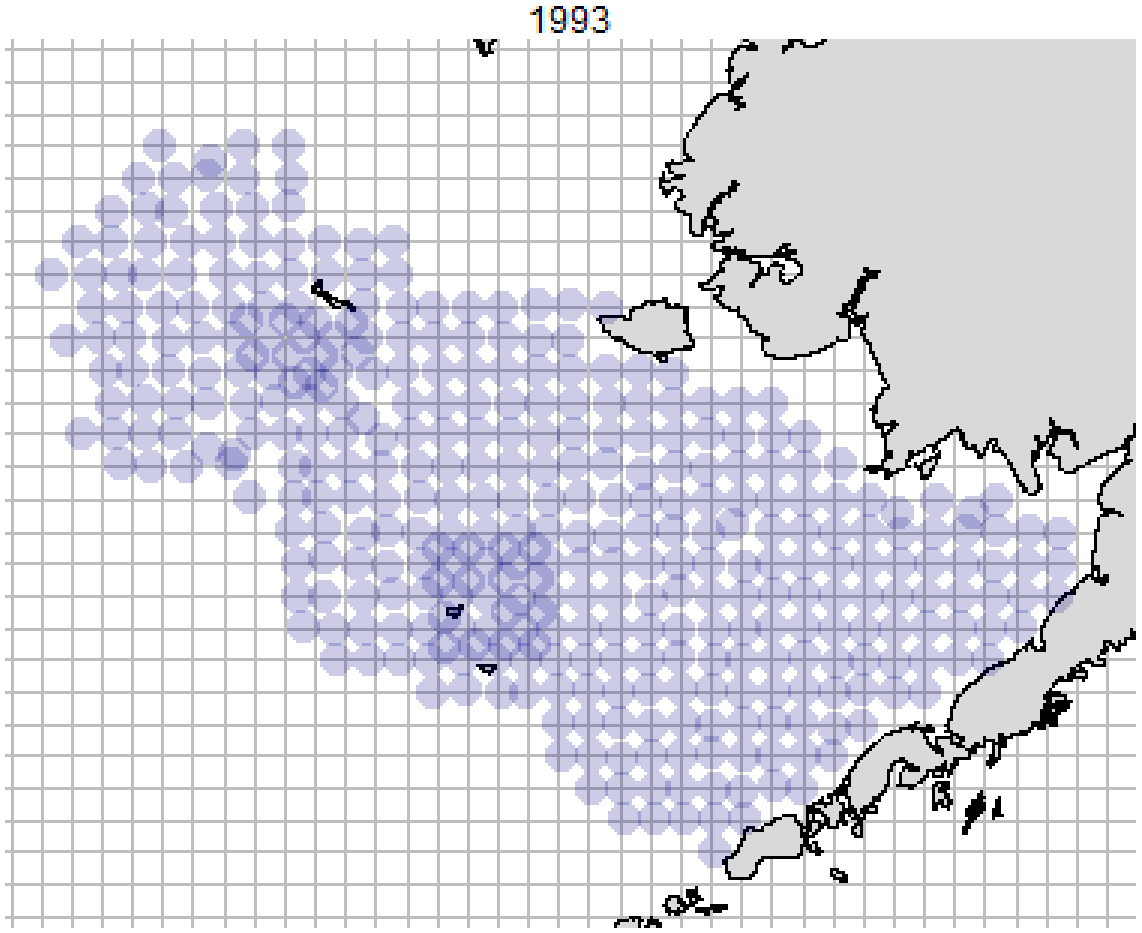
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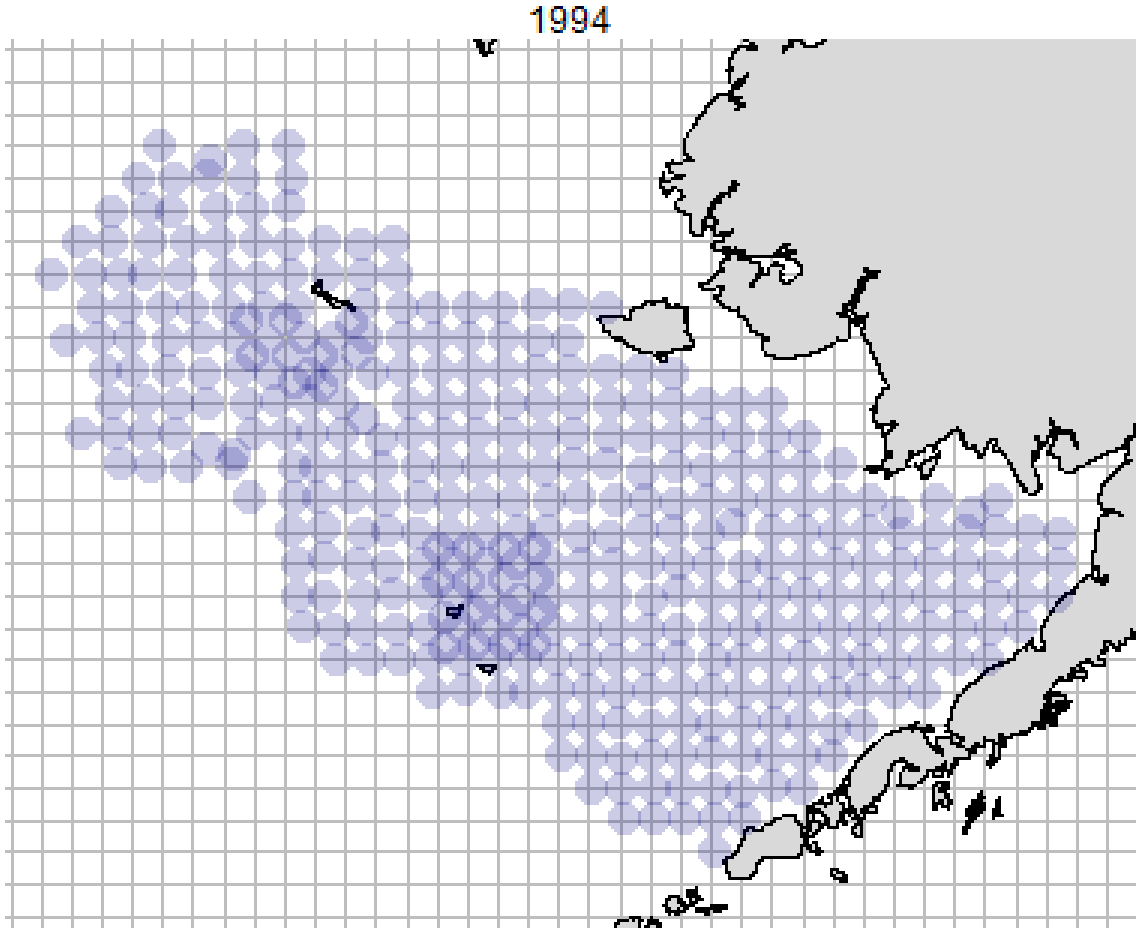
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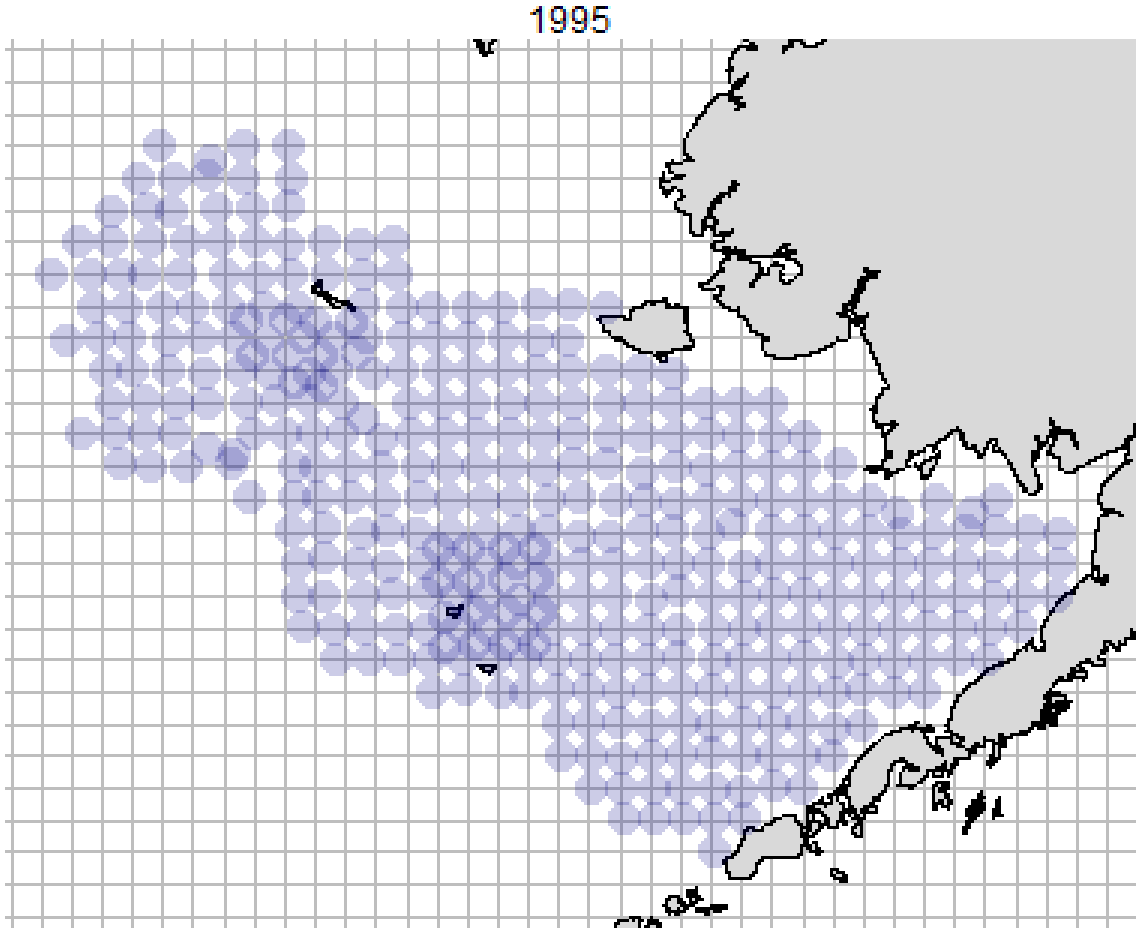
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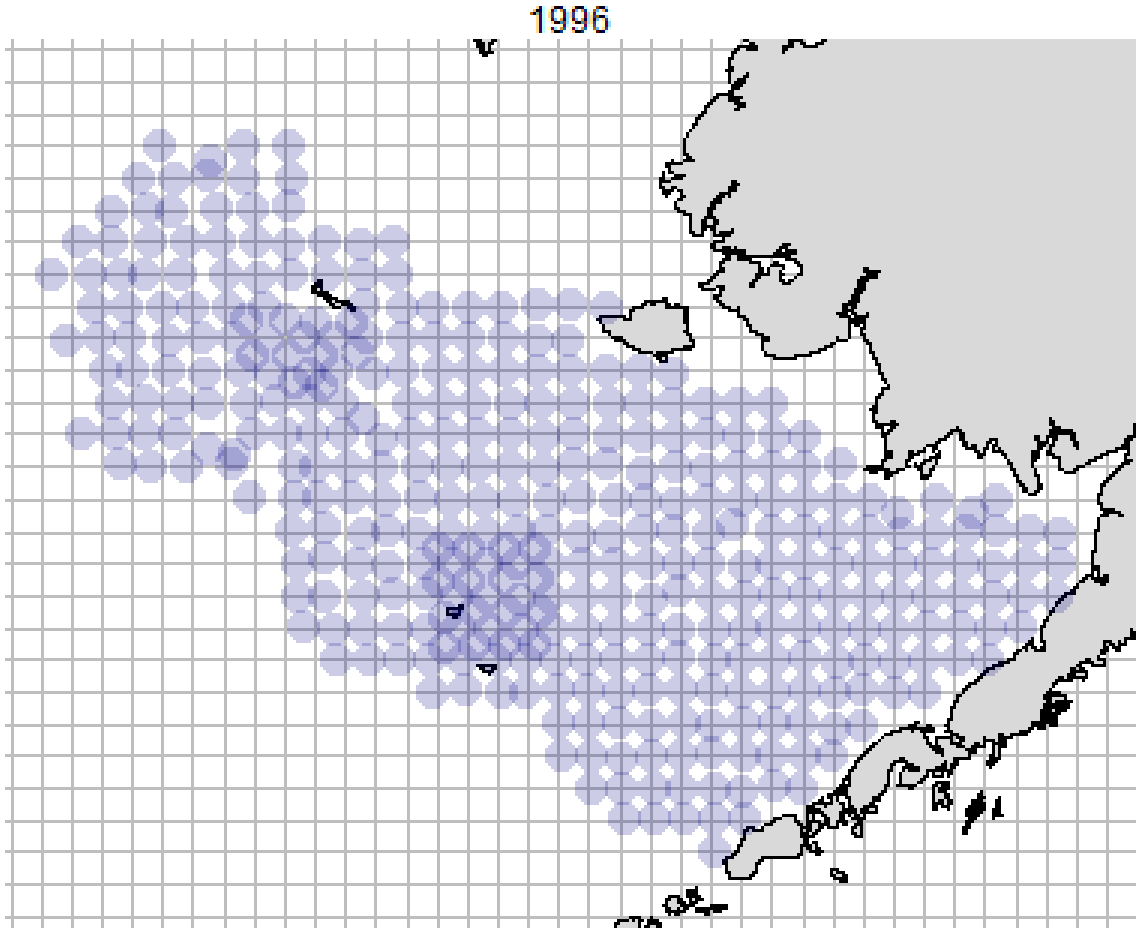
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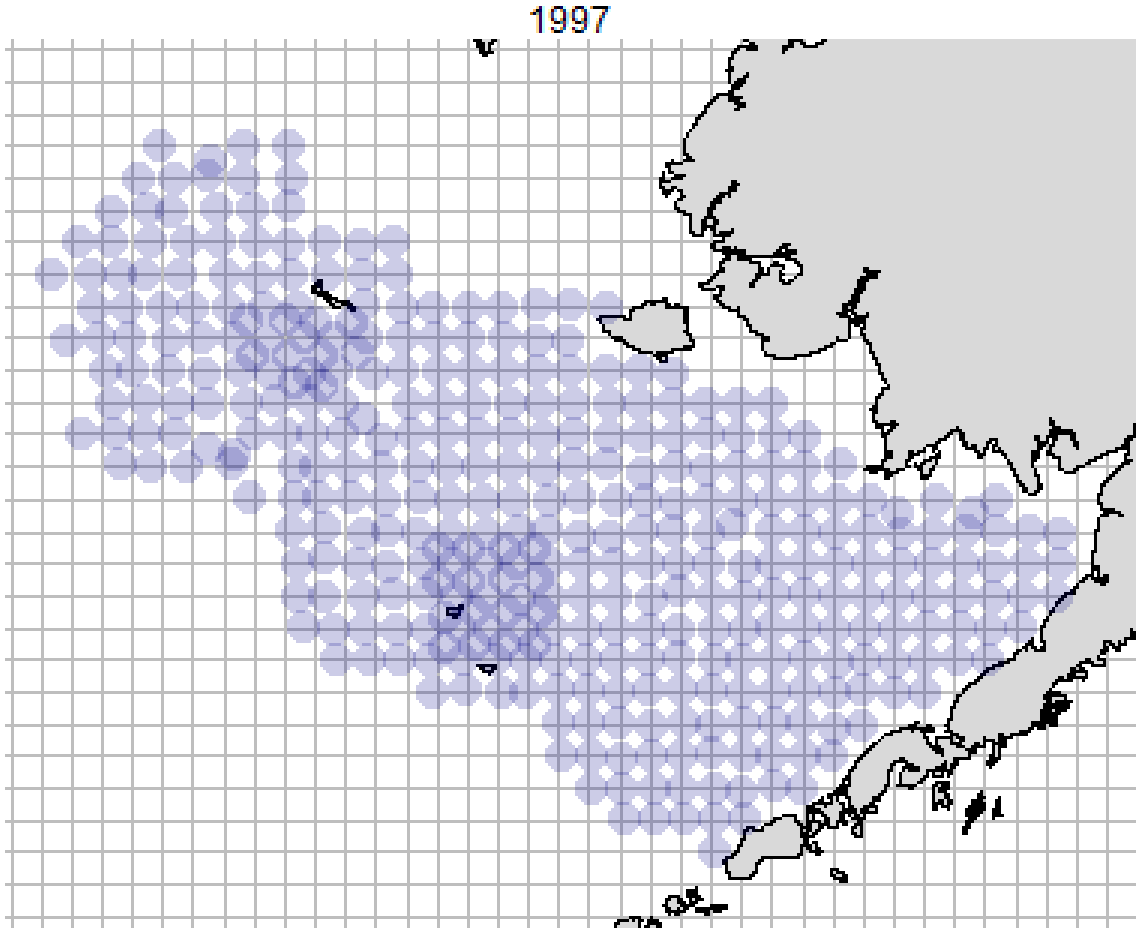
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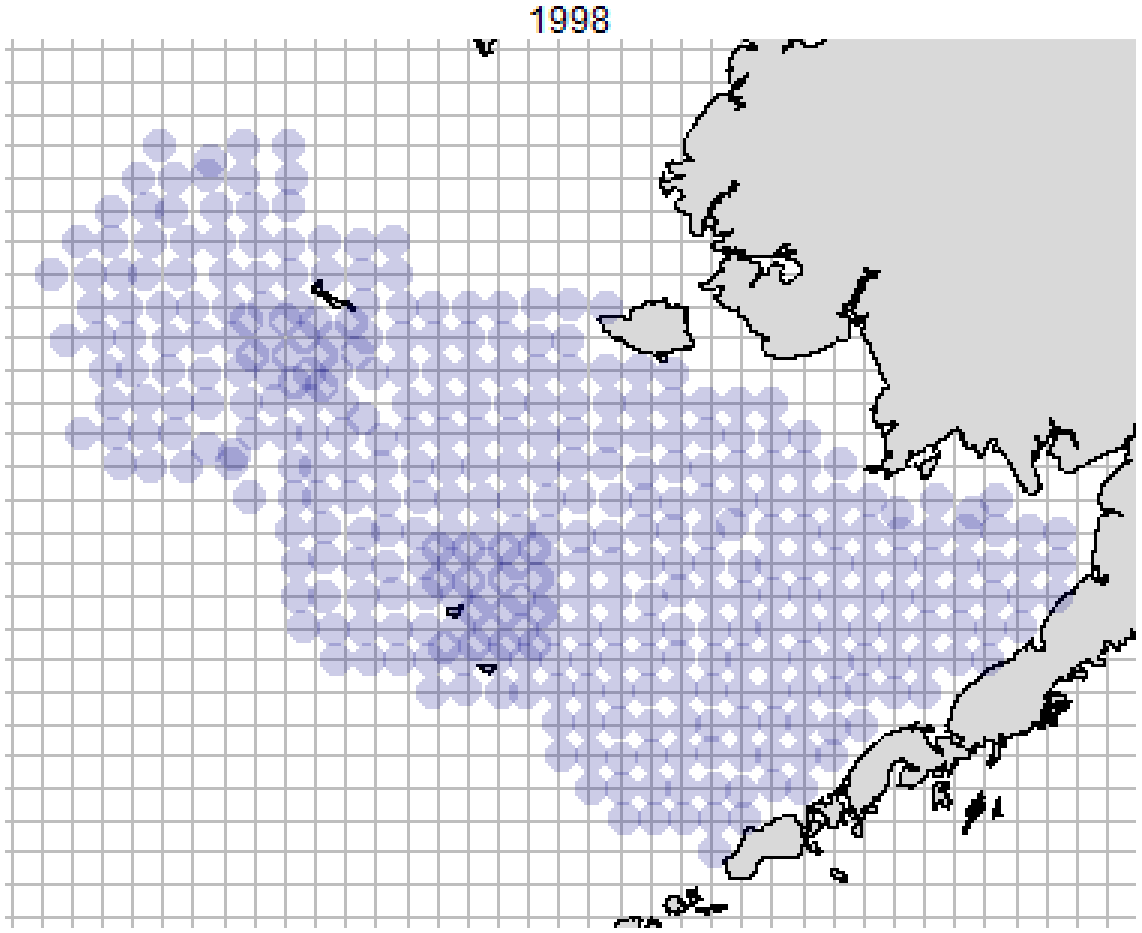
