Eastern Bering Sea snow crab assessment draft

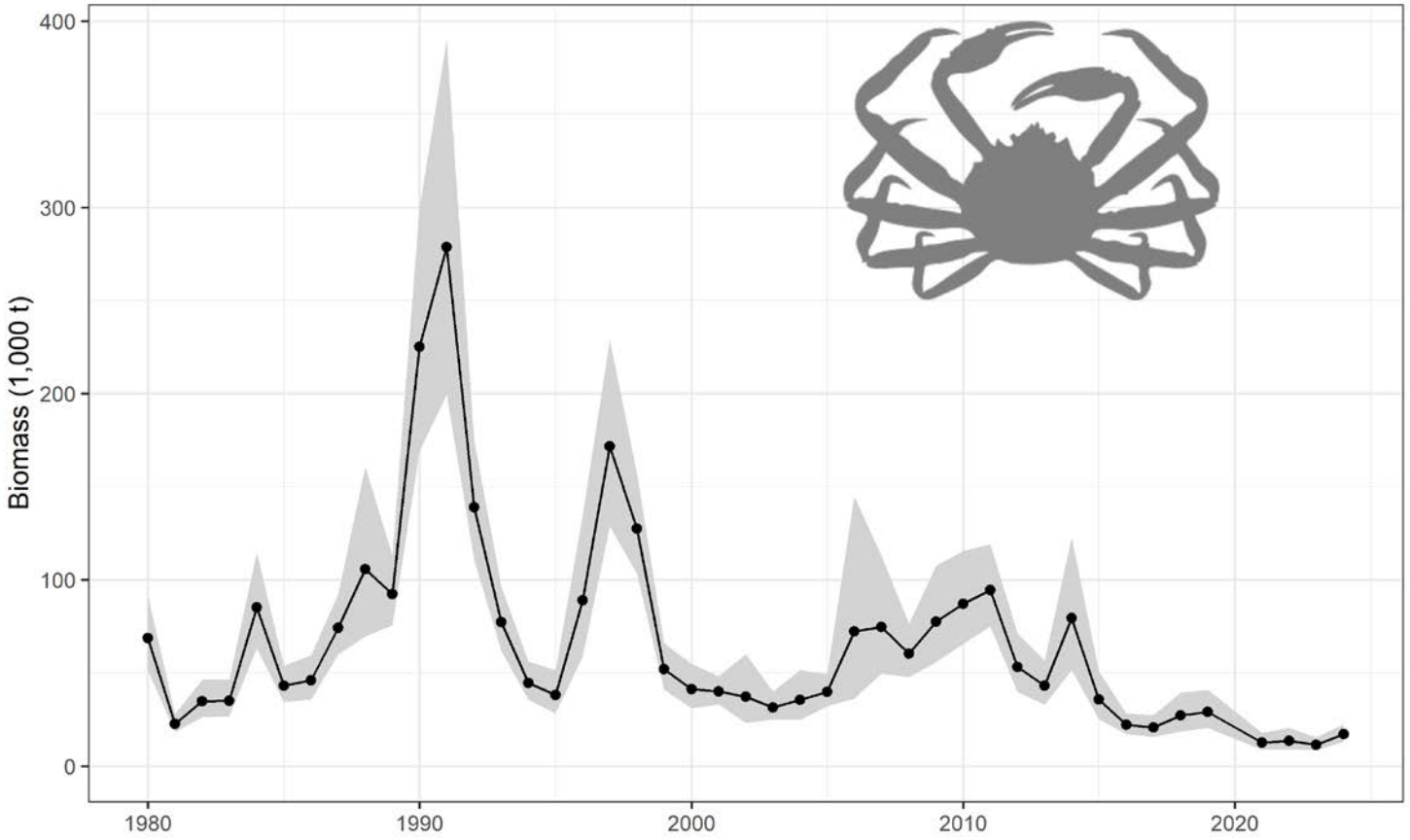
Cody Szuwalski

September 13, 2024

Big picture

- Small increase in commercial males
- Still 4th lowest on record
- 6% of the maximum observed
- 25% of the mean since 1980

- Last 8 years are the lowest on record
  - In order: 2023, 2021, 2022, 2024, 2017, 2016, 2018, 2019