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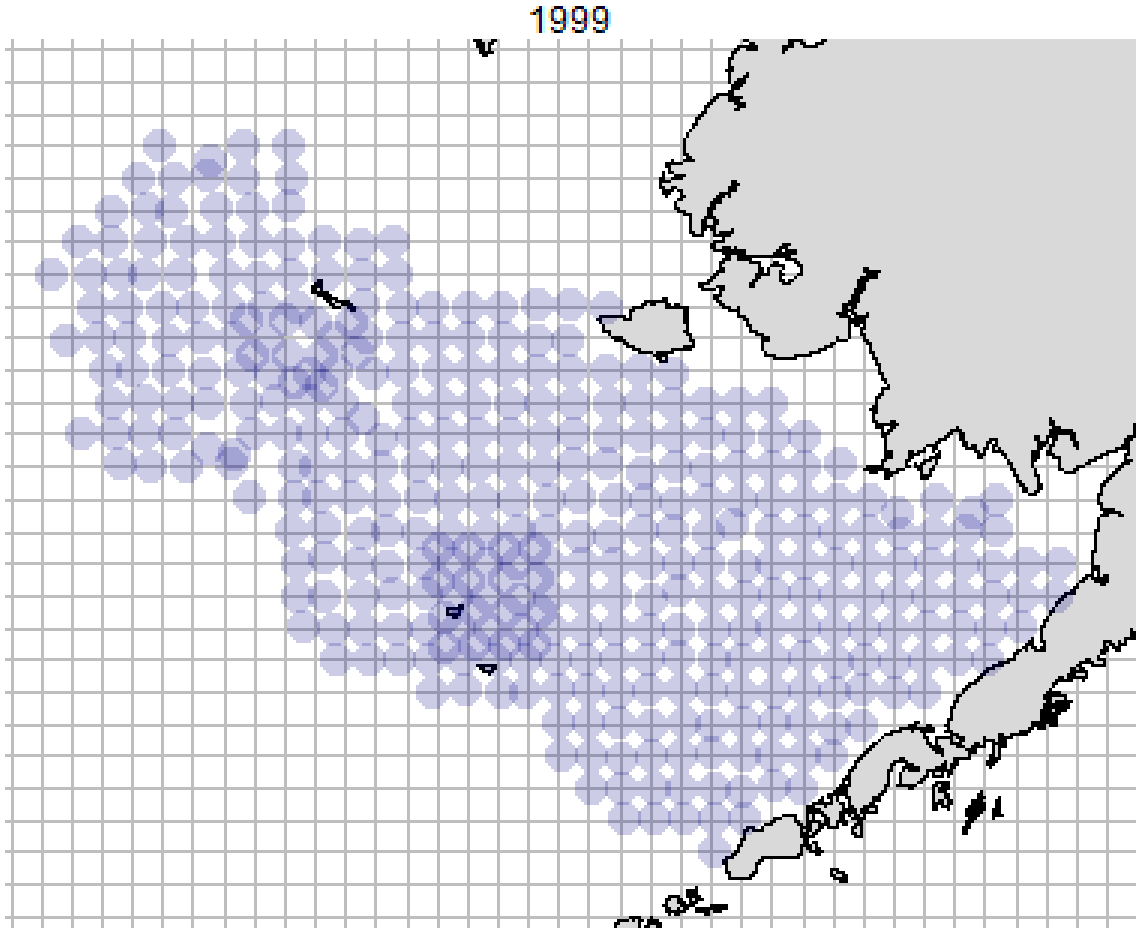
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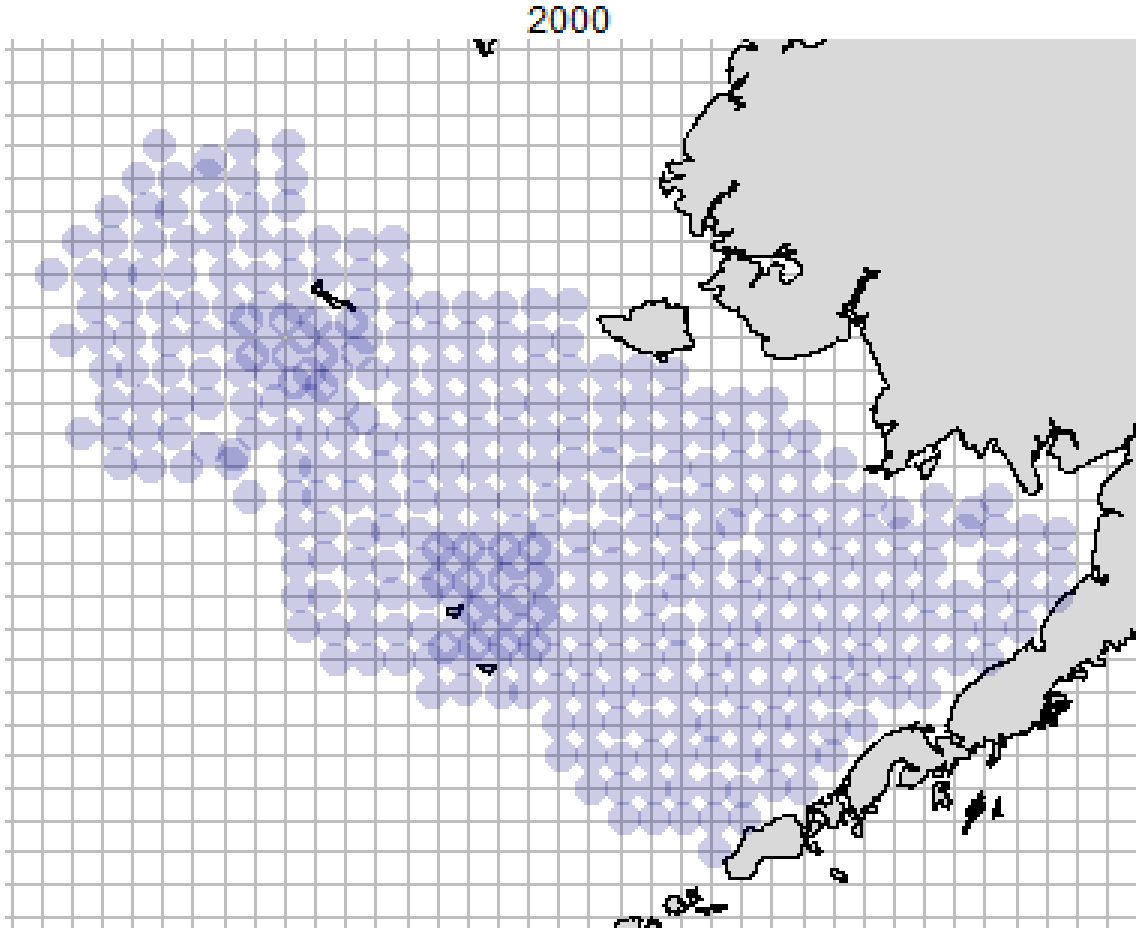
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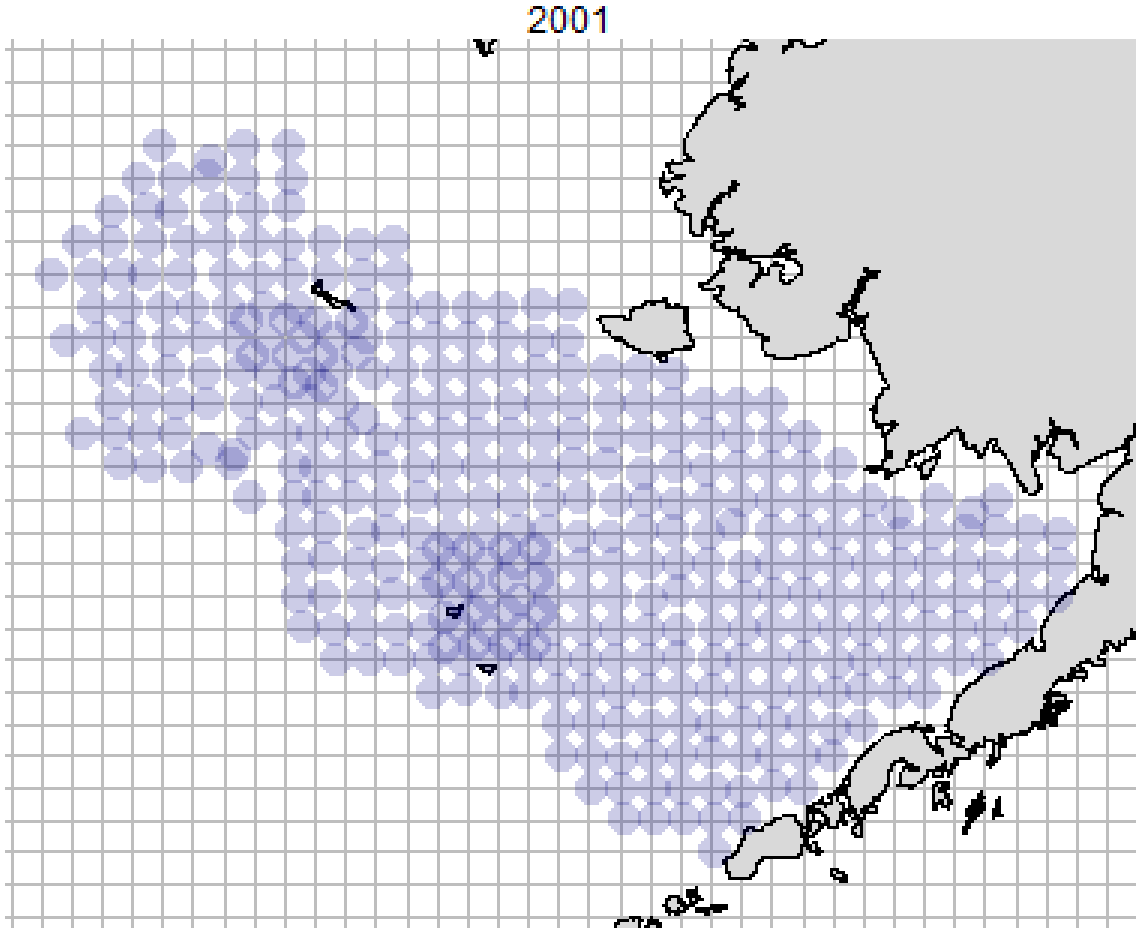
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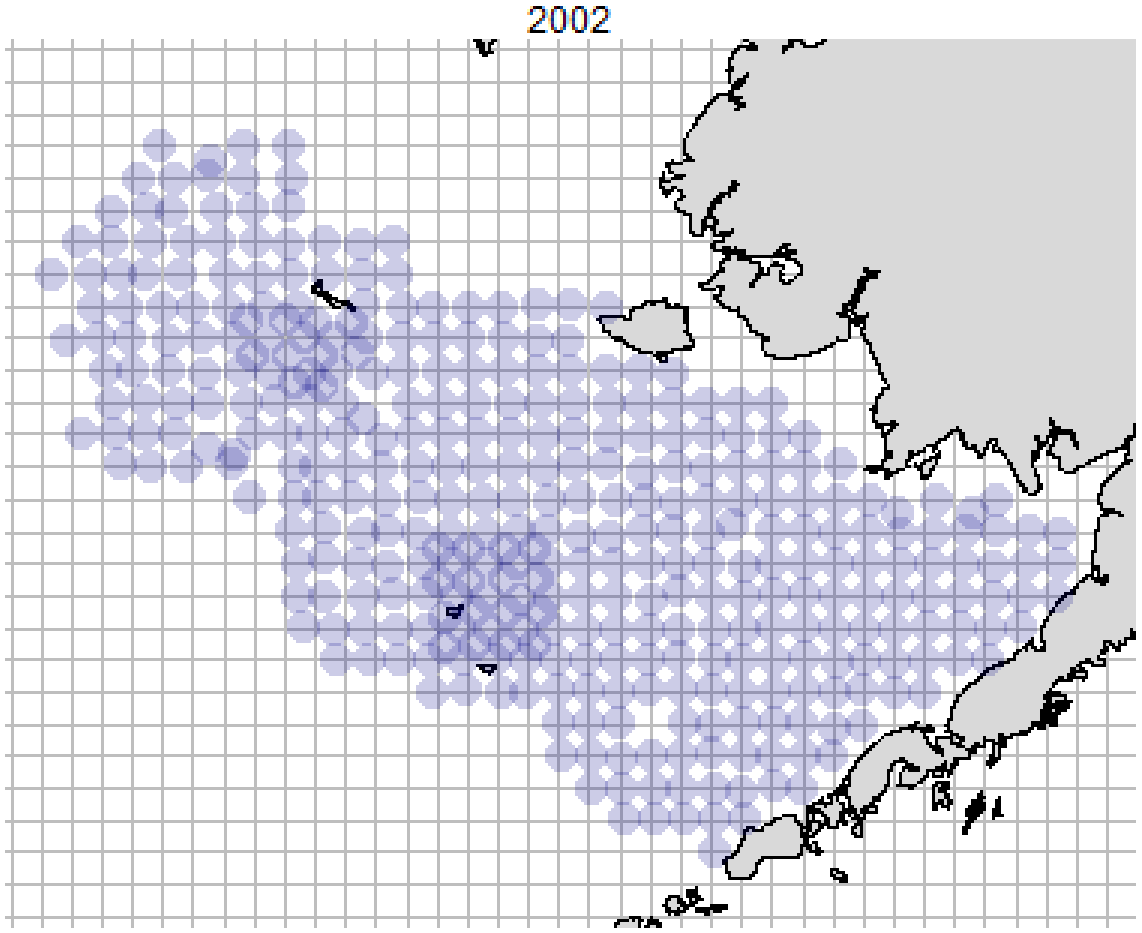
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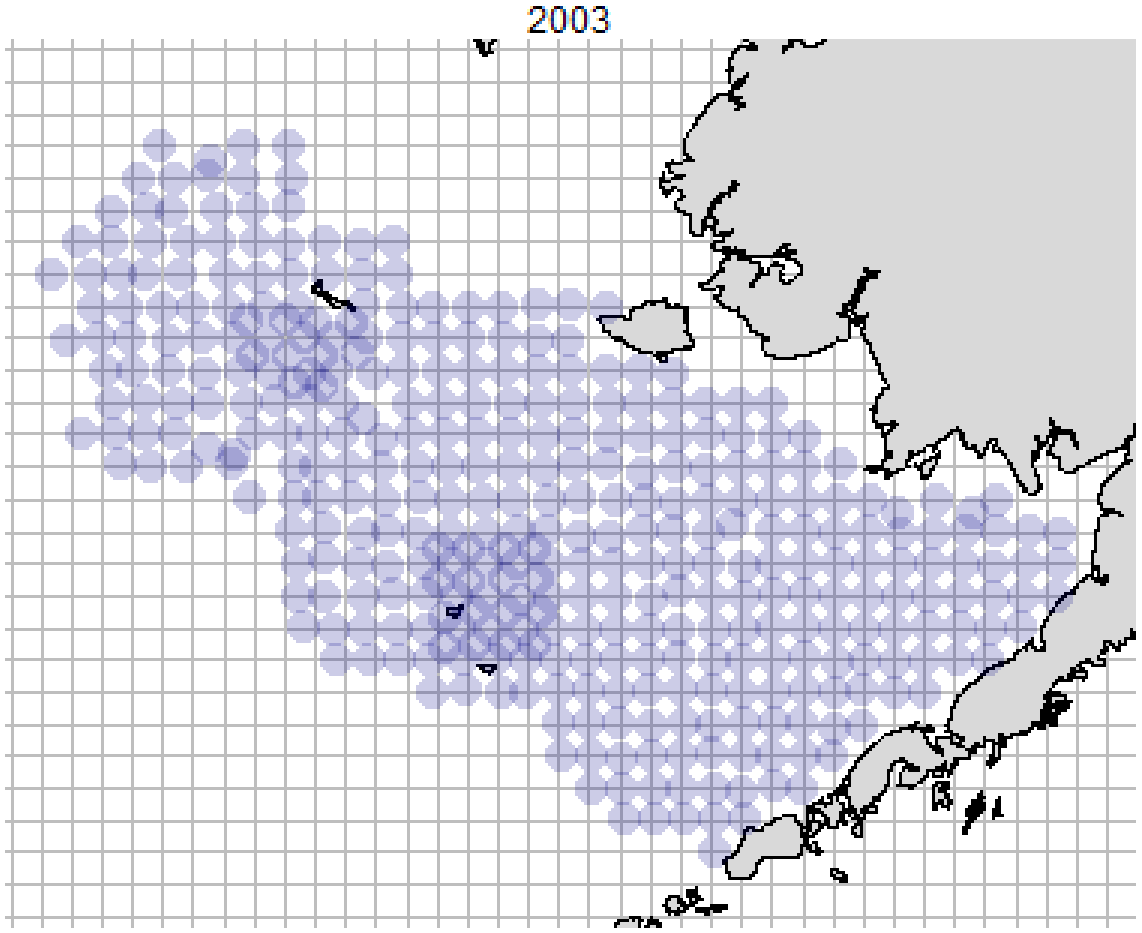
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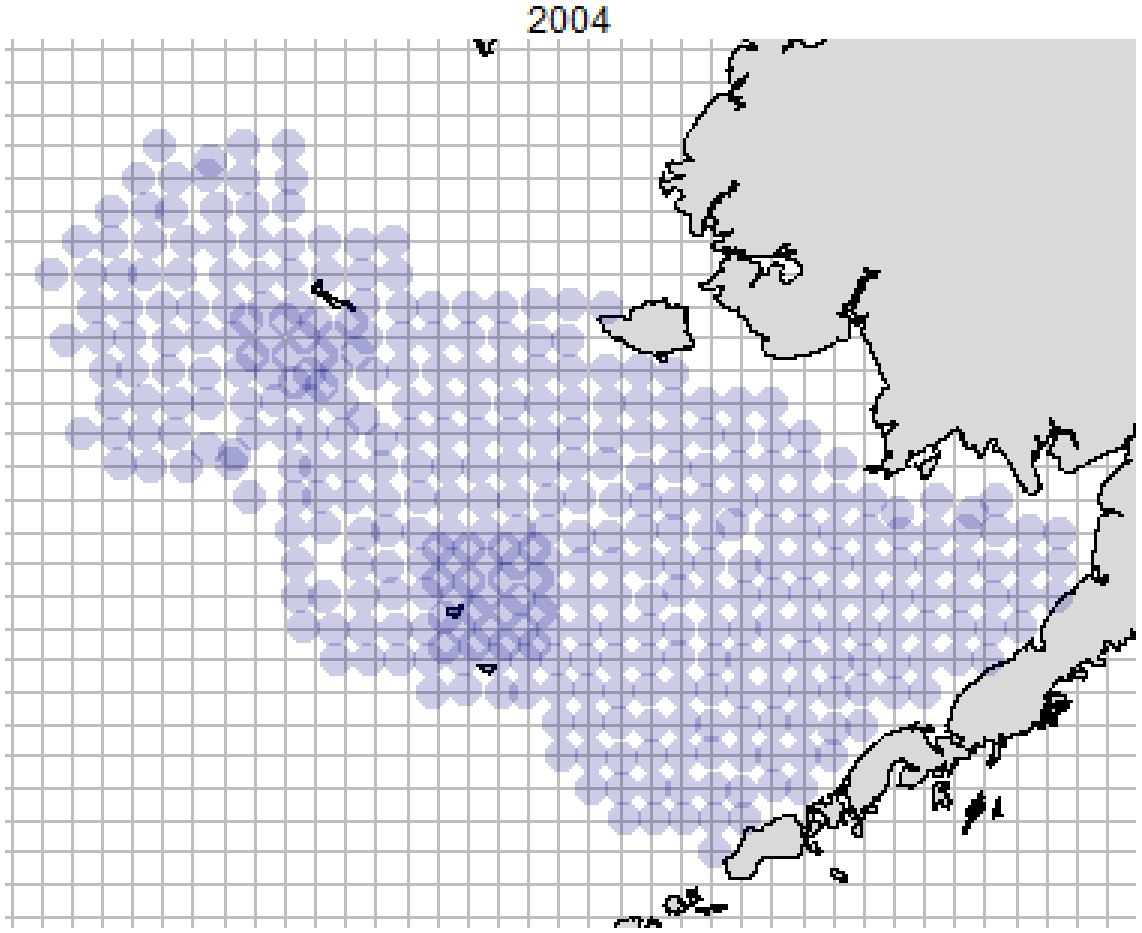
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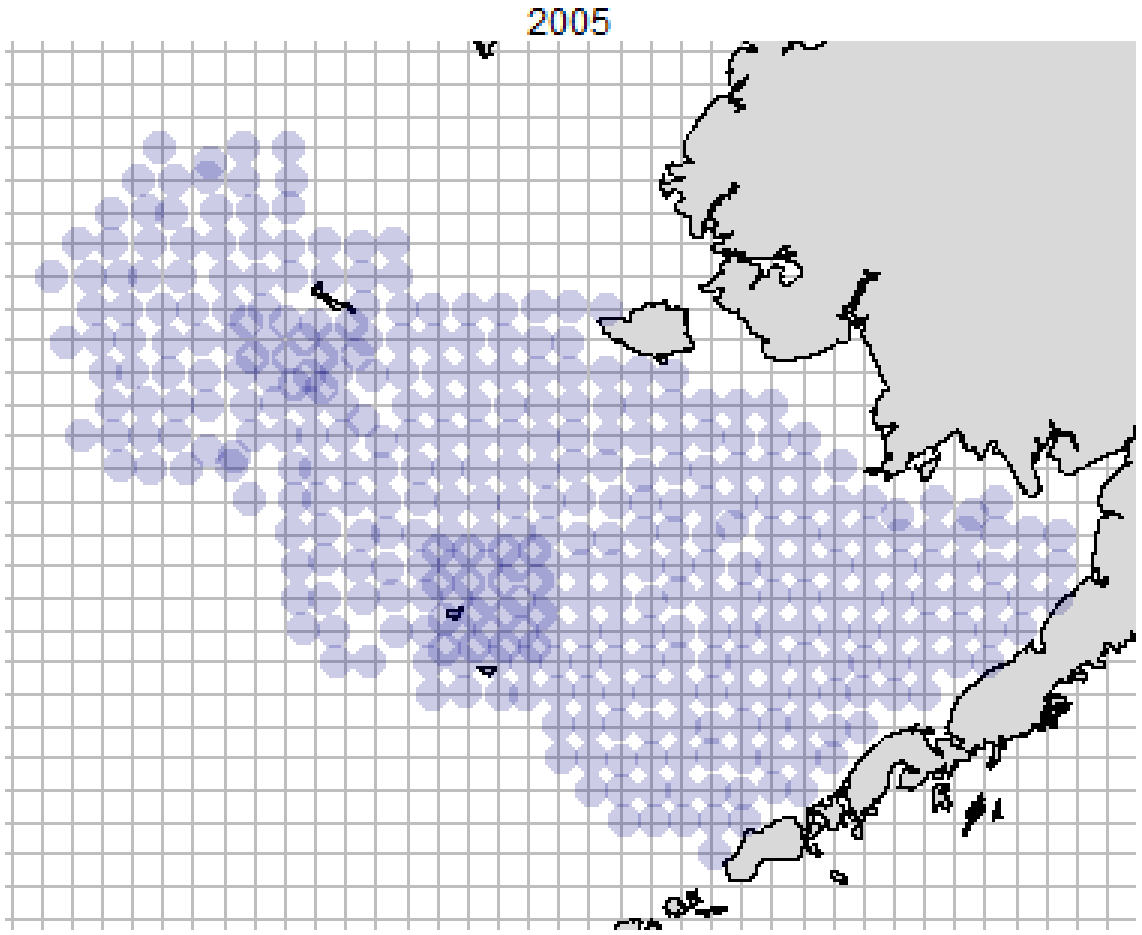
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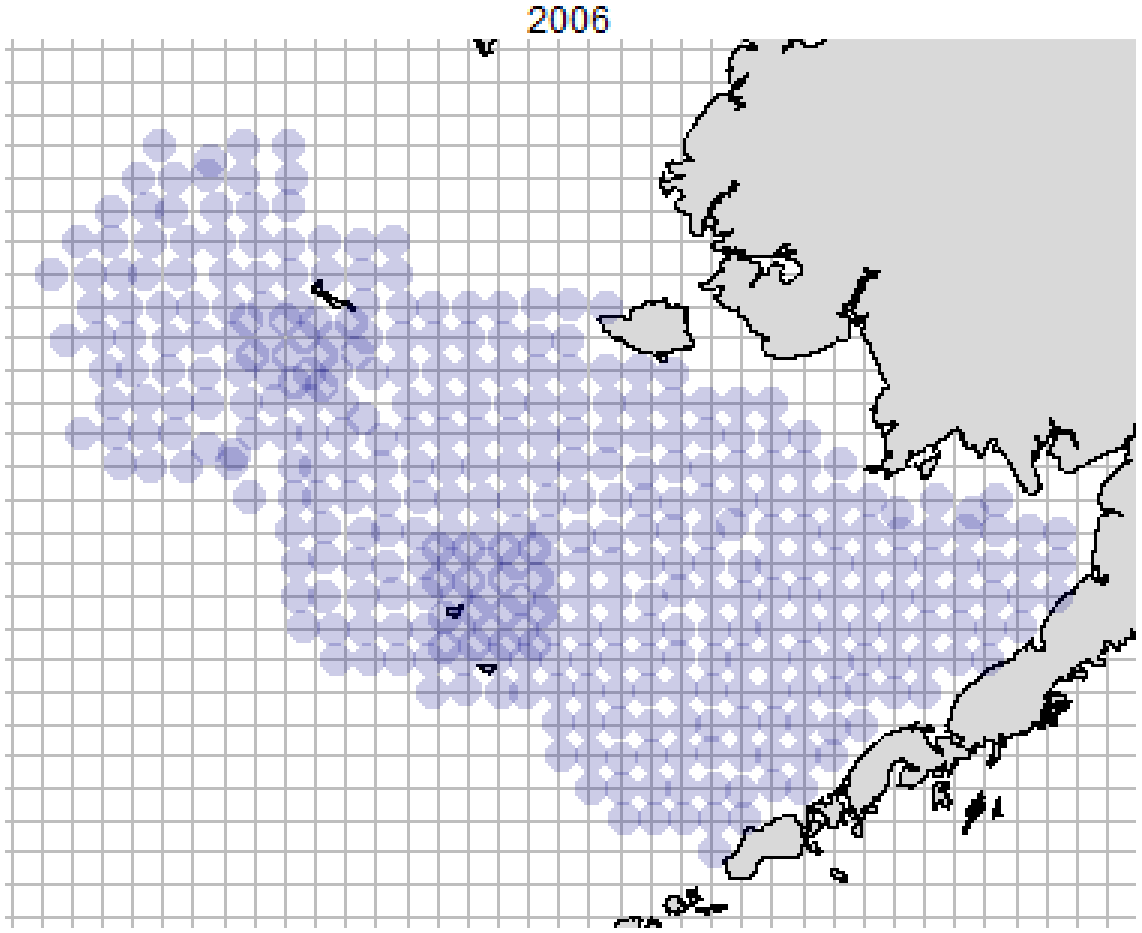
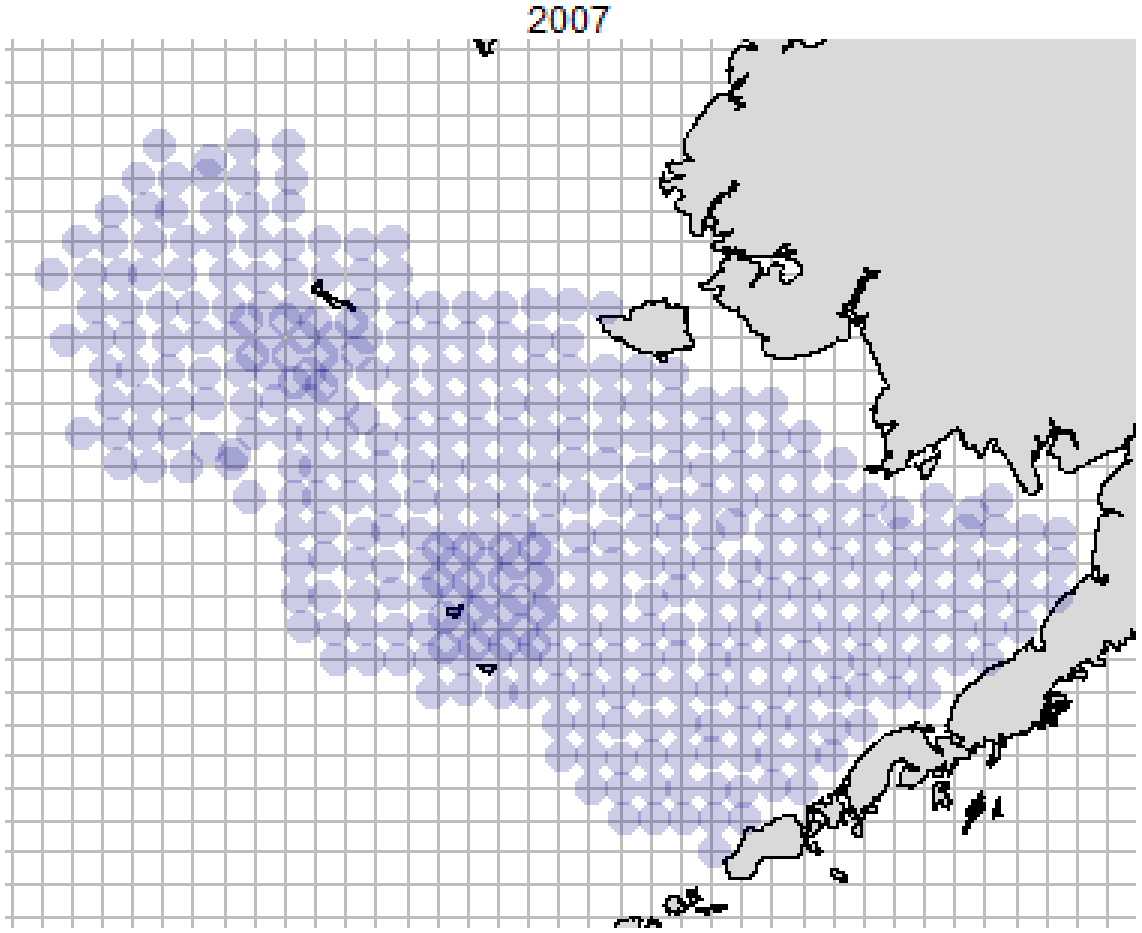
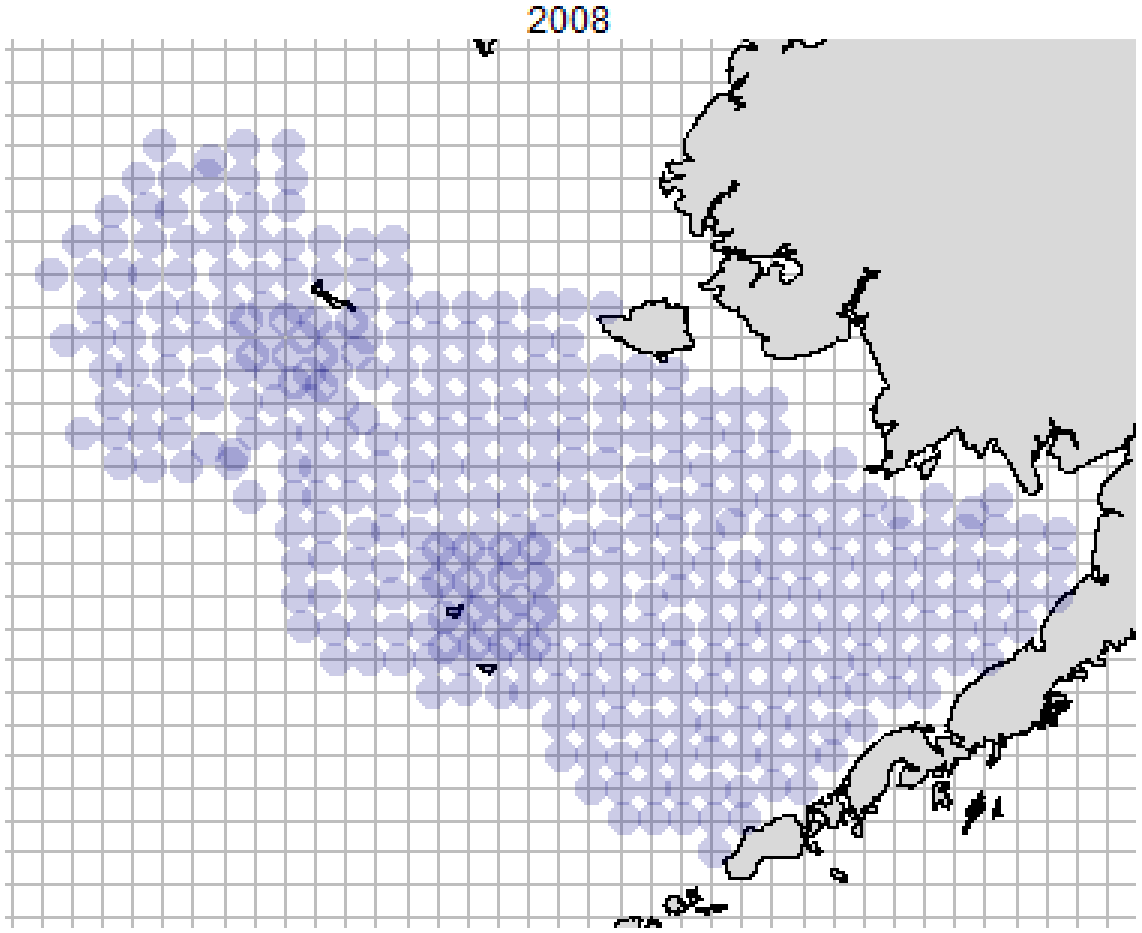
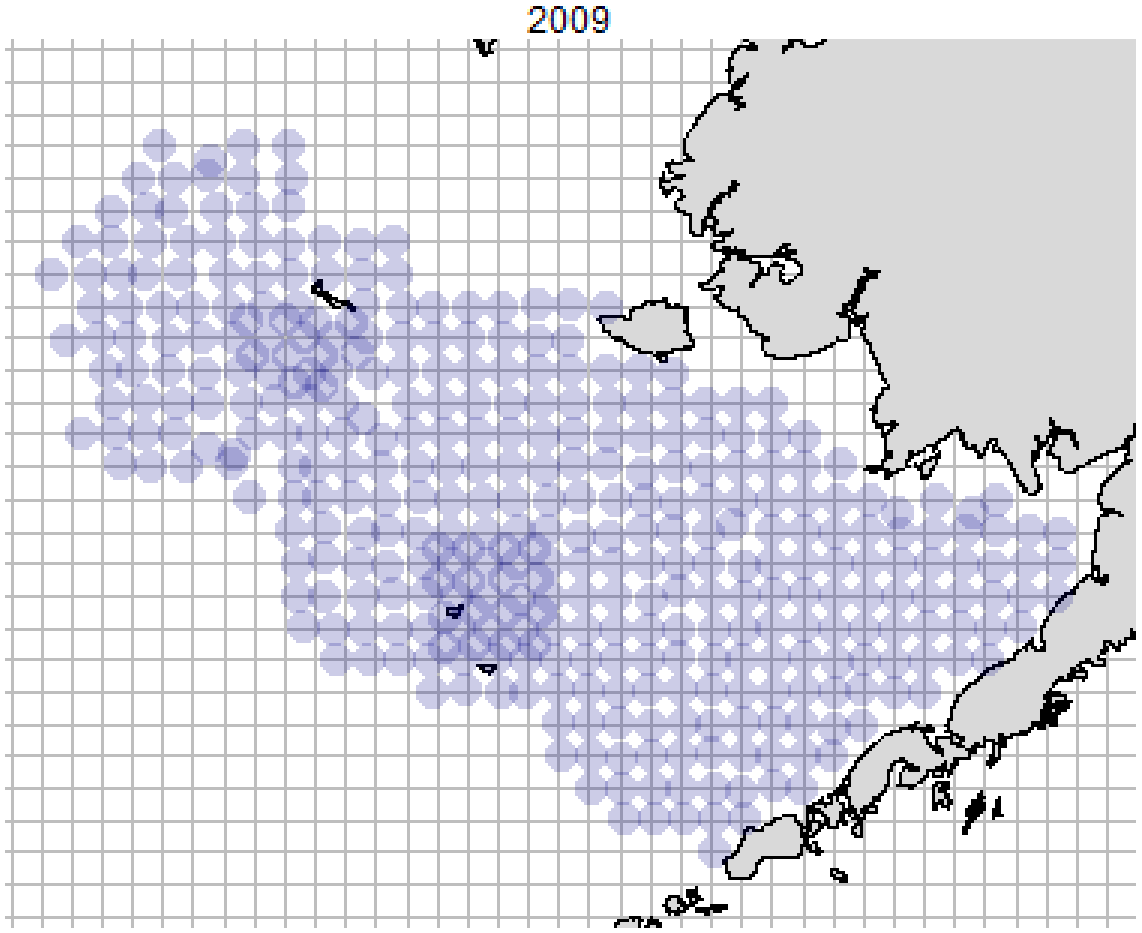
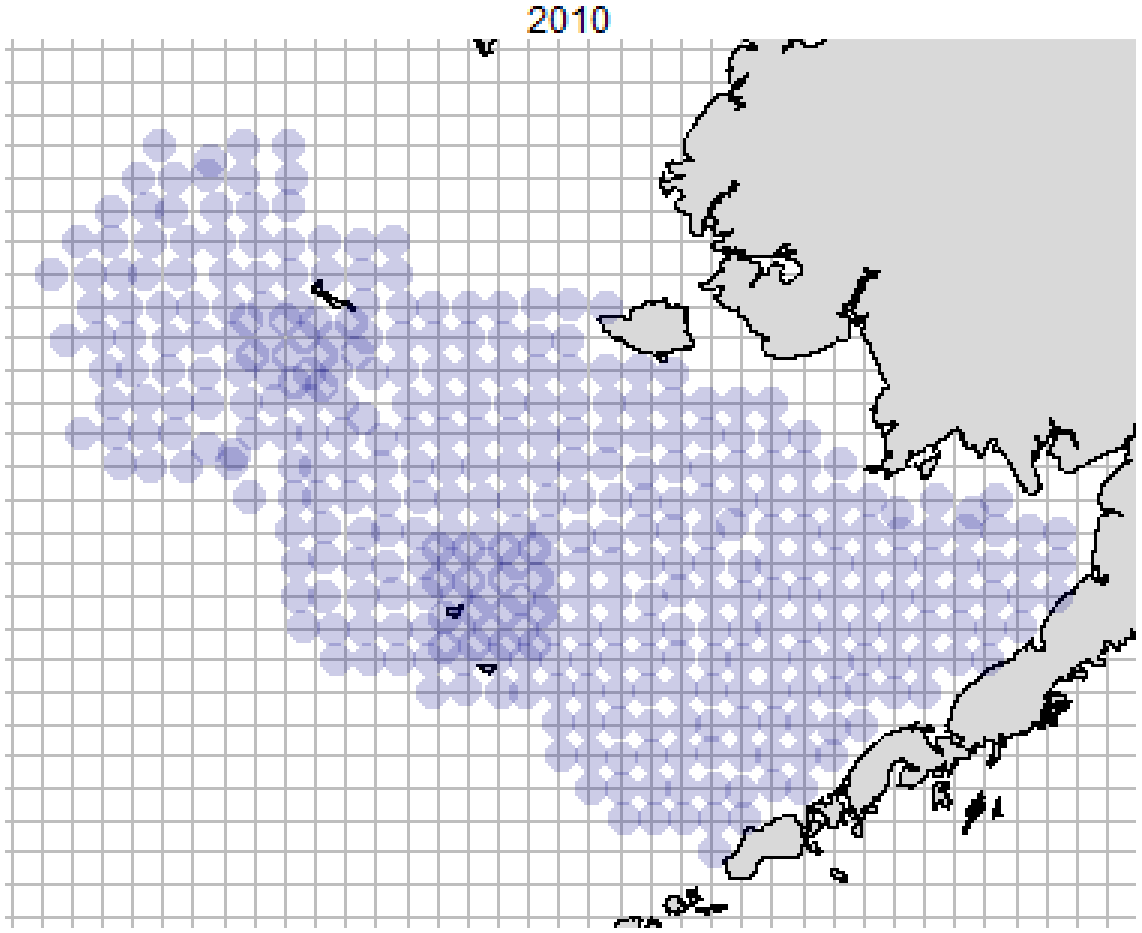
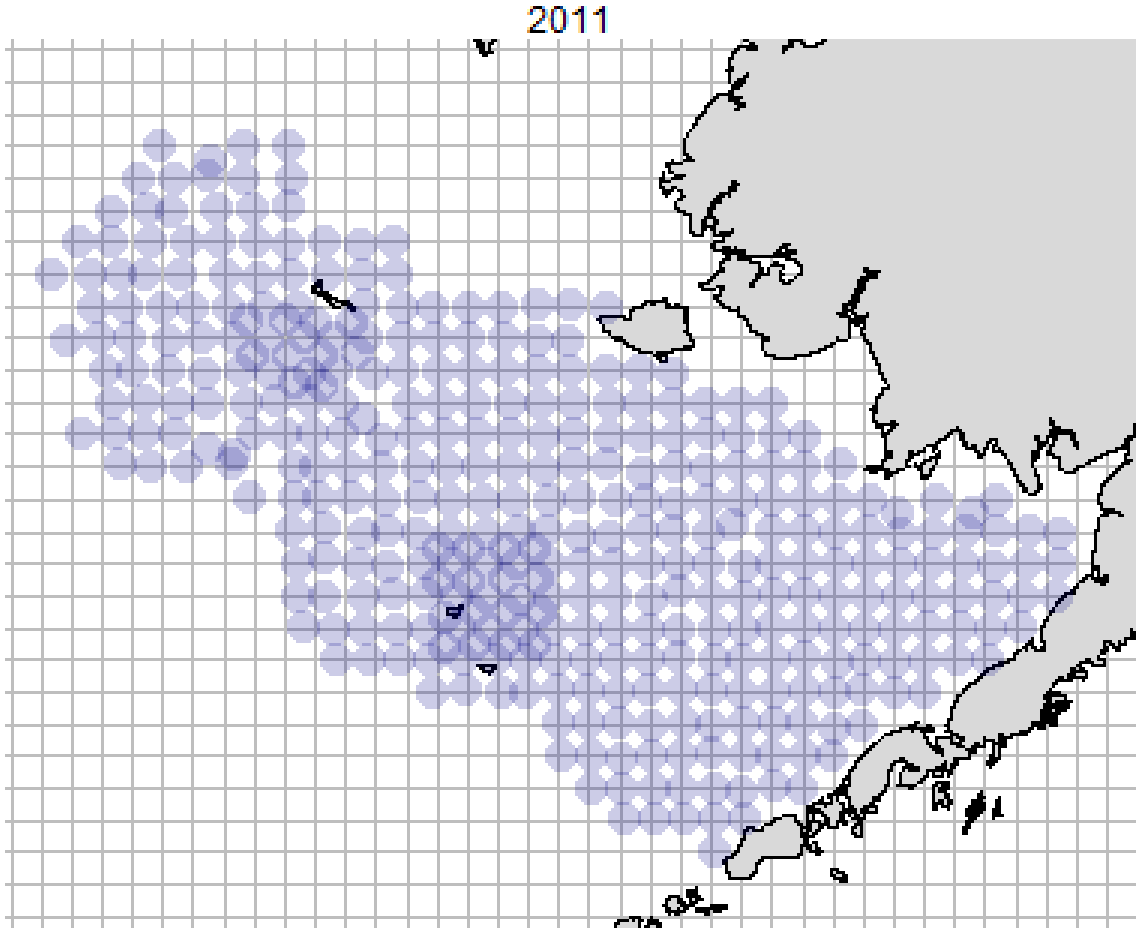