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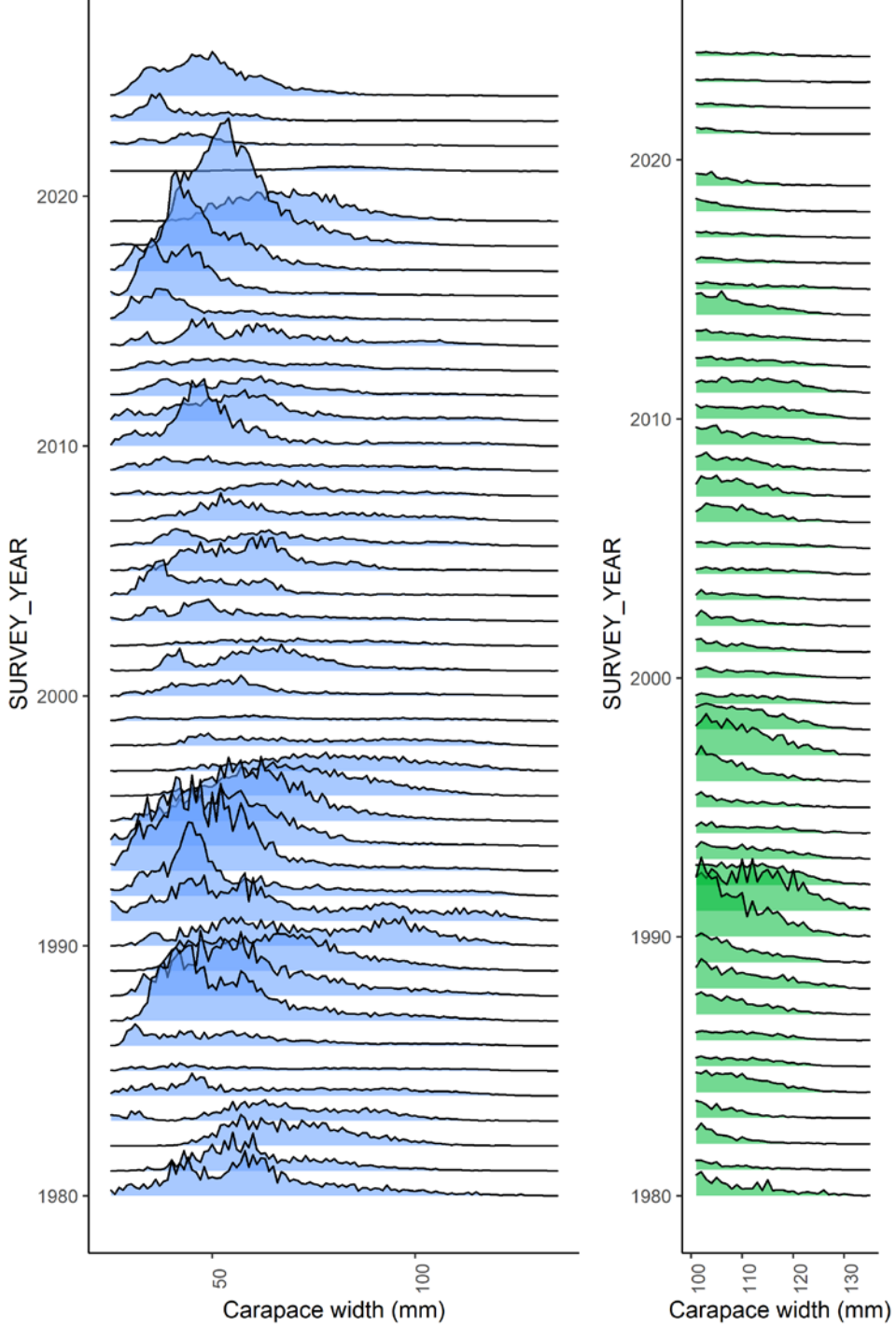

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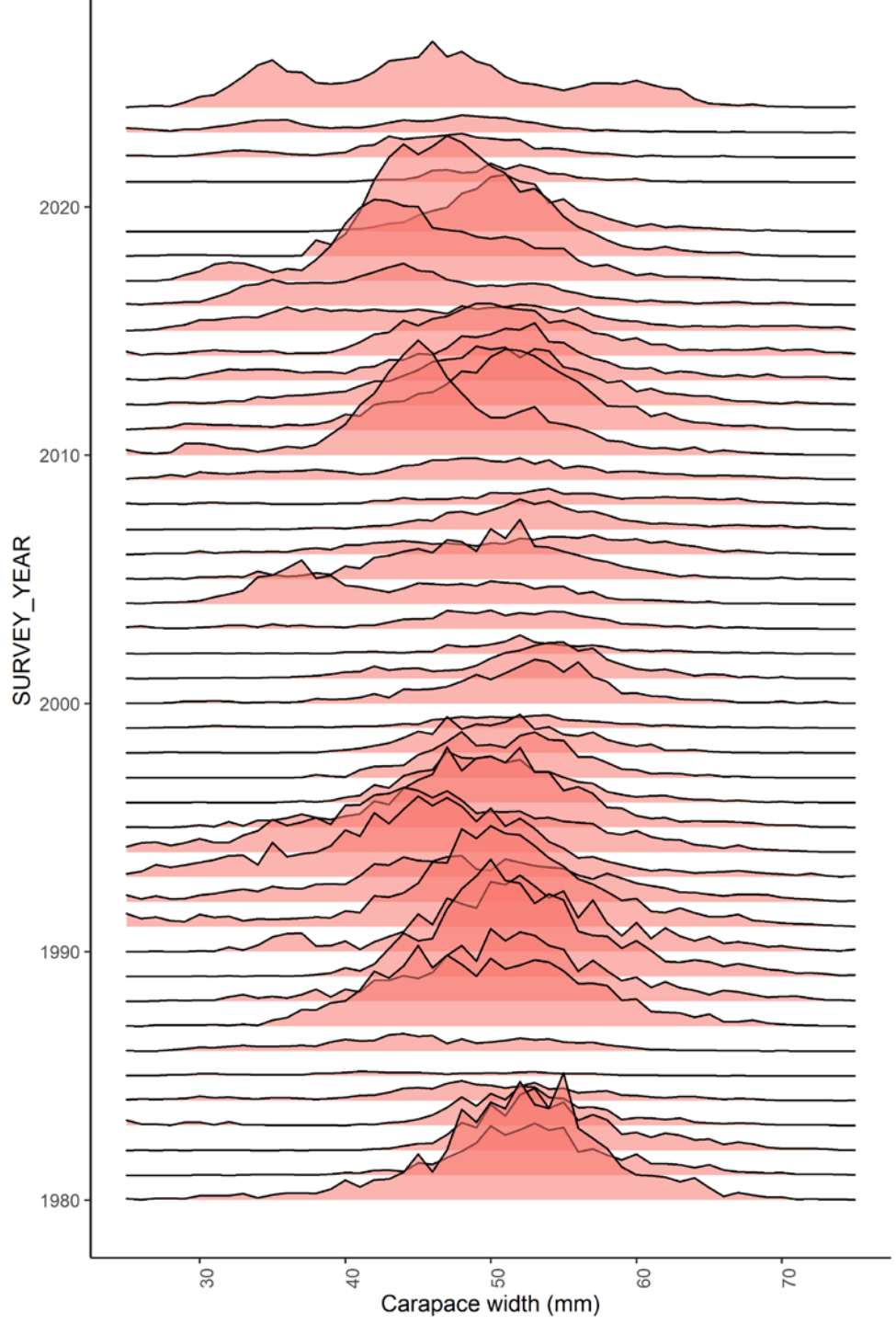
- Encouraging signs
- Surprising female results