2006

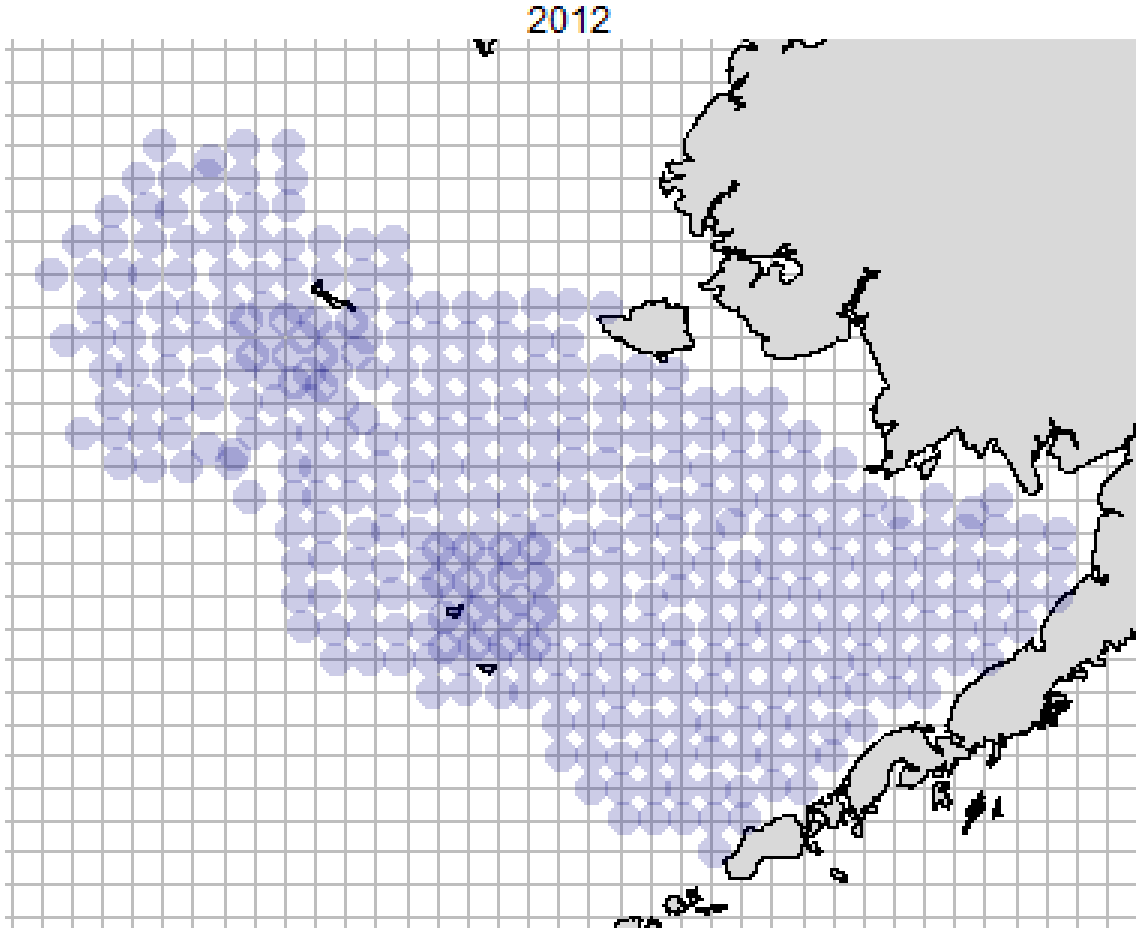

2007

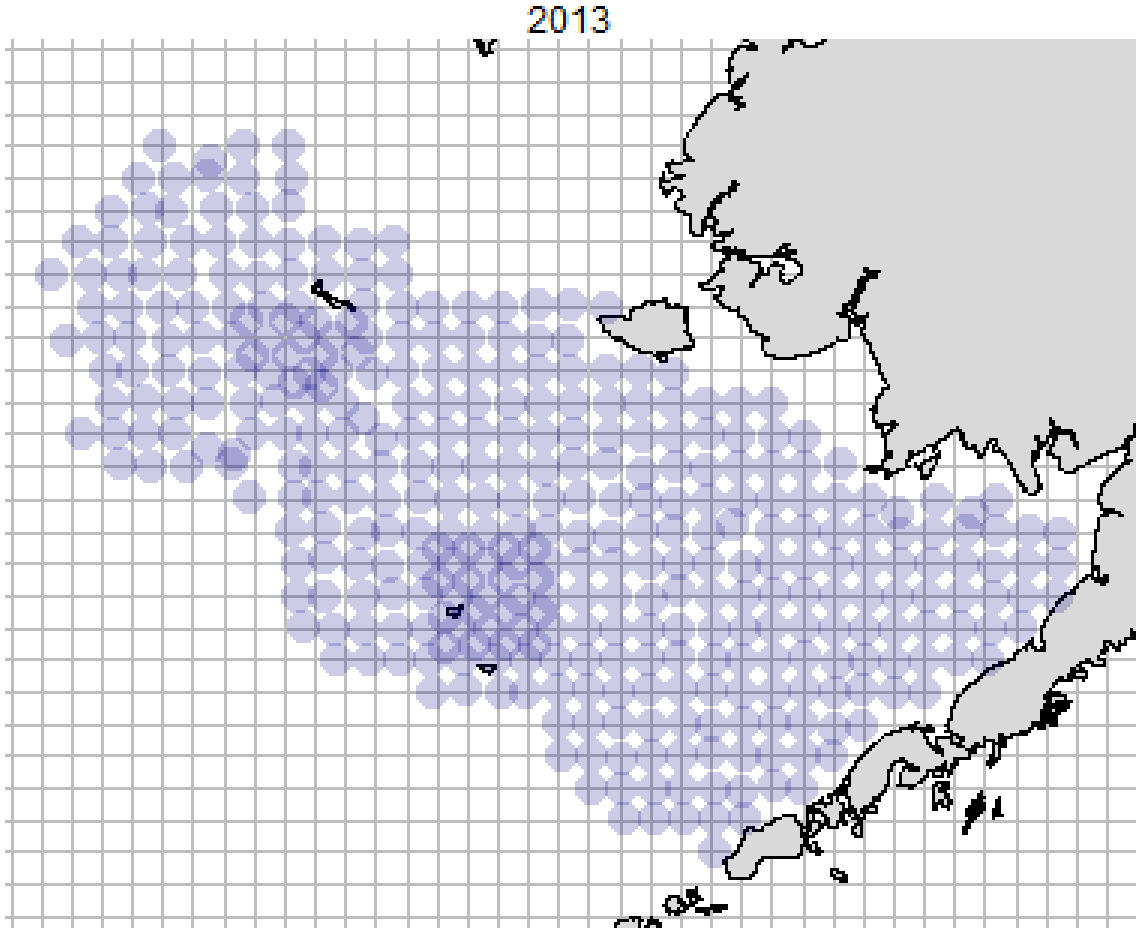

2008

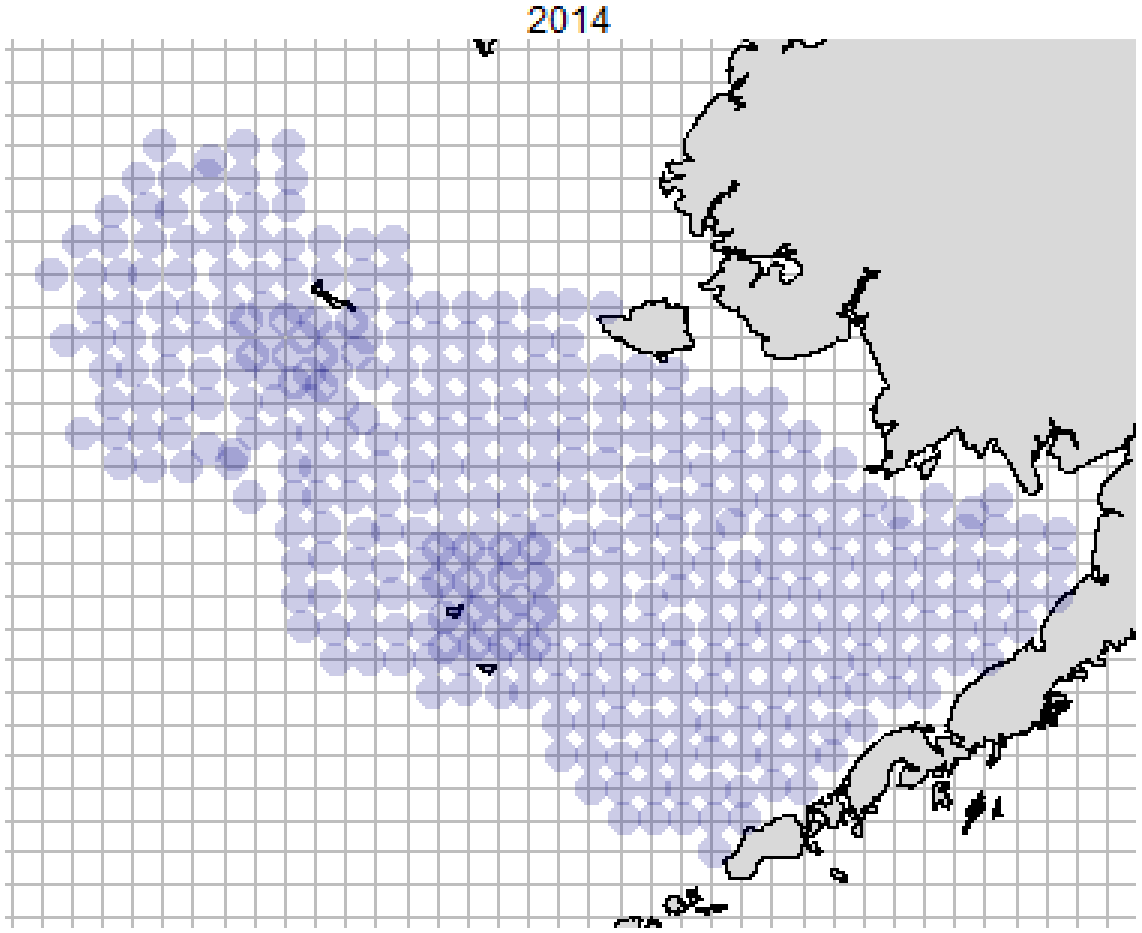

2009

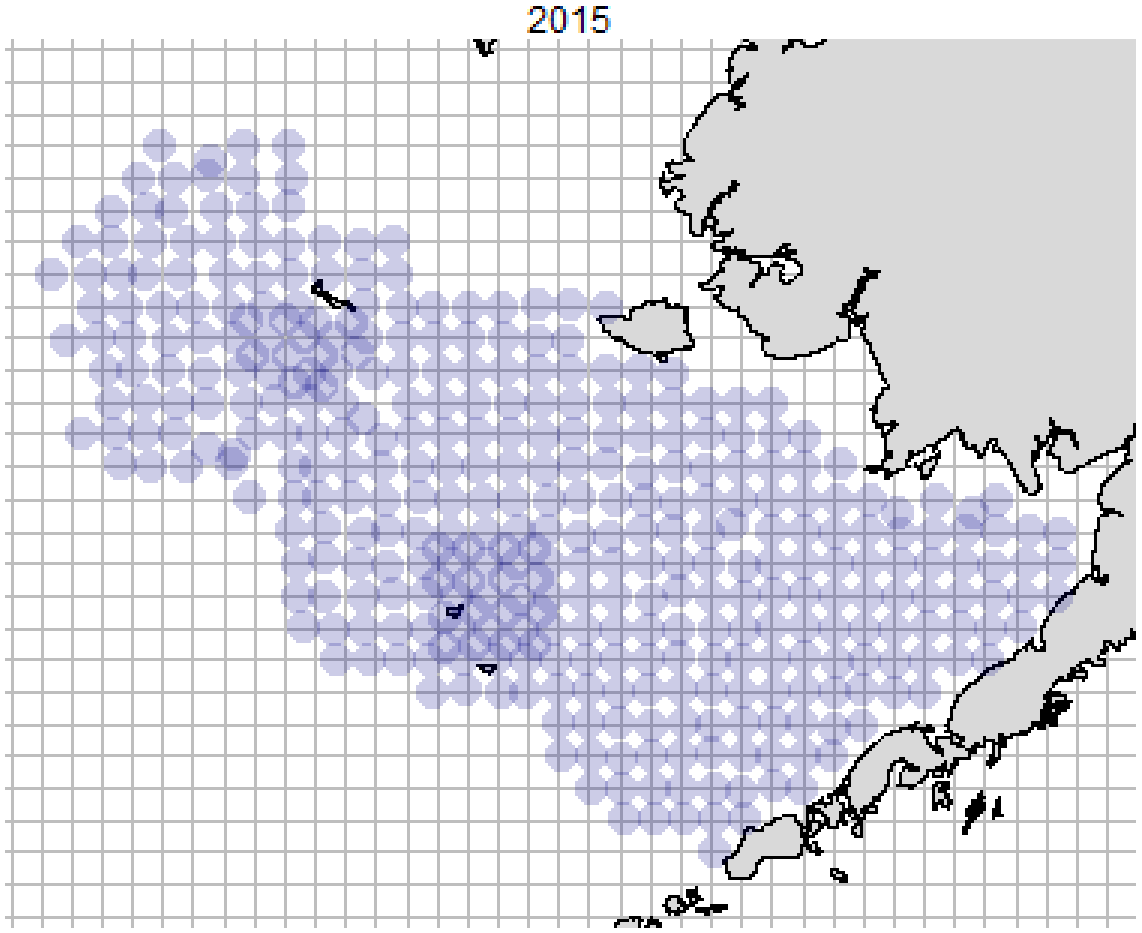

2010

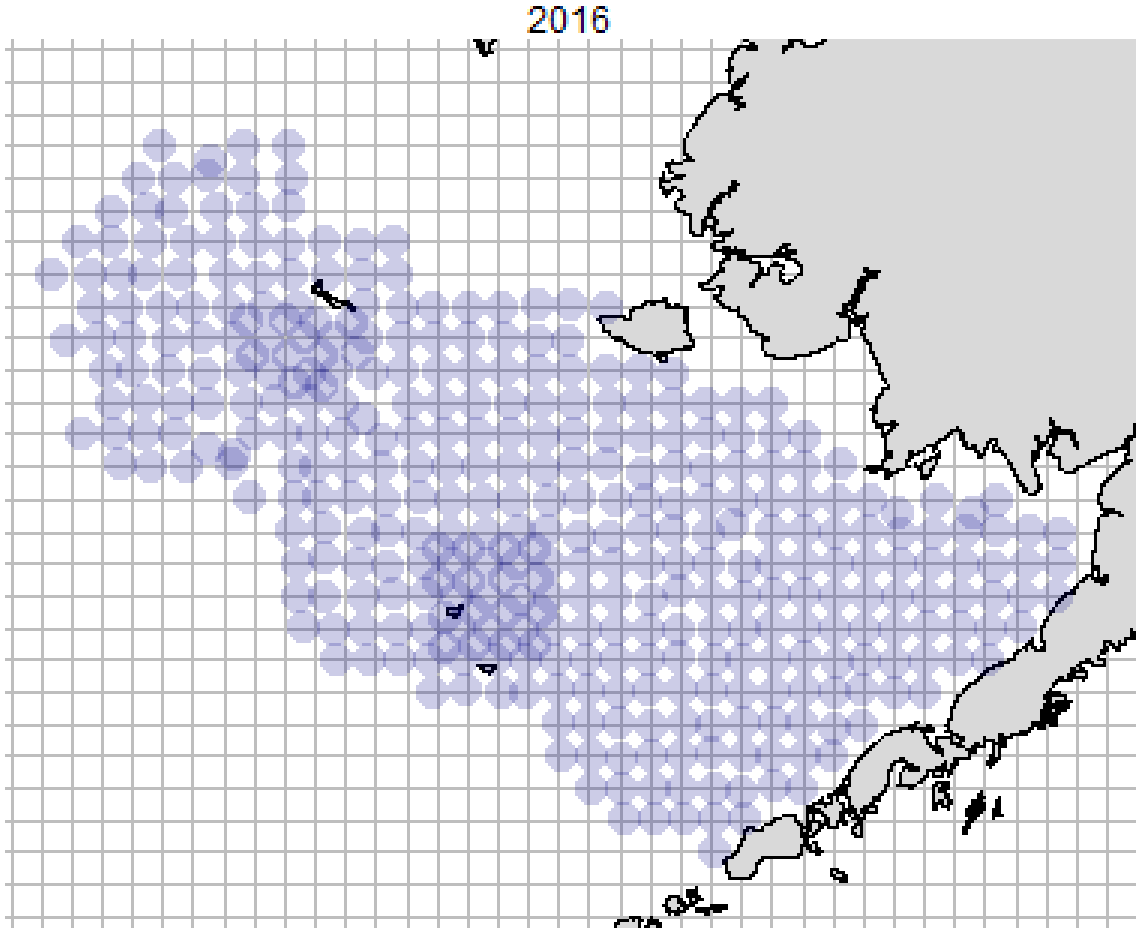

2011

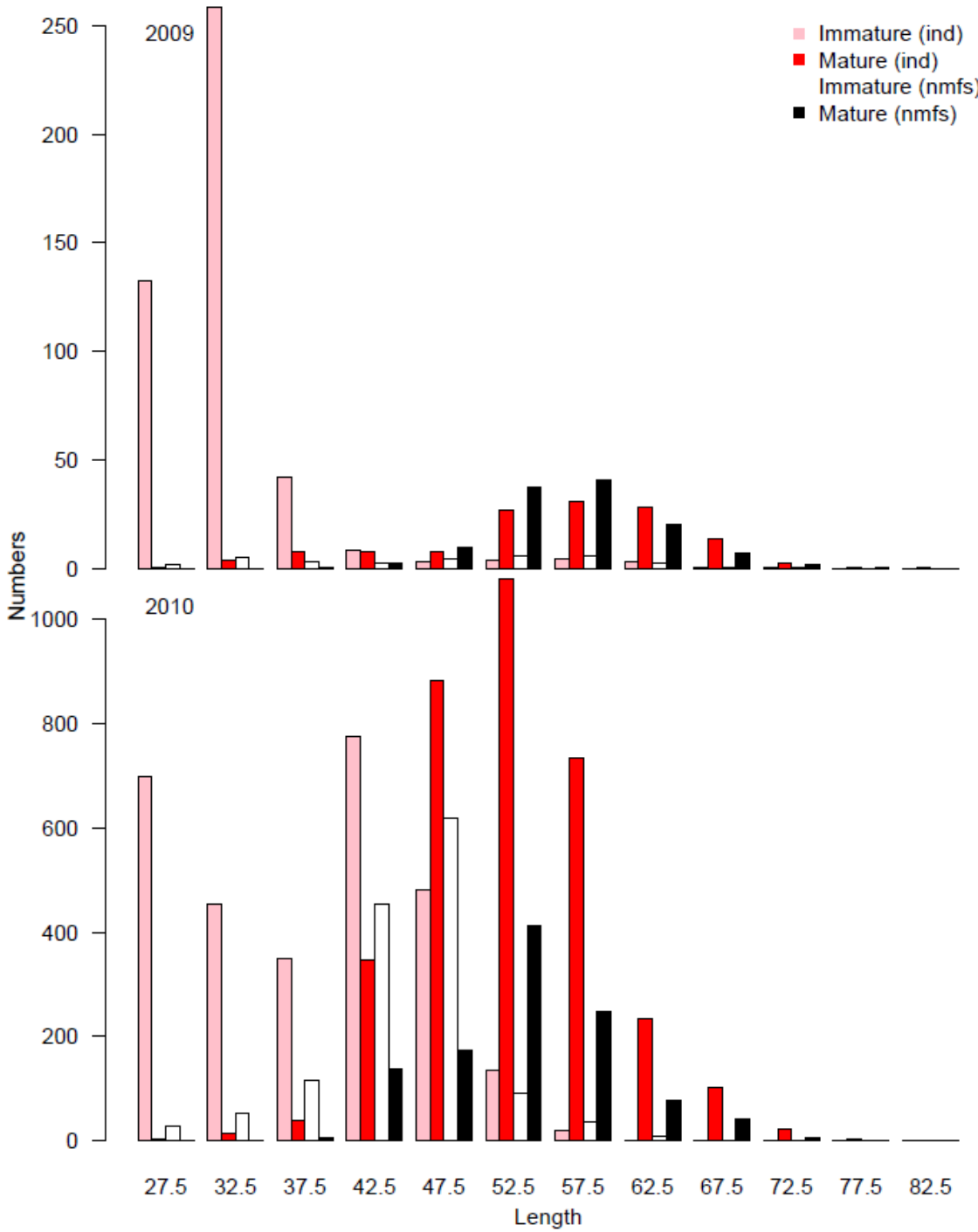

2012

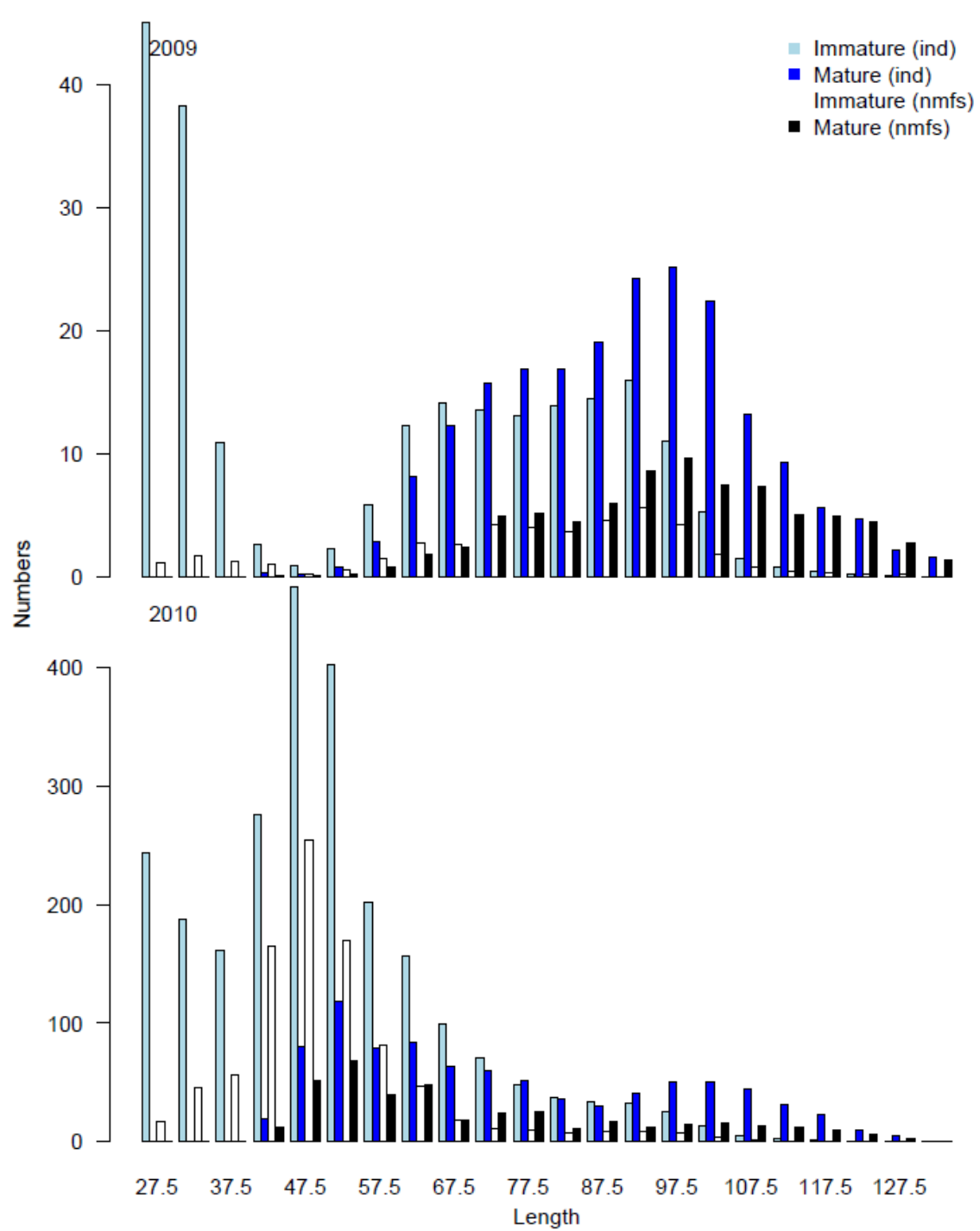

2013

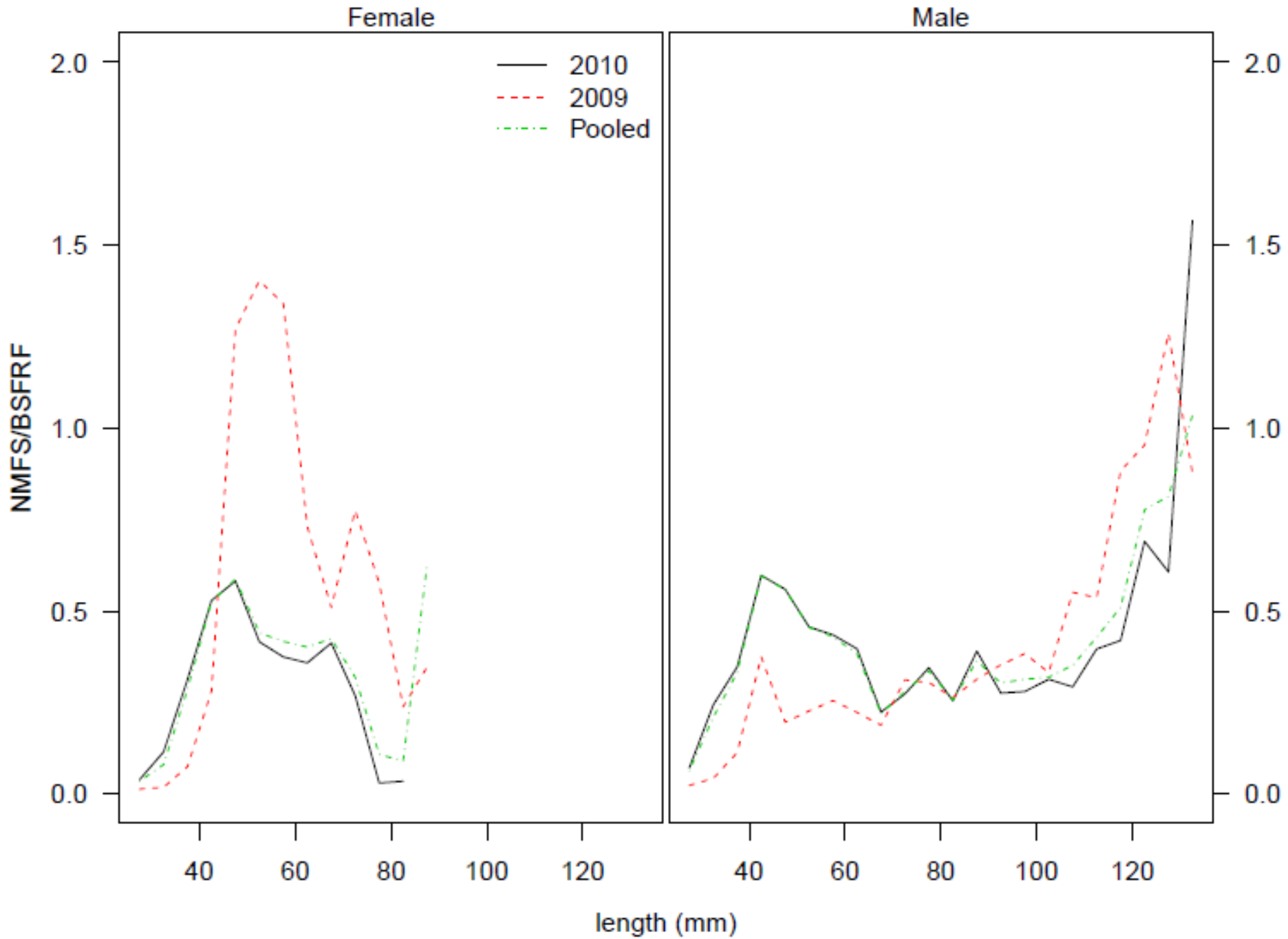

2014


2015


2016

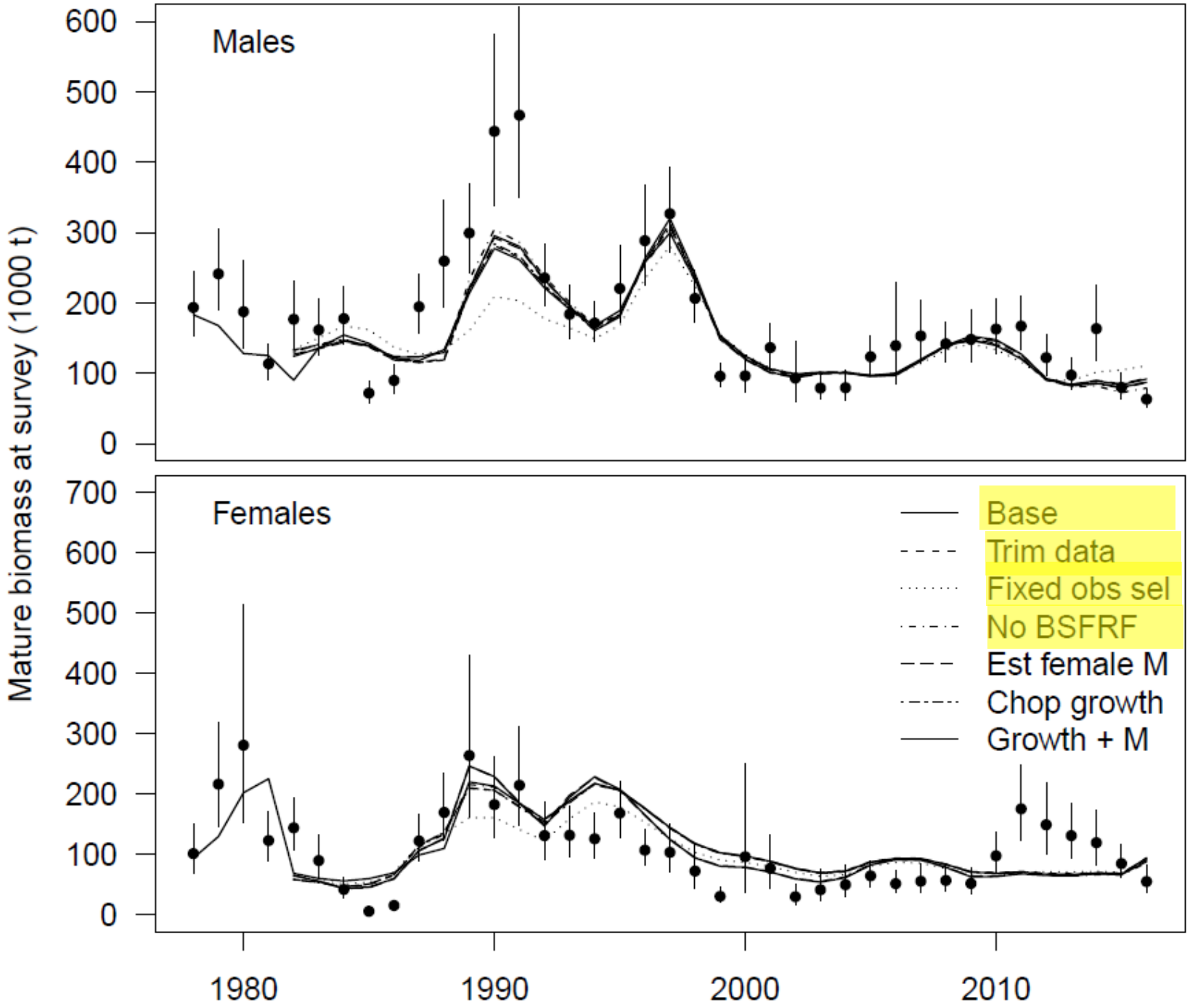

2009
2010
Immature (ind)
Mature (ind)
Immature (nmfs)
Mature (nmfs)
Numbers
Length
0
50
100
150
200
250
200
400
600
800
1000
27.5
32.5
37.5
42.5
47.5
52.5
57.5
62.5
67.5
72.5
77.5
82.5

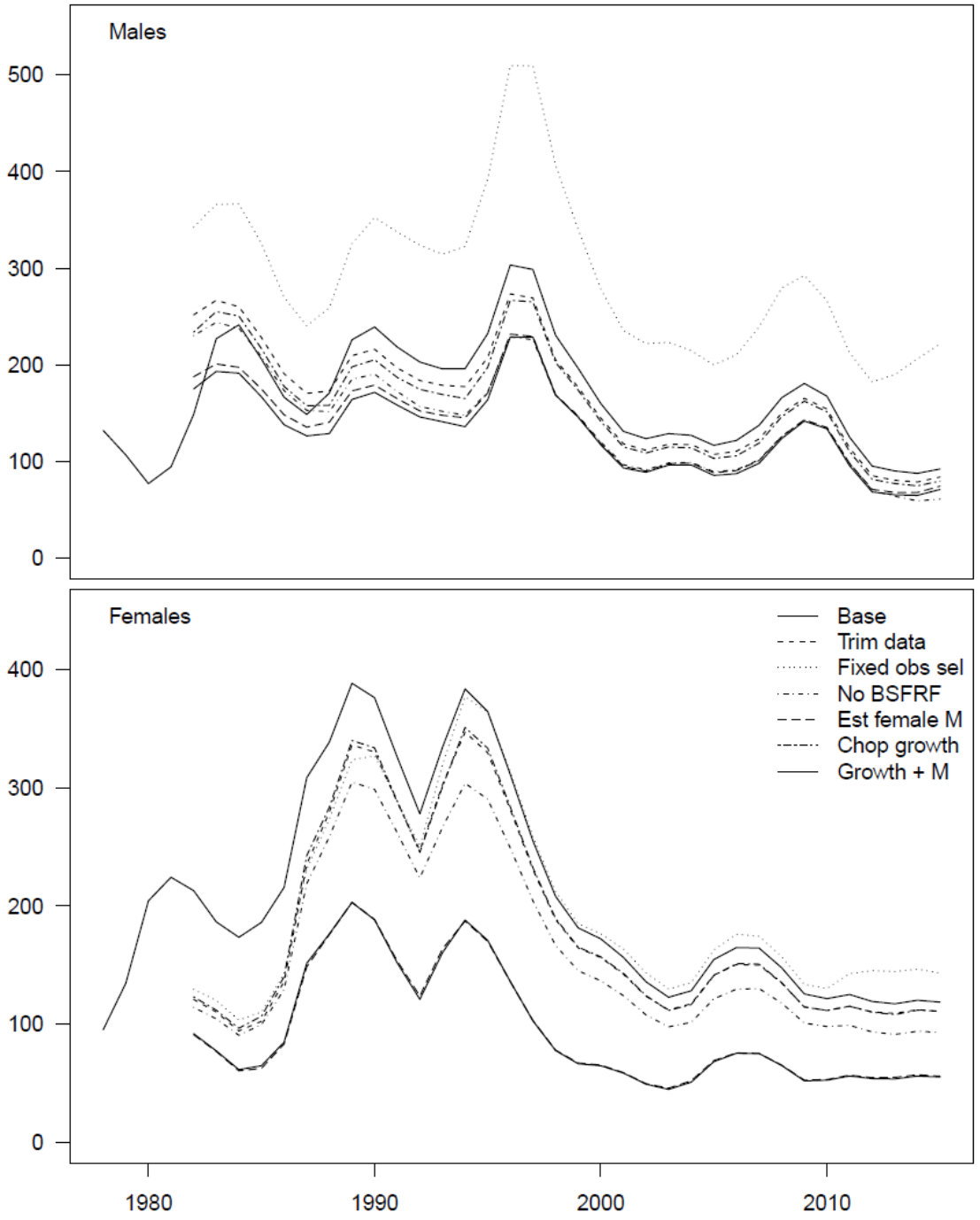

2009
2010
Immature (ind)
Mature (ind)
Immature (nmfs)
Mature (nmfs)
Numbers
Length
0
10
20
30
40
100
200
300
400
27.5
37.5
47.5
57.5
67.5
77.5
87.5
97.5
107.5
117.5
127.5


Female
Male
2010
2009
Pooled
NMFS/BSFRF
length (mm)
0.0
0.5
1.0
1.5
2.0
40
60
80
100
120

Model runs

- ‘Trim data’
  - Excludes all data from 1978-1981, start model in 1982
  - Explores problem of anchoring of q and bound hitting parameters
- ‘Fixed obs sel’
  - ‘Trim data’ + fixing survey selectivity in era 2 and era 3 to selectivity inferred from BSFRF data
  - Explores implications of BSFRF data
- ‘No BSFRF’
  - ‘Trim data’ + setting the weights for the BSFRF likelihood components to 0
  - Explores the impact of the BSFRF data on model output


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
Base
Trim data
Fixed obs sel
No BSFRF
Est female M
Chop growth
Growth + M



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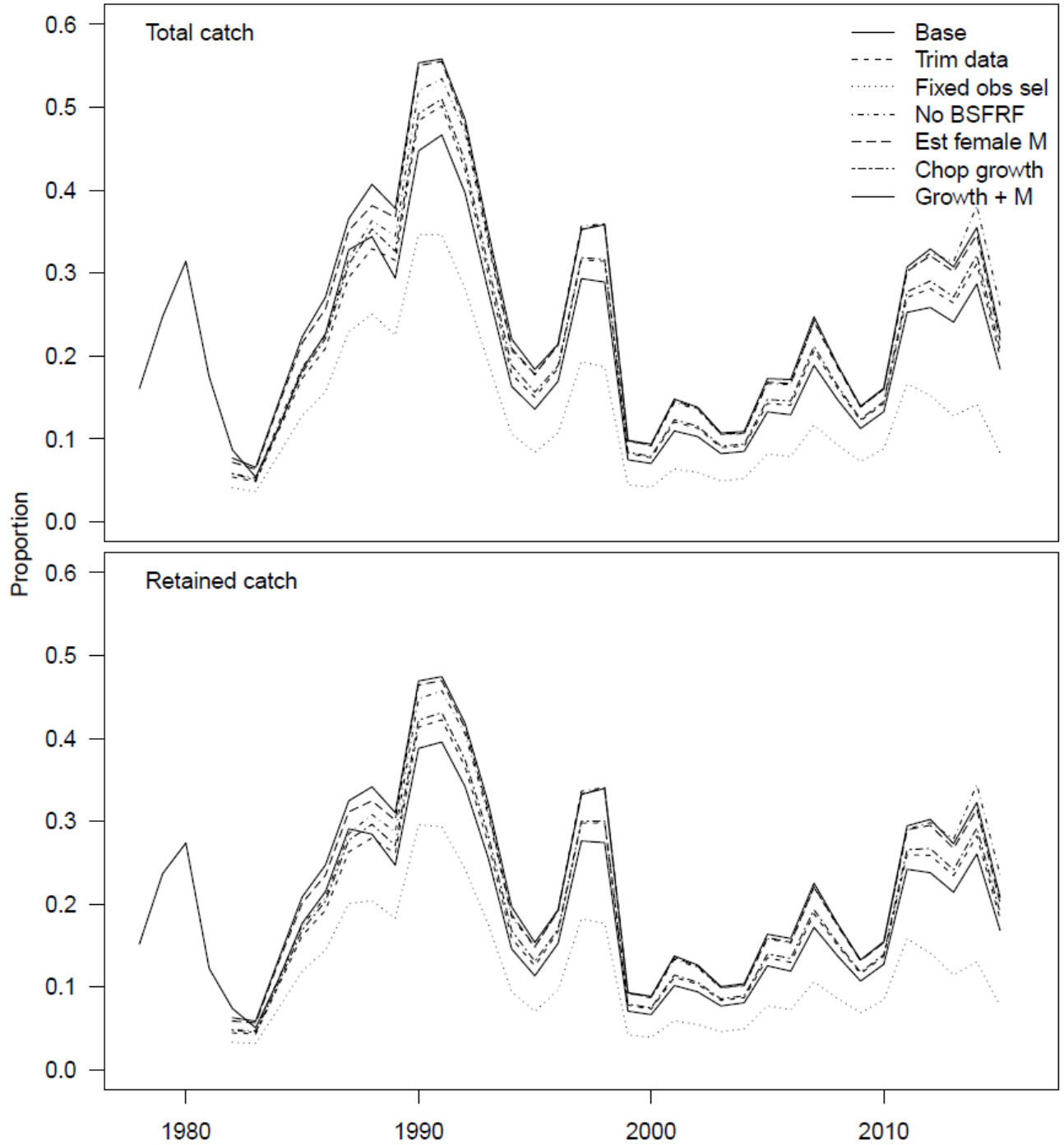
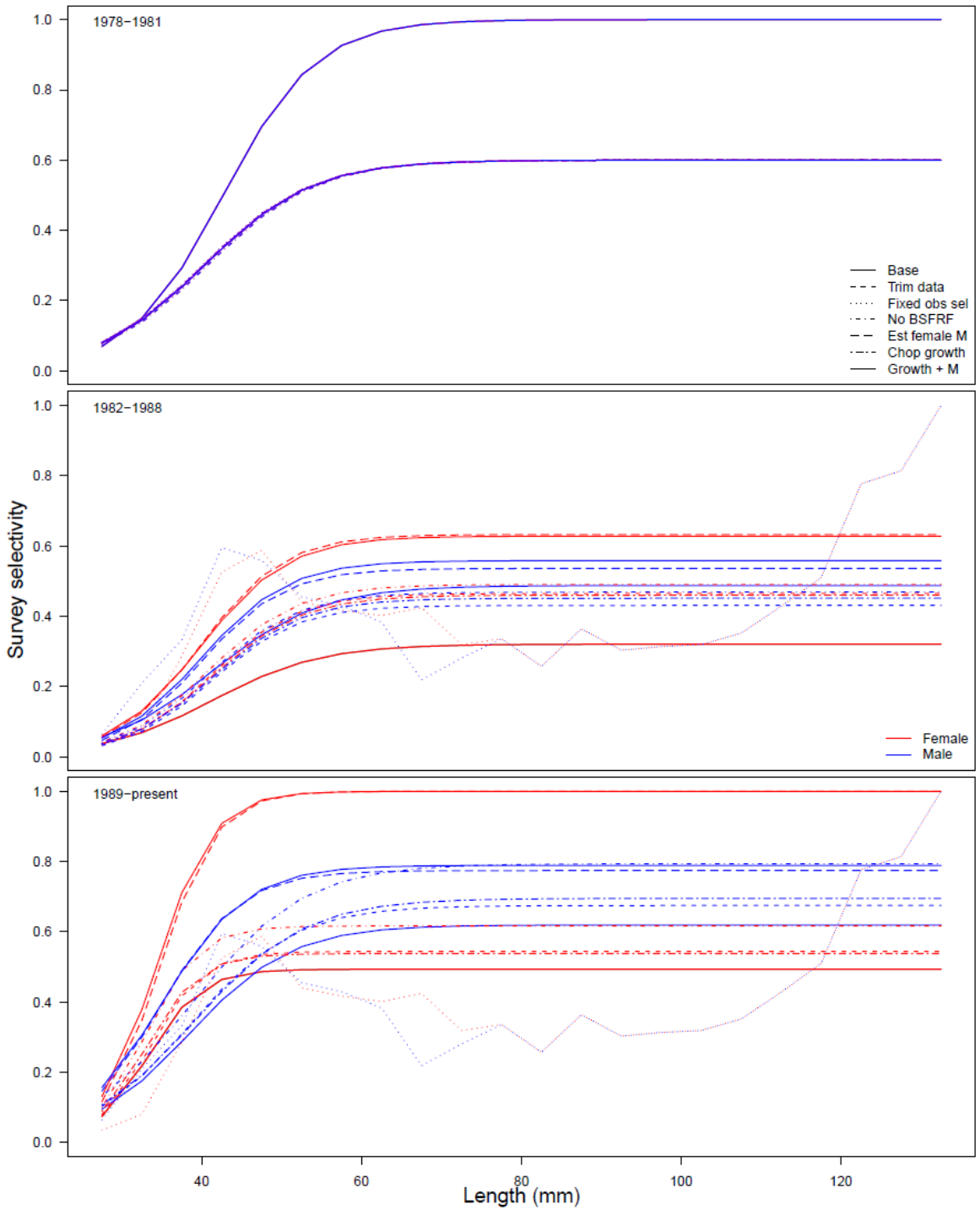
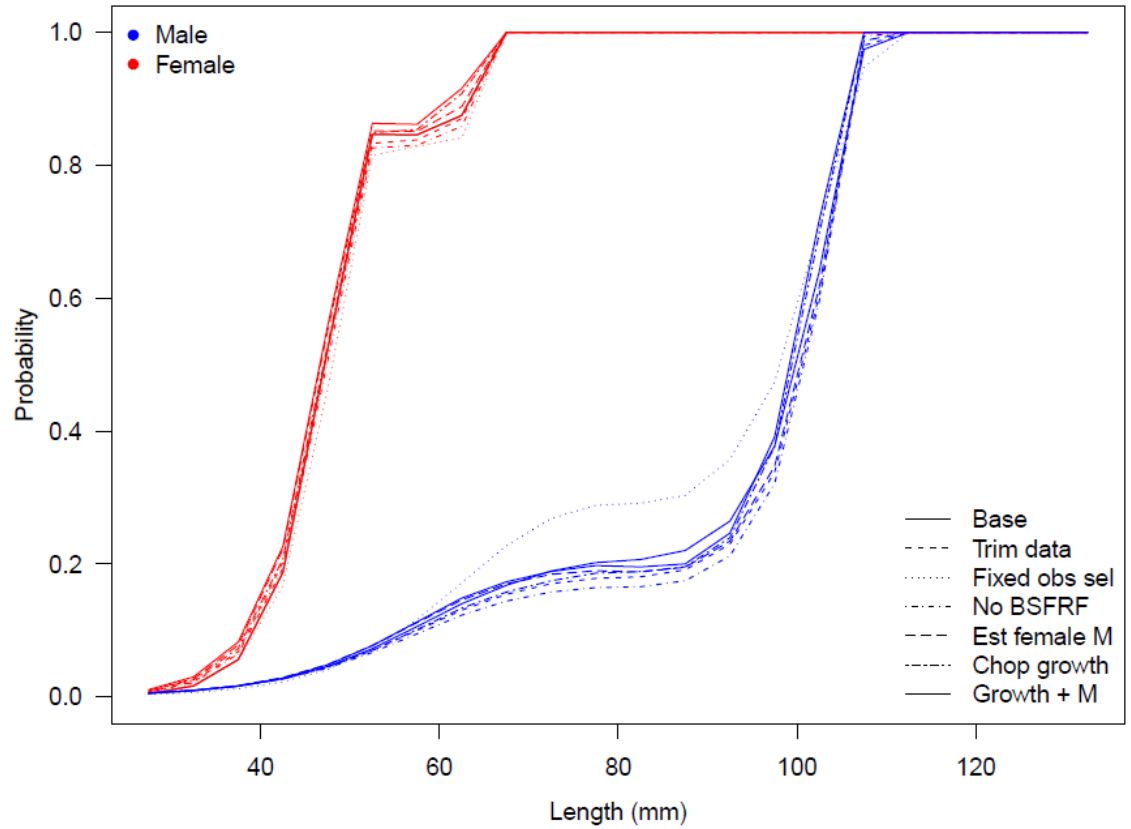
Fixed obs sel	221.6	215.3	3.49	2.62	82.68
No BSFRF	60.86	142.3	1.17	0.56	11.5
Est female M	74.29	139.6	1.21	0.68	18.38
Chop growth	79.57	149.8	1.34	0.75	18.66
Growth + M	70.89	137.4	1.17	0.64	17.35

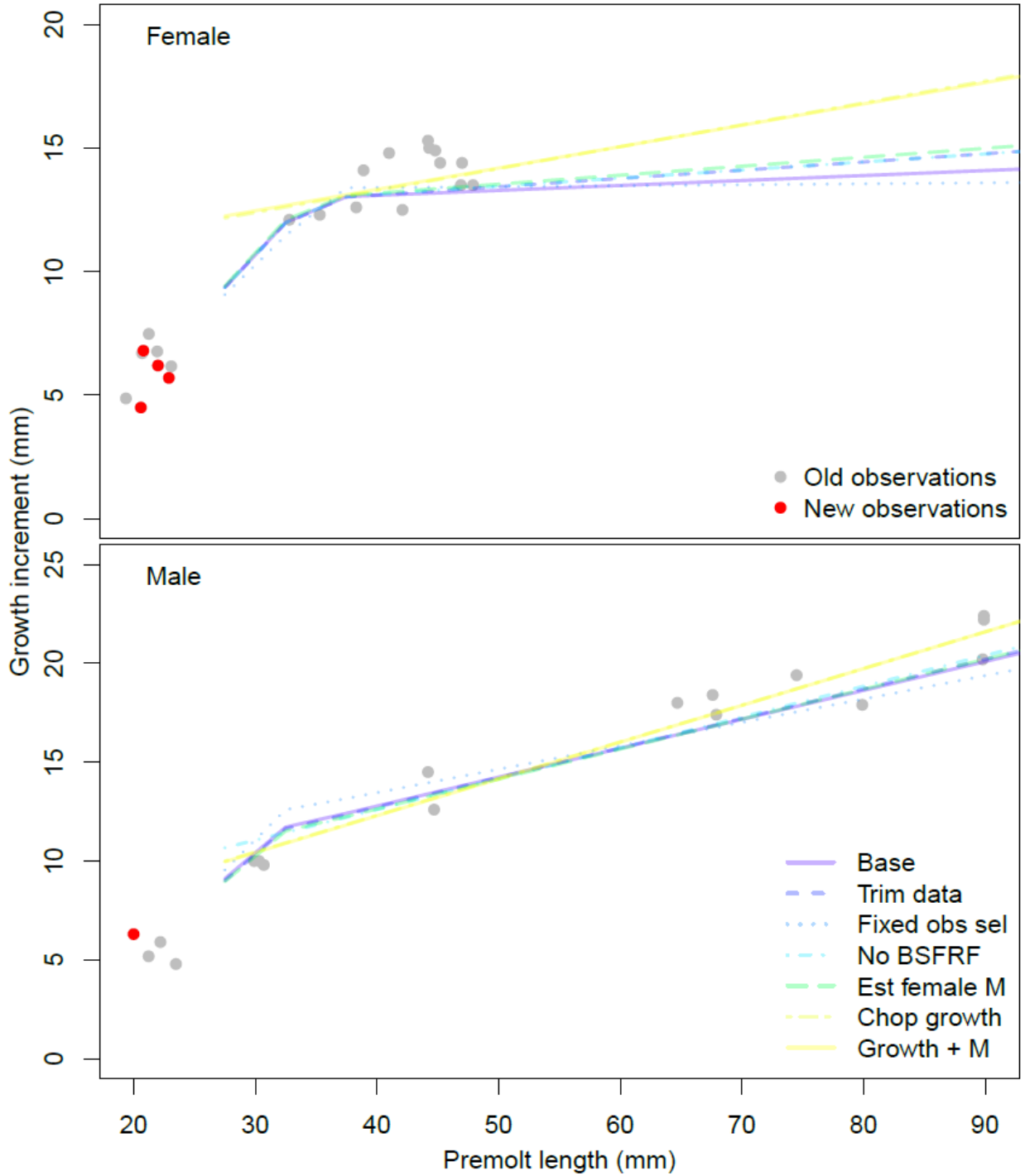

Total catch
Retained catch
Base
Trim data
Fixed obs sel
No BSFRF
Est female M
Chop growth
Growth + M
Proportion
0.0
0.1
0.2
0.3
0.4
0.5
0.6
1980
1990
2000
2010


1978–1981
1982–1988
1989–present
Survey selectivity
Length (mm)
Base
Trim data
Fixed obs sel
No BSFRF
Est female M
Chop growth
Growth + M
Female
Male

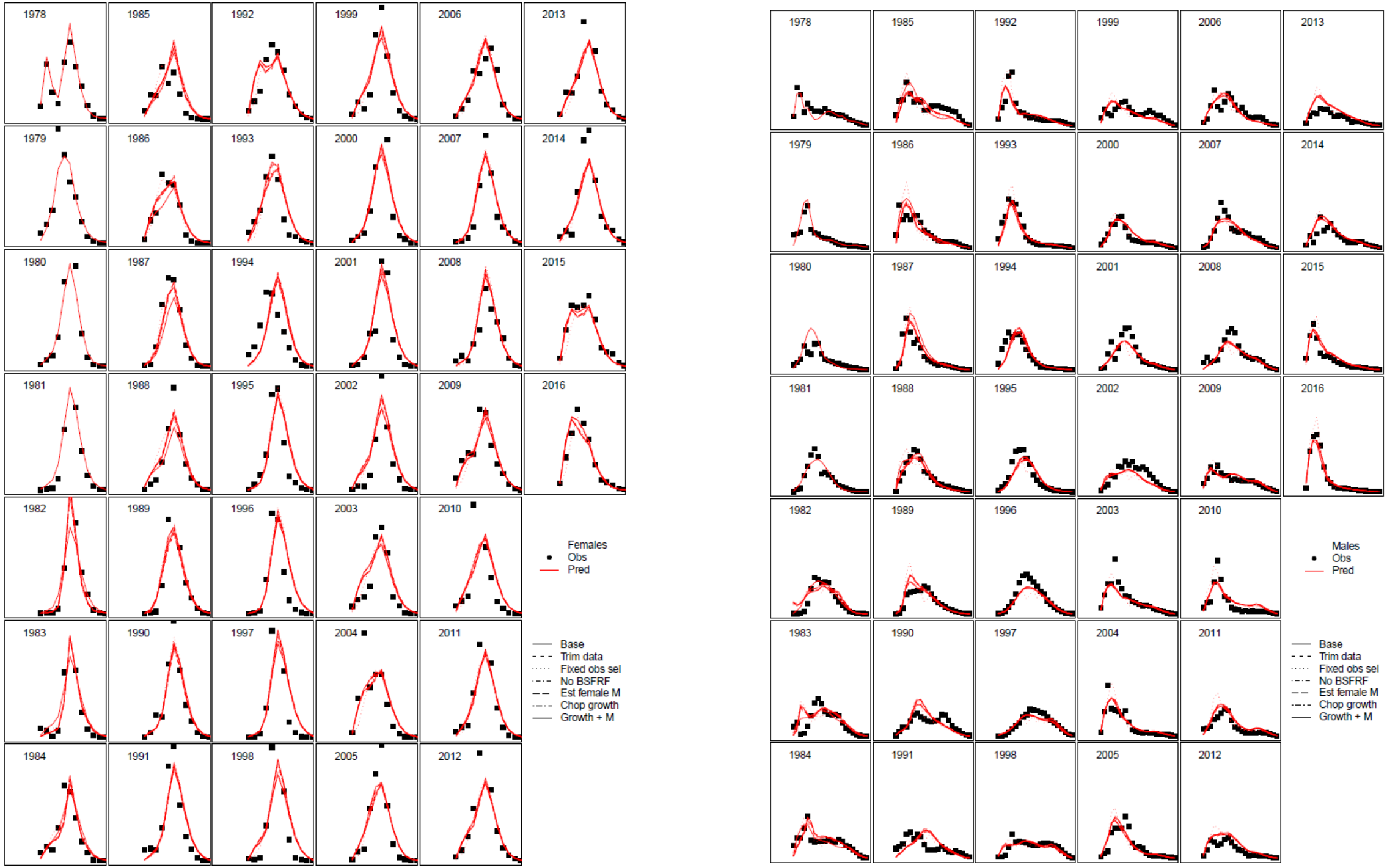

Male
Female
Probability
Length (mm)
Base
Trim data
Fixed obs sel
No BSFRF
Est female M
Chop growth
Growth + M

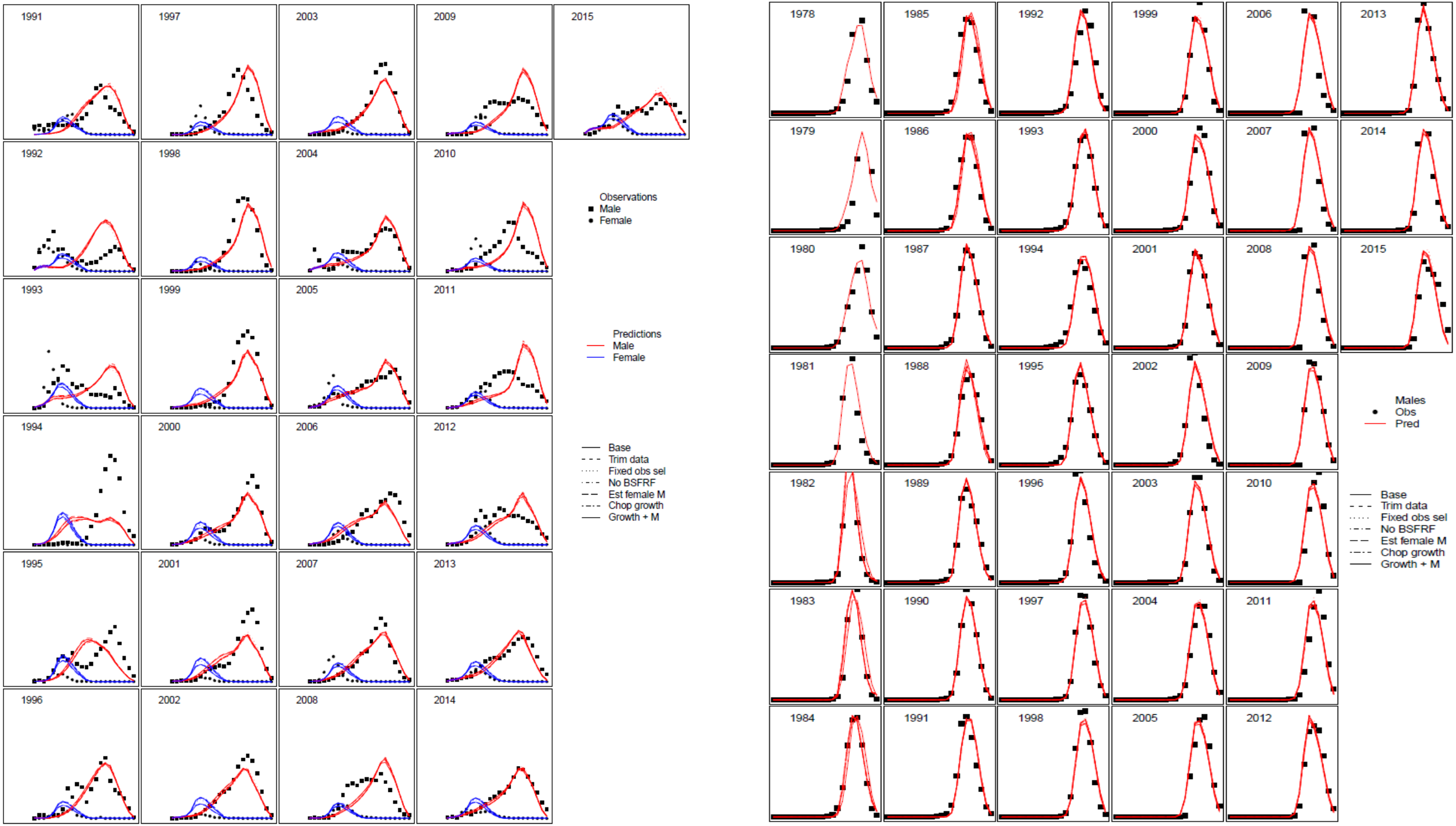
Parameter	Base	Trim data	Fixed obs sel	No BSFRF	Est female M	Chop growth	Growth + M
srv1_q	1	0.6	0.6	0.6	0.6	0.6	0.6
srv1_q_f	1	0.6	0.6	0.6	0.6	0.6	0.6
srv1_sel95	59.89	60.19	60	60.74	60.21	60.34	60.35
srv1_sel50	42.66	40.18	40	40.69	40.2	40.32	40.33
srv2_q	0.49	0.43	0.6	0.47	0.54	0.45	0.56
srv2_q_f	0.32	0.46	0.6	0.49	0.63	0.46	0.63
srv2_sel95	61.3	57.05	105	57.32	55.24	58.05	56.01
srv2_sel50	41.32	41.18	40	40.84	39.82	41.35	39.86
srv3_q	0.62	0.68	0.6	0.79	0.77	0.7	0.79
srv3_sel95	57.24	57.63	120	59.43	49.53	59.37	50.62
srv3_sel50	38.42	38.59	57.5	38.78	34.78	39.15	34.94
srv3_q_f	0.49	0.54	0.6	0.62	1	0.54	1
srv3_sel95_f	43.09	43.42	95	42.85	45.23	42.84	44.8
srv3_sel50_f	33.27	33.47	45	32.97	34.73	32.94	34.27

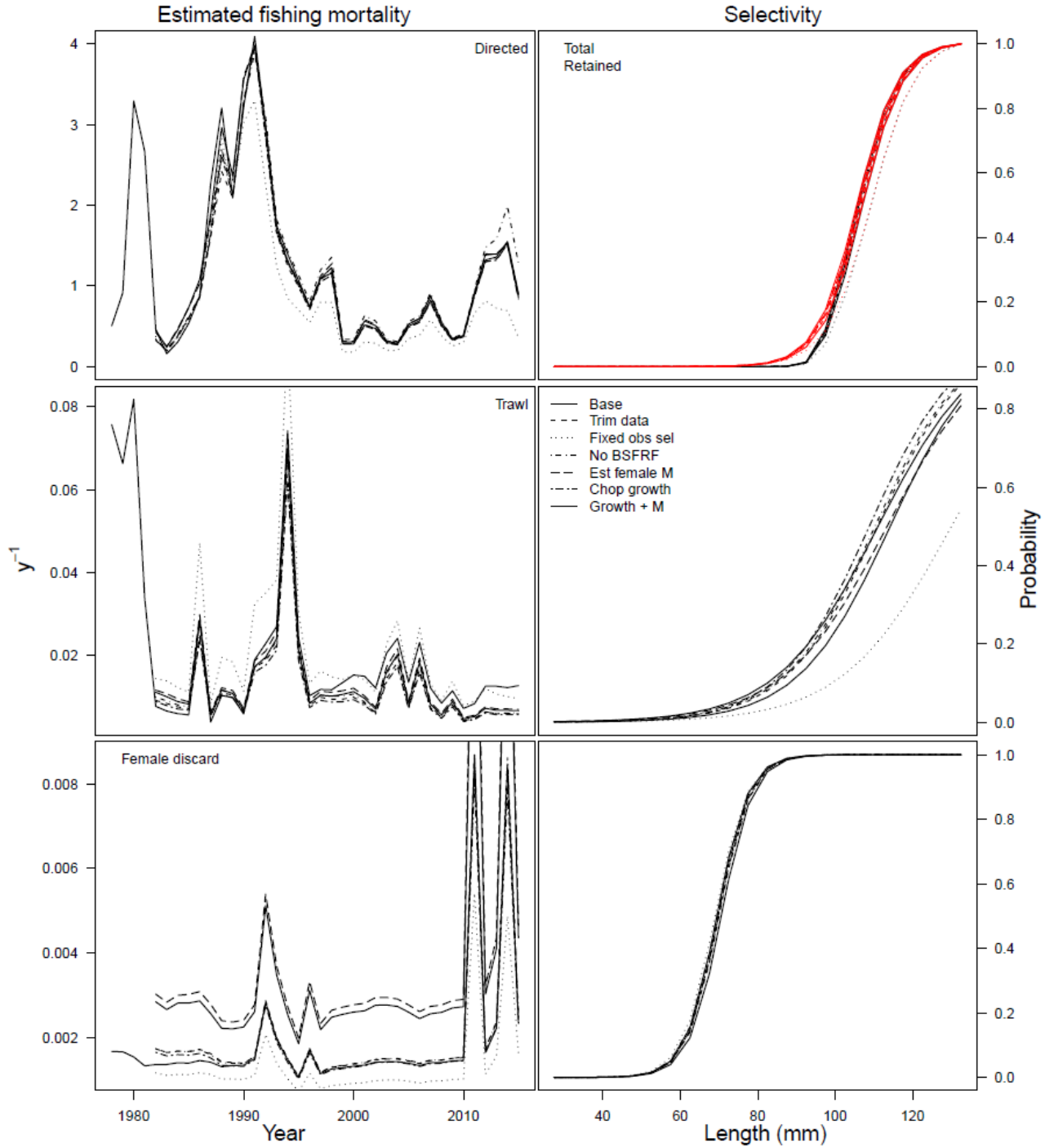
Parameter	Base	Trim data	Fixed obs sel	No BSFRF	Est female M	Chop growth	Growth + M
Mmult_imat	1.8	1.81	1.22	1.74	1.28	1.81	1.27
Mmult	1.13	1.08	1.13	1.06	1.15	1.09	1.16
Mmultf	1	1	1	1	1.41	1	1.42

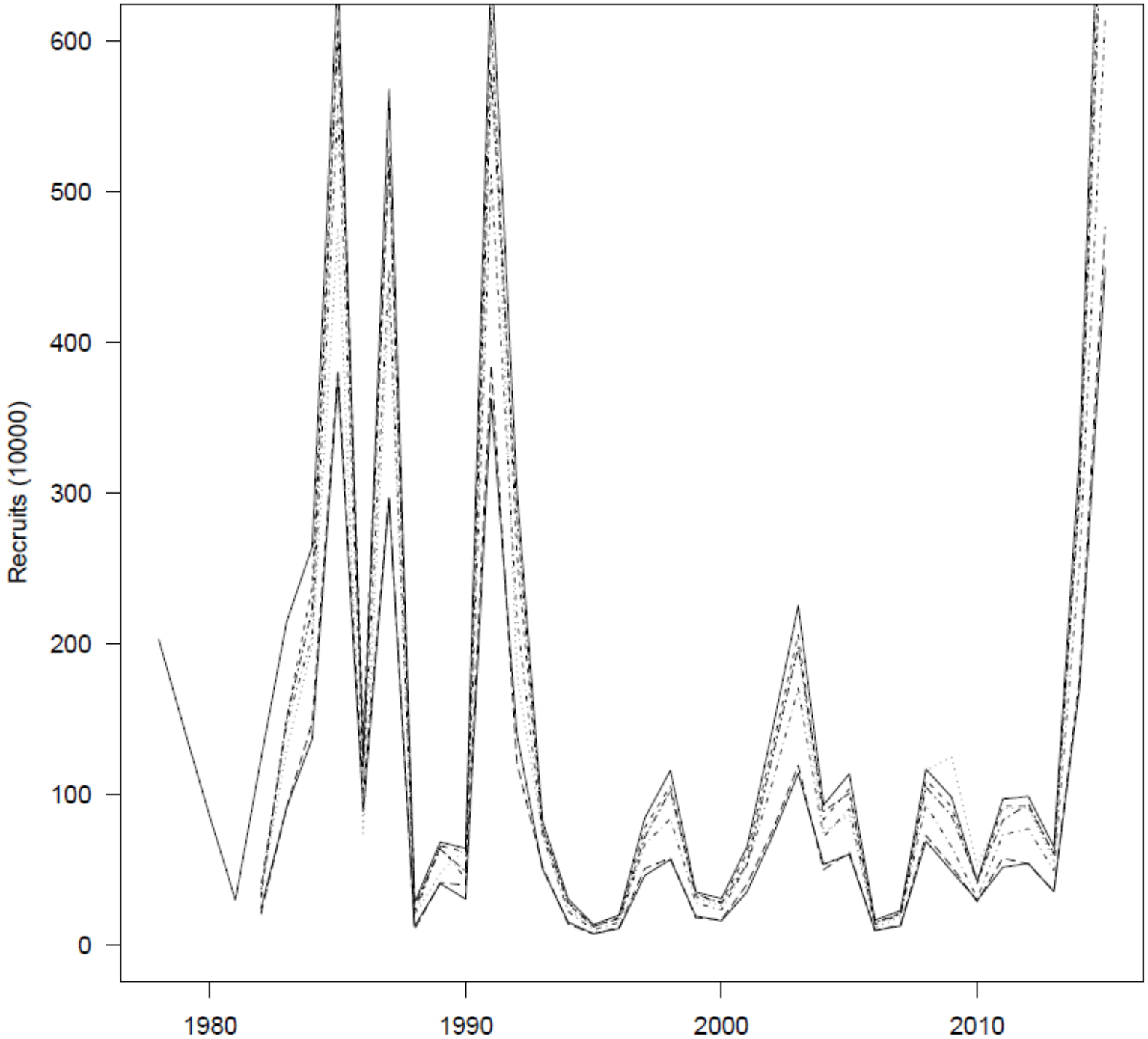

Female
Male
Old observations
New observations
Base
Trim data
Fixed obs sel
No BSFRF
Est female M
Chop growth
Growth + M
Growth increment (mm)
Premolt length (mm)
0
5
10
15
20
25
20
30
40
50
60
70
80
90

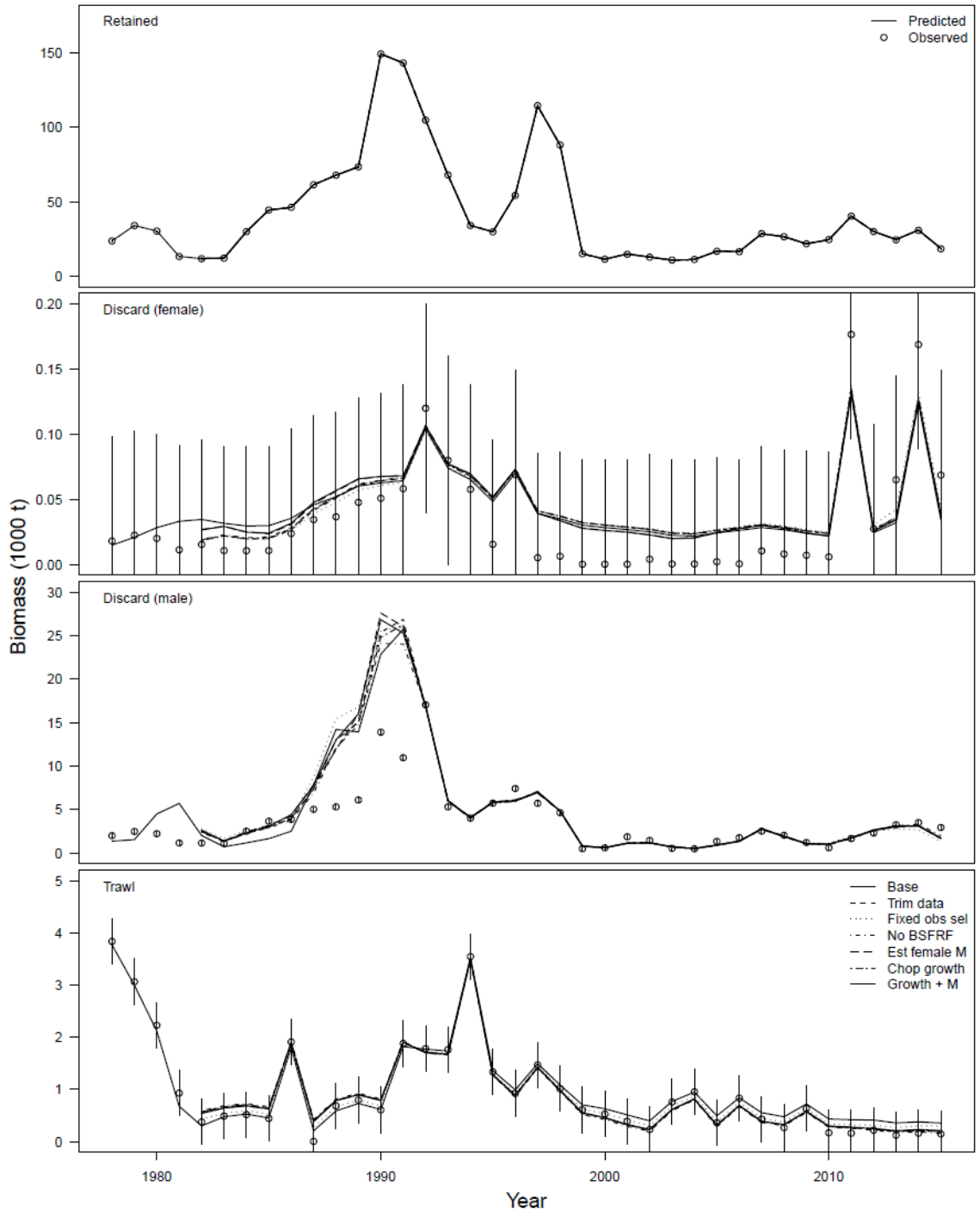
Parameter	Base	Trim data	Fixed obs sel	No BSFRF	Est female M	Chop growth	Growth + M
af	-5.08	-5.06	-4.1	-5.08	-5.29	9.72	9.87
am	-5.74	-5.83	-7.48	-12.2	-5.61	4.89	4.84
bf	1.53	1.52	1.48	1.53	1.53	1.09	1.09
bm	1.54	1.54	1.62	1.83	1.53	1.19	1.19
b1	1.15	1.15	1.12	1.16	1.15	1.25	1.25
bf1	1.02	1.03	1	1.03	1.04	1.5	1.5
deltam	32.2	32.25	32.37	27.47	32.19	30	30
deltaf	34.37	34.29	36.51	34.33	34.13	27.5	27.5


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
Obs
Pred
Base
Trim data
Fixed obs sel
No BSFRF
Est female M
Chop growth
Growth + M
Males
Obs
Pred
Base
Trim data
Fixed obs sel
No BSFRF
Est female M
Chop growth
Growth + M


1991
1997
2003
2009
2015
1992
1998
2004
2010
1993
1999
2005
2011
1994
2000
2006
2012
1995
2001
2007
2013
1996
2002
2008
2014
Observations
Male
Female
Predictions
Male
Female
Base
Trim data
Fixed obs sel
No BSFRF
Est female M
Chop growth
Growth + M
1978
1985
1992
1999
2006
2013
1979
1986
1993
2000
2007
2014
1980
1987
1994
2001
2008
2015
1981
1988
1995
2002
2009
1982
1989
1996
2003
2010
1983
1990
1997
2004
2011
1984
1991
1998
2005
2012
Males
Obs
Pred
Base
Trim data
Fixed obs sel
No BSFRF
Est female M
Chop growth
Growth + M


Estimated fishing mortality
Selectivity
Directed
Total
Retained
Trawl
Female discard
Base
Trim data
Fixed obs sel
No BSFRF
Est female M
Chop growth
Growth + M
y⁻¹
Probability
Year
Length (mm)


Recruits (10000)
600
500
400
300
200
100
0
1980
1990
2000
2010


Retained
Predicted
Observed
Discard (female)
Discard (male)
Trawl
Base
Trim data
Fixed obs sel
No BSFRF
Est female M
Chop growth
Growth + M
Biomass (1000 t)
Year
1980
1990
2000
2010

Model results

- ‘Trim data’
  - OFL decreased compared to ‘Base’, primarily because q in era 3 increased
  - Decrease in estimated probability of maturing and natural mortality for brought down F35%
- ‘Fixed obs sel’
  - OFL increased (a lot) compared to ‘Base’ from a decrease in q, probability of maturing, and growth
  - Much worse fits to survey MMB, survey selectivity much lower than any of the estimated scenarios
- ‘No BSFRF’
  - OFL decreased compared to ‘Base’, primarily because q in era 3 increased
  - Shifts breakpoint in growth
  - F35% decreases relative to ‘Base’ due to decreases in natural mortality and probability of maturing

Table 1: Changes in management quantities for each scenario considered. Reported quantites are the MLEs because running MCMC for every model was prohibitively time-consuming. The MLEs for scenarios in which MCMCs were performed are very close to the medians of the posterior distributions.

Model	MMB	B35	F35	FOFL	OFL
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Est female M	74.29	139.6	1.21	0.68	18.38
Chop growth	79.57	149.8	1.34	0.75	18.66
Growth + M	70.89	137.4	1.17	0.64	17.35

Recommendations

- ‘Trim data’
  - Adopt exclusion of all data from 1978-1981, start model in 1982
  - Rationale: Including this era artificially anchors catchability at 1. Given the uncertainties around expected changes under different survey gear and the potential for catch to be missing in the early years, the risks outweigh the benefits
  - Era 3 should start in 1988 instead of 1989
- ‘Fixed obs sel’ & “No BSFRF”
  - Neither of these should be adopted, but were used illustratively
  - Think harder about how to do incorporate extra survey
  - Issues:
    - problems with variables hitting bounds
    - Large disconnect between ‘observed’ selectivity and estimated
    - Stock is at it’s lowest, in spite of an assumption of a higher q than implied by the industry surveys—changing this assumption to the ‘observed’ would have exacerbated the decline in MMB

Natural mortality

- Current:
  - Immature M (male and female):
    - 0.41 (estimated)
    - Prior = N(0.23, 0.154)
  - Mature female M:
    - 0.23 (fixed)
  - Mature male M:
    - 0.26 (estimated)
    - Prior = N(0.23,0.054)
- Issues
  - Mature male M was higher than female, which was biologically questionable
  - No natural mortality specific data (e.g. tagging data)
  - Has a large impact on reference points
  - Poorly documented rationale

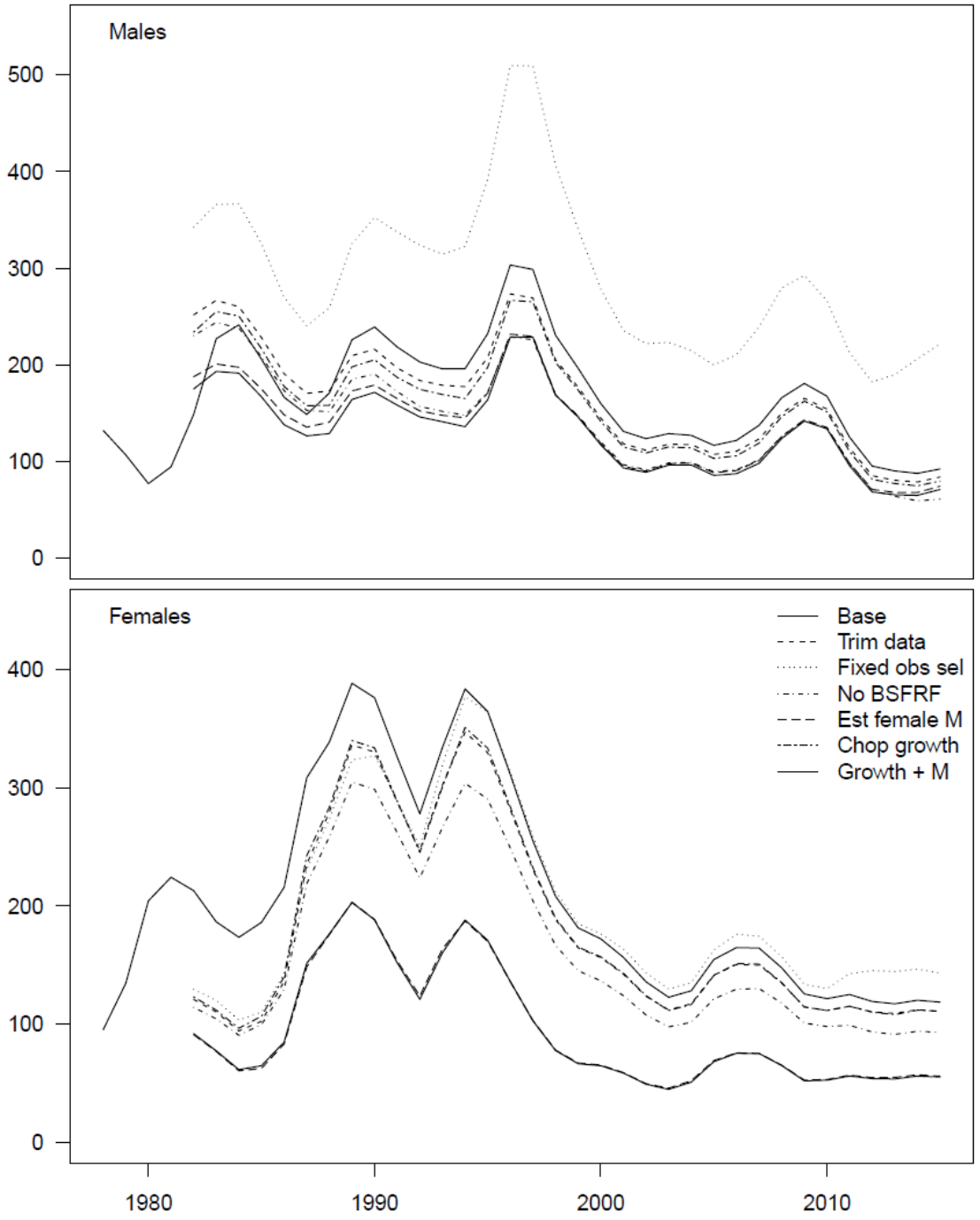
Model runs

- ‘Est female M’
  - ‘Trim data’ + estimating mature female M + setting the prior for immature crab equal to prior for mature crab
  - Potentially corrects for flip-flop of M between sexes and corrects the prior to conform to the rationale of M being based on longevity

Model results

- ‘Trim data’
  - Immature M (male and female):
    - 0.29 (estimated, decreased from 0.41)
    - Prior = N(0.23, 0.054) [sd decreased from 0.154]
  - Mature female M:
    - 0.32 (estimated, increased from 0.23)
    - Prior = N(0.23,0.054)
  - Mature male M:
    - 0.26 (estimated; did not change)
    - Prior = N(0.23,0.054)
  - Survey catchability is pegged at 1 for females when estimating mature M
  - OFL decreased compared to ‘Base’, primarily because q in era 3 increased
  - Decrease in estimated probability of maturing for brought down F35%

Parameter	Base	Trim data	Fixed obs sel	No BSFRF	Est female M	Chop growth	Growth + M
srv1_q	1	0.6	0.6	0.6	0.6	0.6	0.6
srv1_q_f	1	0.6	0.6	0.6	0.6	0.6	0.6
srv1_sel95	59.89	60.19	60	60.74	60.21	60.34	60.35
srv1_sel50	42.66	40.18	40	40.69	40.2	40.32	40.33
srv2_q	0.49	0.43	0.6	0.47	0.54	0.45	0.56
srv2_q_f	0.32	0.46	0.6	0.49	0.63	0.46	0.63
srv2_sel95	61.3	57.05	105	57.32	55.24	58.05	56.01
srv2_sel50	41.32	41.18	40	40.84	39.82	41.35	39.86
srv3_q	0.62	0.68	0.6	0.79	0.77	0.7	0.79
srv3_sel95	57.24	57.63	120	59.43	49.53	59.37	50.62
srv3_sel50	38.42	38.59	57.5	38.78	34.78	39.15	34.94
srv3_q_f	0.49	0.54	0.6	0.62	1	0.54	1
srv3_sel95_f	43.09	43.42	95	42.85	45.23	42.84	44.8
srv3_sel50_f	33.27	33.47	45	32.97	34.73	32.94	34.27



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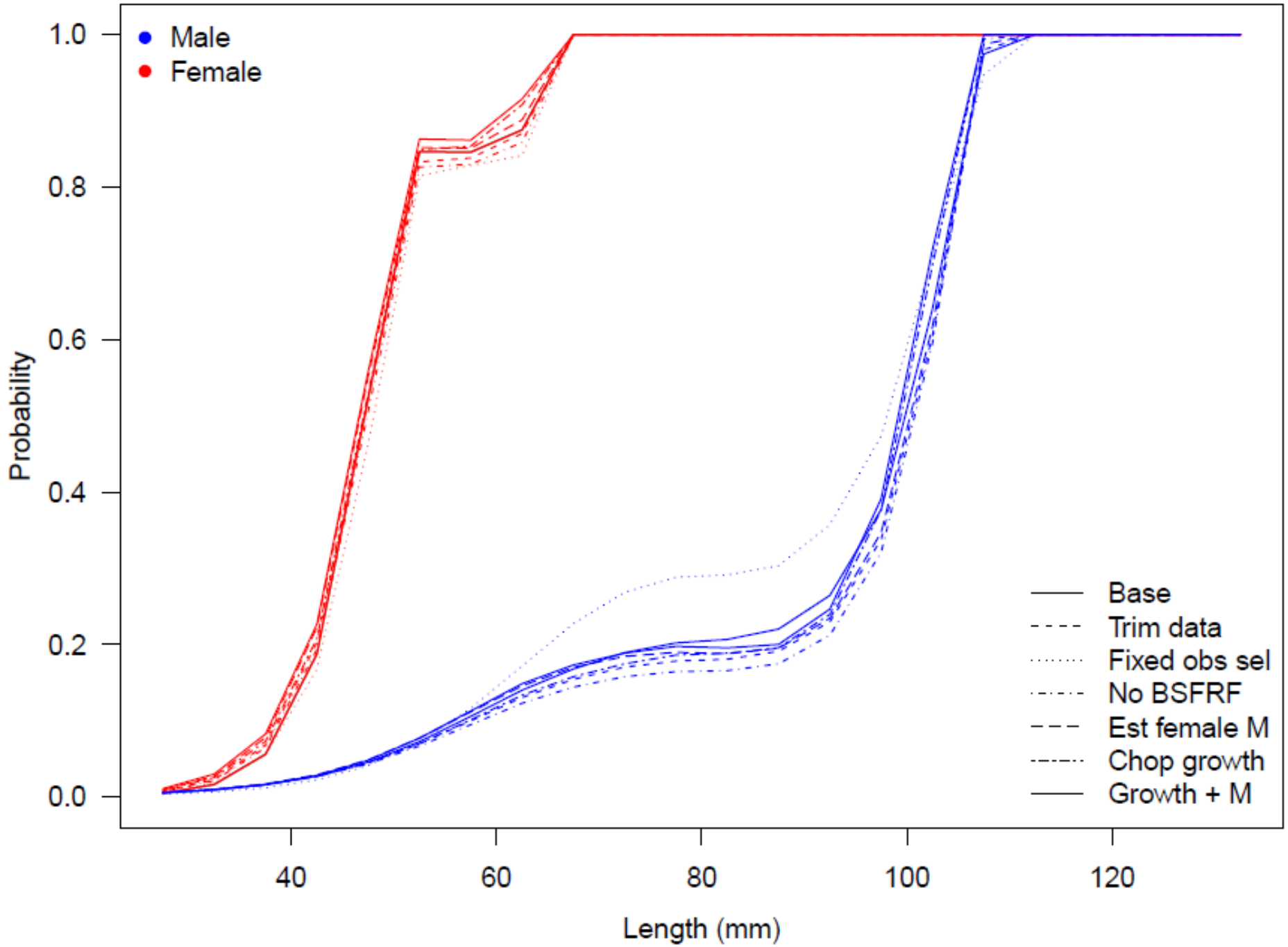
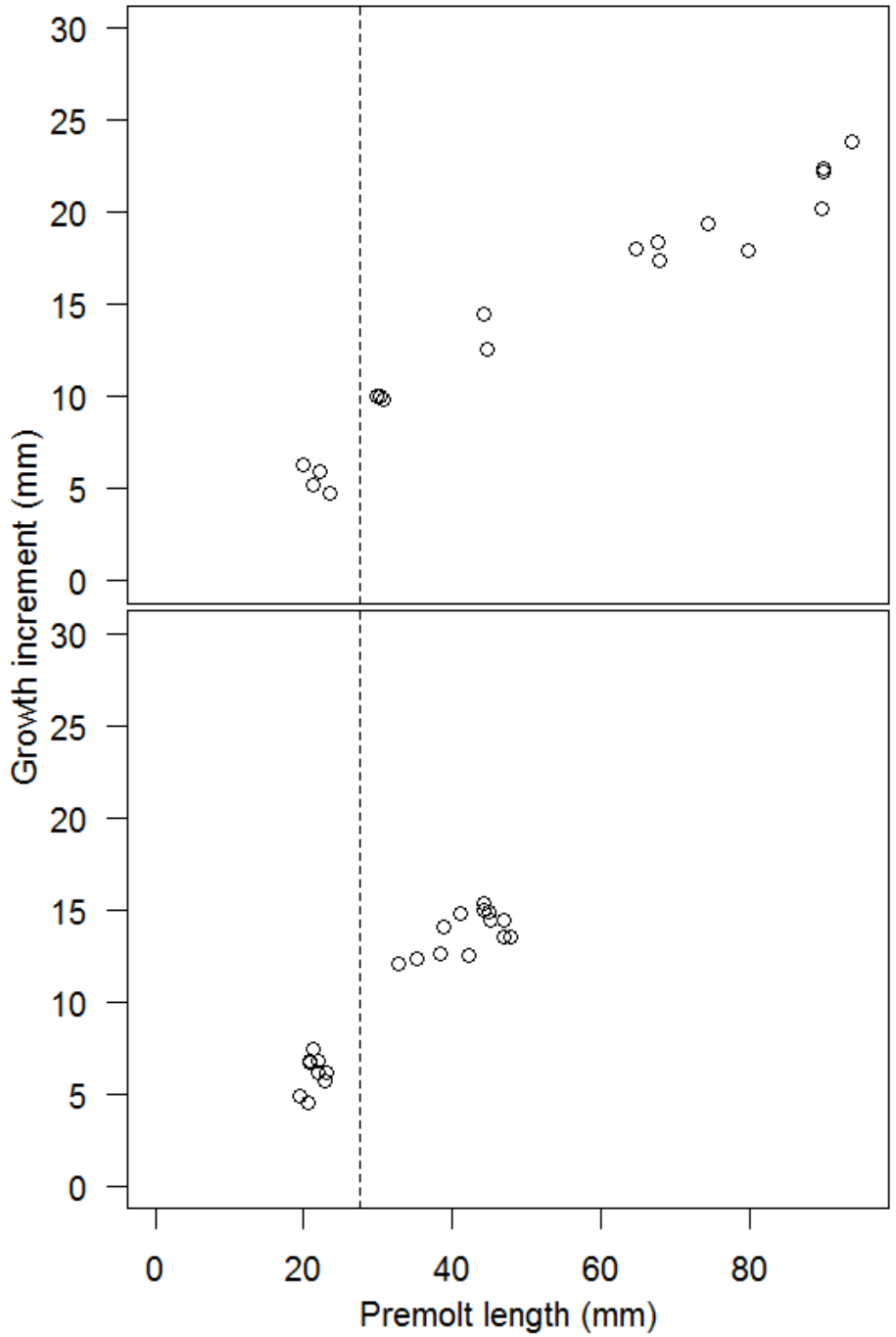

Male
Female
1.0
0.8
0.6
0.4
0.2
0.0
Probability
40
60
80
100
120
Length (mm)
Base
Trim data
Fixed obs sel
No BSFRF
Est female M
Chop growth
Growth + M

Recommendations

- It makes sense to estimate mature female natural mortality and corrects the relationship between mature male and mature female M, but now survey q in era 3 for females hits its bound of 1.
- Immature natural mortality is now flipped, but this is a result of placing the same prior on immature M that is placed on mature M.

Growth model and available data

- Current: Piece-wise linear model
- 8 estimated parameters
- 40 data points
- Issues
  - No data where the breakpoint, resulting in poor estimation
  - Data beneath the breakpoint impacts the model little
  - Growth parameters hit bounds and are generally poorly behaved
- What model should be used for growth?



Growth model and available data

- Current: Piece-wise linear model
- 8 estimated parameters
- 40 data points
- Issues
  - No data where the breakpoint, resulting in poor estimation
  - Data beneath the breakpoint impacts the model little
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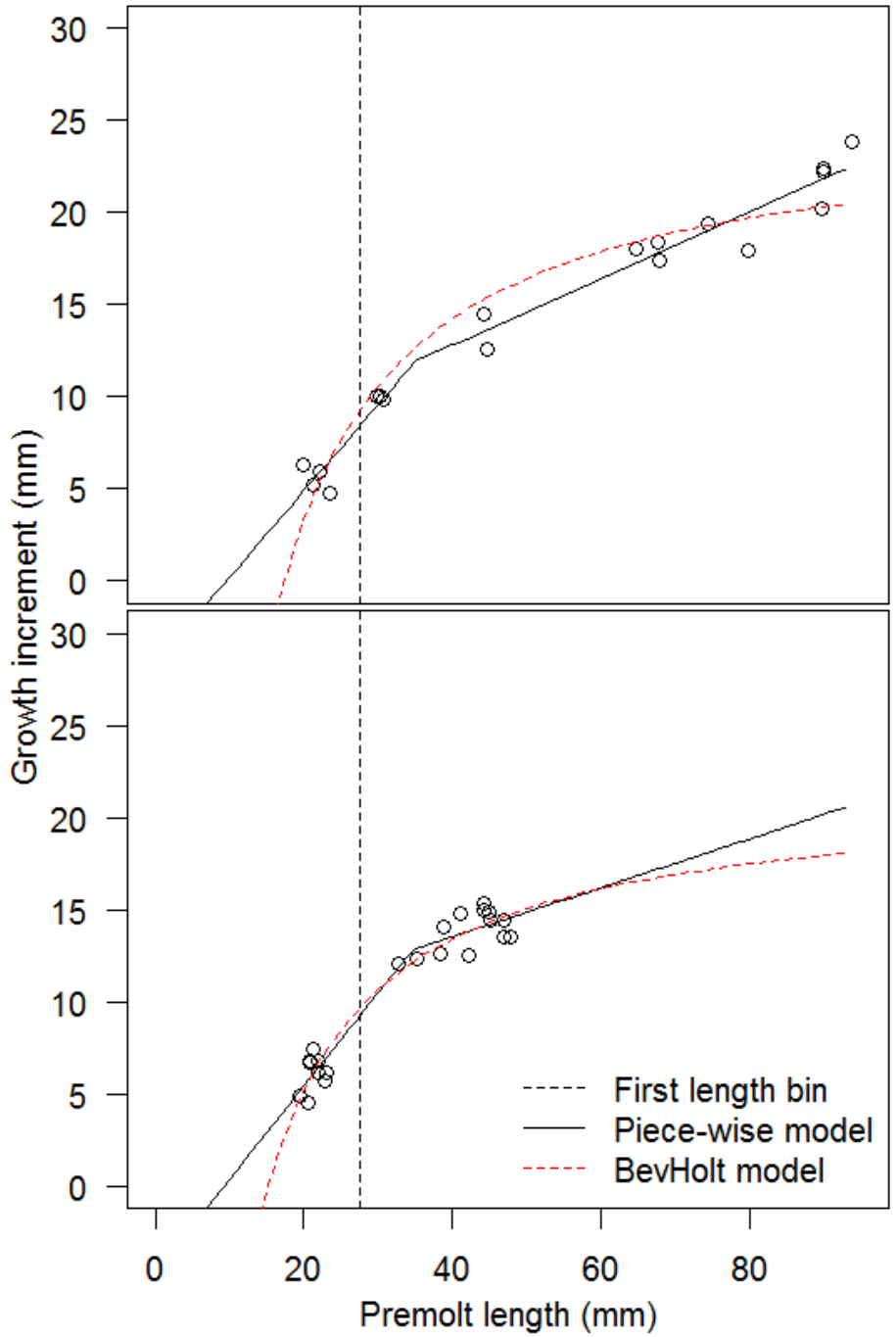

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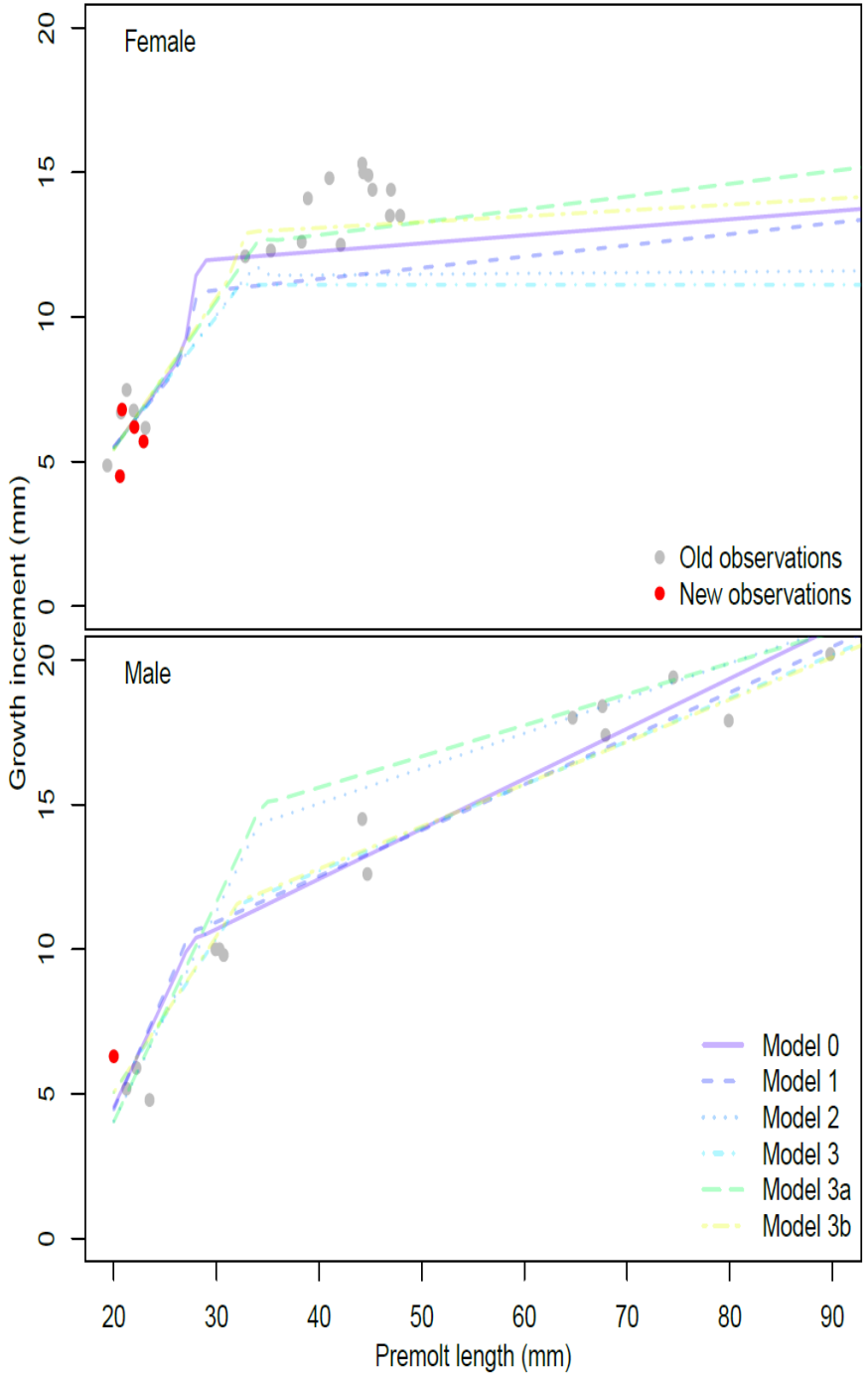


Model runs

- ‘Chop growth’
  - “Trim data” + excludes all growth data with a premolt size of <27.5 mm, then estimates only a linear model for both males and females
  - Explores problem of bound hitting and poorly estimated growth parameters
- ‘Growth + M’
  - ‘Chop growth’ + estimating mature female M
  - Growth and natural mortality are somewhat confounded

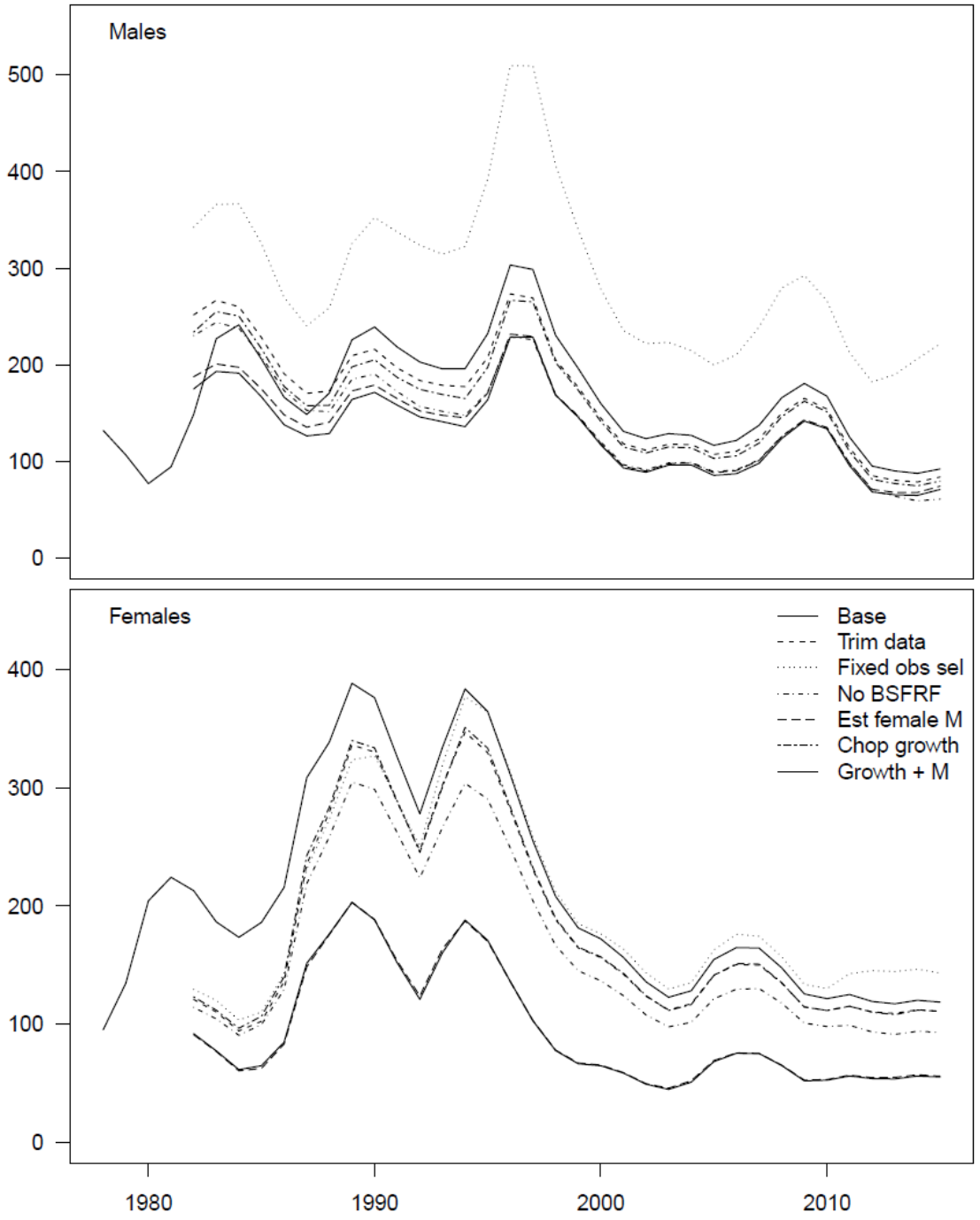
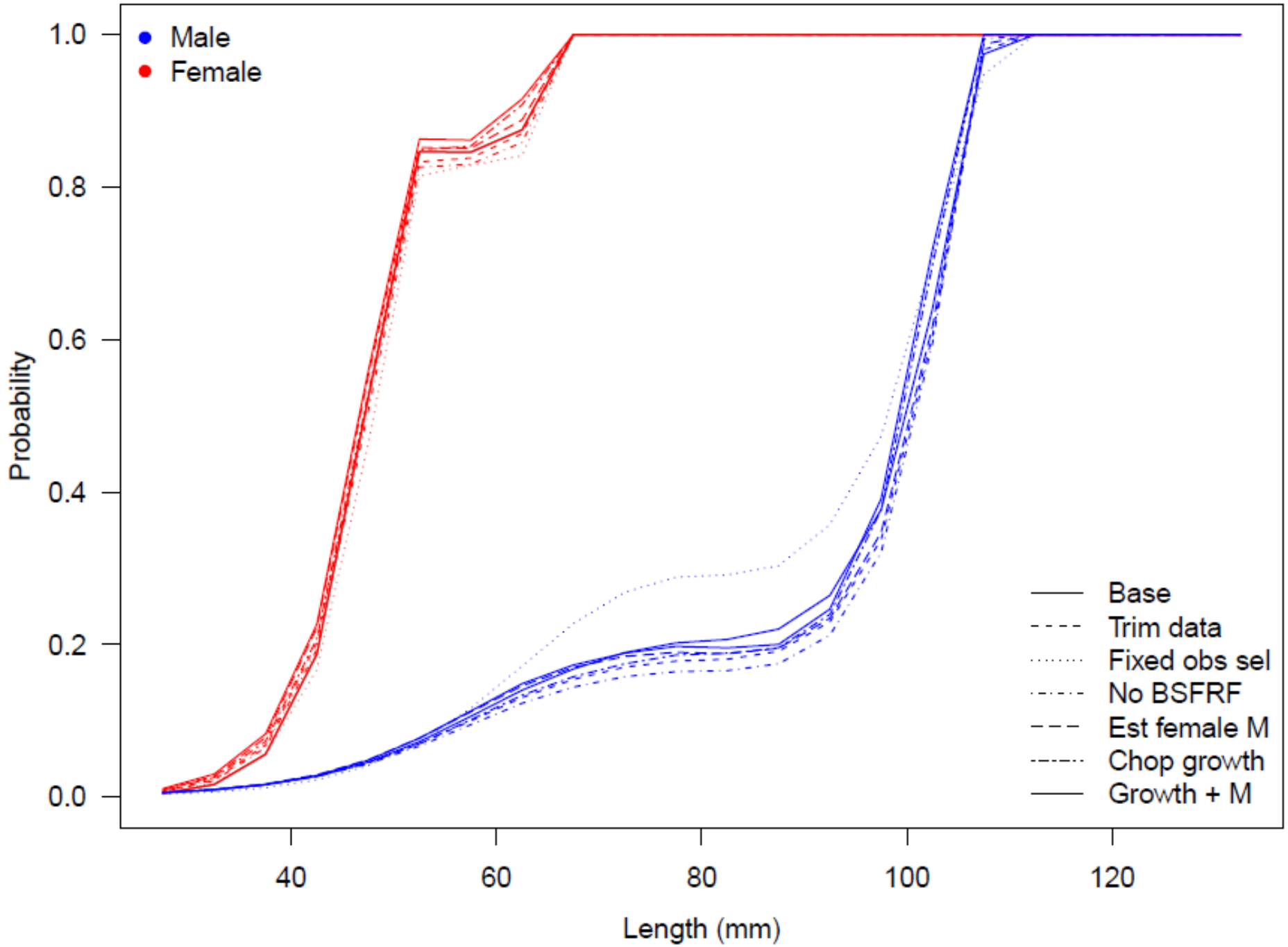
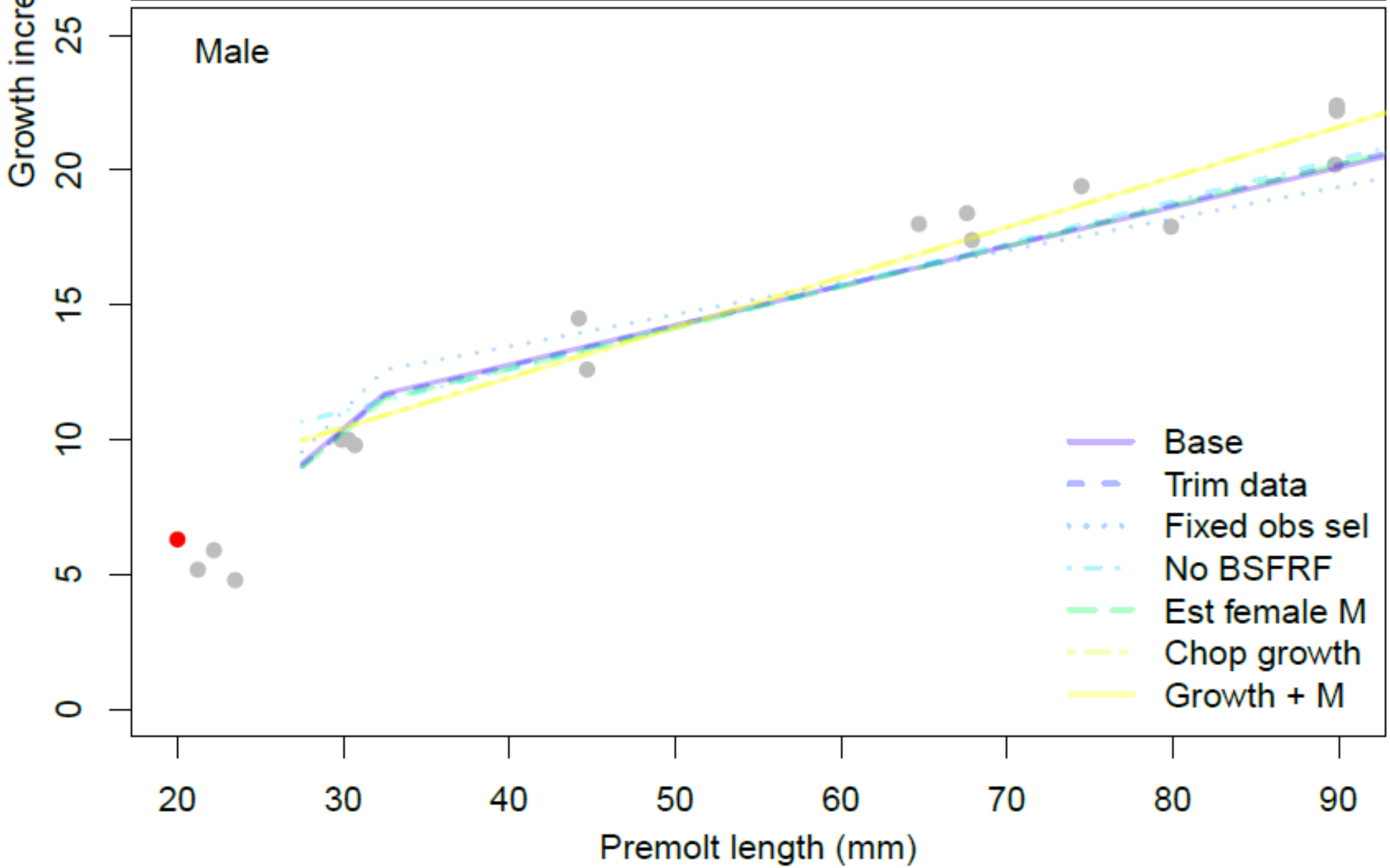


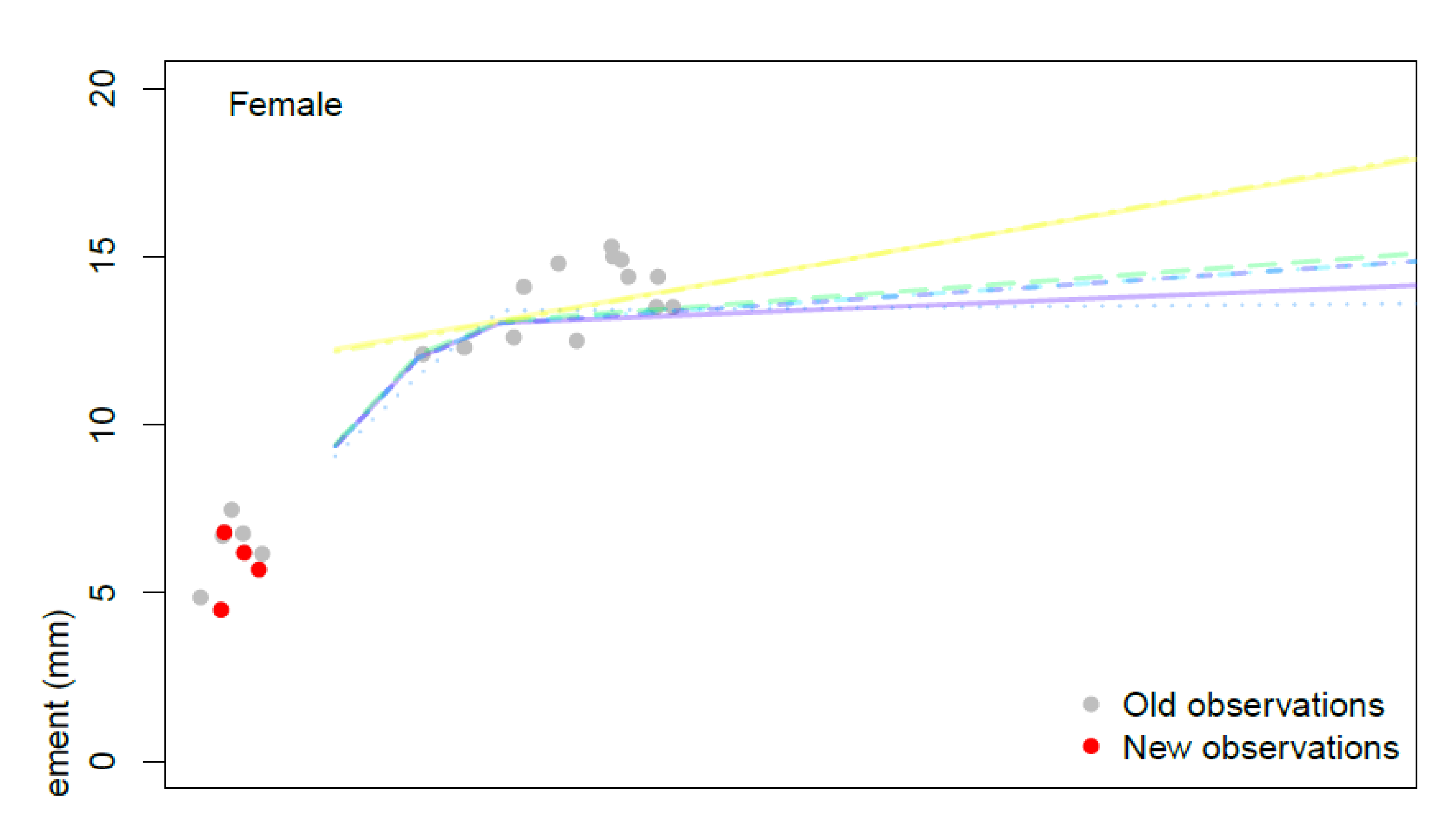
Table 1: Changes in management quantities for each scenario considered. Reported quantites are the MLEs because running MCMC for every model was prohibitively time-consuming. The MLEs for scenarios in which MCMCs were performed are very close to the medians of the posterior distributions.

Model	MMB	B35	F35	FOFL	OFL
Base	92.09	152.3	1.91	1.14	24.59
Trim data	83.8	152.3	1.42	0.81	19.97
Fixed obs sel	221.6	215.3	3.49	2.62	82.68
No BSFRF	60.86	142.3	1.17	0.56	11.5
Est female M	74.29	139.6	1.21	0.68	18.38
Chop growth	79.57	149.8	1.34	0.75	18.66
Growth + M	70.89	137.4	1.17	0.64	17.35

Parameter	Base	Trim data	Fixed obs sel	No BSFRF	Est female M	Chop growth	Growth + M
srv1_q	1	0.6	0.6	0.6	0.6	0.6	0.6
srv1_q_f	1	0.6	0.6	0.6	0.6	0.6	0.6
srv1_sel95	59.89	60.19	60	60.74	60.21	60.34	60.35
srv1_sel50	42.66	40.18	40	40.69	40.2	40.32	40.33
srv2_q	0.49	0.43	0.6	0.47	0.54	0.45	0.56
srv2_q_f	0.32	0.46	0.6	0.49	0.63	0.46	0.63
srv2_sel95	61.3	57.05	105	57.32	55.24	58.05	56.01
srv2_sel50	41.32	41.18	40	40.84	39.82	41.35	39.86
srv3_q	0.62	0.68	0.6	0.79	0.77	0.7	0.79
srv3_sel95	57.24	57.63	120	59.43	49.53	59.37	50.62
srv3_sel50	38.42	38.59	57.5	38.78	34.78	39.15	34.94
srv3_q_f	0.49	0.54	0.6	0.62	1	0.54	1
srv3_sel95_f	43.09	43.42	95	42.85	45.23	42.84	44.8
srv3_sel50_f	33.27	33.47	45	32.97	34.73	32.94	34.27


Male
Female
1.0
0.8
0.6
0.4
0.2
0.0
Probability
40
60
80
100
120
Length (mm)
Base
Trim data
Fixed obs sel
No BSFRF
Est female M
Chop growth
Growth + M


Male
Growth incre
0
5
10
15
20
25
20
30
40
50
60
70
80
90
Premolt length (mm)
Base
Trim data
Fixed obs sel
No BSFRF
Est female M
Chop growth
Growth + M


Female
20
15
10
5
0
ement (mm)
Old observations
New observations

Model results

- ‘Growth + M’
  - ‘Growth + M’ is the ‘synthesis’ of all the changes—excludes 1978-1981 data, estimates mature female M, eliminates problem parameters from growth
  - BUT, new problems arise:
    - Survey q (females era 3) is now estimated at 1
    - Survey q (males era 3) is now estimated at 0.79, which is a large increase over the ‘Base’

Recommendations summary

- Select a method for computing a distribution of the OFL based on uncertainty in the data and parameter estimates
- Drop 1978-1981 data
- Start era 3 in 1988
- Use a model selection approach to identify a model other than the piece-wise linear models for growth?
- Estimate mature female M, but whack-a-mole era 3 survey q?