Recommendations

- Reference points
  - Status quo tier 3 reference points too aggressive
  - Modified tier 3 reference points too conservative
  - **Tier 4 recommended**
- GMACS vs. survey
  - No immediate way to actually apply the exploitation rate associated with M given the estimated fishery selectivity
  - GMACS underestimates the large males considerably
  - Jittering issues also present with GMACS
  - **Use the survey estimates of males >101mm**

Year	Tier	BMSY	Males_com	Status	FOFL	OFL	Years	M
2023/2024	4_author	57.27	14.58	0.25	0.05	0.66	1982-2022	0.27
2023/2024	4_SSC	NA	16.56	NA	0.27	3.92	NA	0.27

Overview

- Review of key changes to dynamics
  - Probability of undergoing terminal molt
  - Exploitation rates on large males under status quo reference points
- Incorporating uncertainty into management targets
  - SBPR%
  - Currency of management
- Application in GMACS
  - Diagnostics
  - Fits and OFLs
- Management recommendations
  - Tier 3 vs 4
  - Model-based vs. observed estimates of biomass
- Rumination on reproduction

SSC recommendations

- **SSC comment: The SSC requests that the Clark maximin re-analysis more closely follow the original analysis, which was carefully crafted to encompass a reasonable range of discrete stock productivities. Clark (1991) used both Ricker and Beverton Holt curves, used three curves intended to span a plausible range of steepness (0.50, 0.67, and 0.80), and excluded alternatives of 0.33 and 0.89 steepness. The SSC notes that FX% is the fishing mortality associated with an X percent reduction in spawning output per recruit (not percent reduction in stock size as shown in the draft document). It will be important to provide plots showing yield and the percent reduction in the different reproductive output measures as a function of fishing mortality. The SSC also requests that an exploitation rate be reported in addition to fishing mortality, which can be misleading because of the right-shifted selectivity curve for snow crab. This shift results in very few crab experiencing full-selection fishing mortality. Ideally, this analysis would use the parameters estimated in the GMACS operational model, rather than the snow crab research model. **
- **This has been done to the best of my ability in the time available and is detailed in appendix A.**
- **SSC comment: Concerning the GMACS assessment model, the SSC continues to recommend that the assessment author explore ways to incorporate the molt to maturity data in the model in a way that reflects the observation error associated with those estimates. An analysis in a GLMM modeling framework, which treats years as random effects, would provide smoother estimates, accommodate differing sample sizes by year and length, and deal appropriately with years in which data are missing. Another possibility that was suggested in the CPT report was to include the annual observed probabilities of terminal molt as data and then fit them, as in the Tanner crab assessment. **
- **Not addressed in this document.**
- **SSC comment: The SSC recommends that this model be brought forward in the fall but requests that an additional Tier 4 model be provided for comparison, as recommended in the Simpler Modeling Workshop report and requested in the SSC's June 2023 and October 2023 Reports. This additional model would use the random effects model (REMA) to smooth survey estimates and would not decrement with natural mortality.**
- **This is included in this document.**

SSC recommendations

- Each of these points has been discussed to some extent at CPT meetings and will be addressed more thoroughly when time allows.

From Sept 2023:

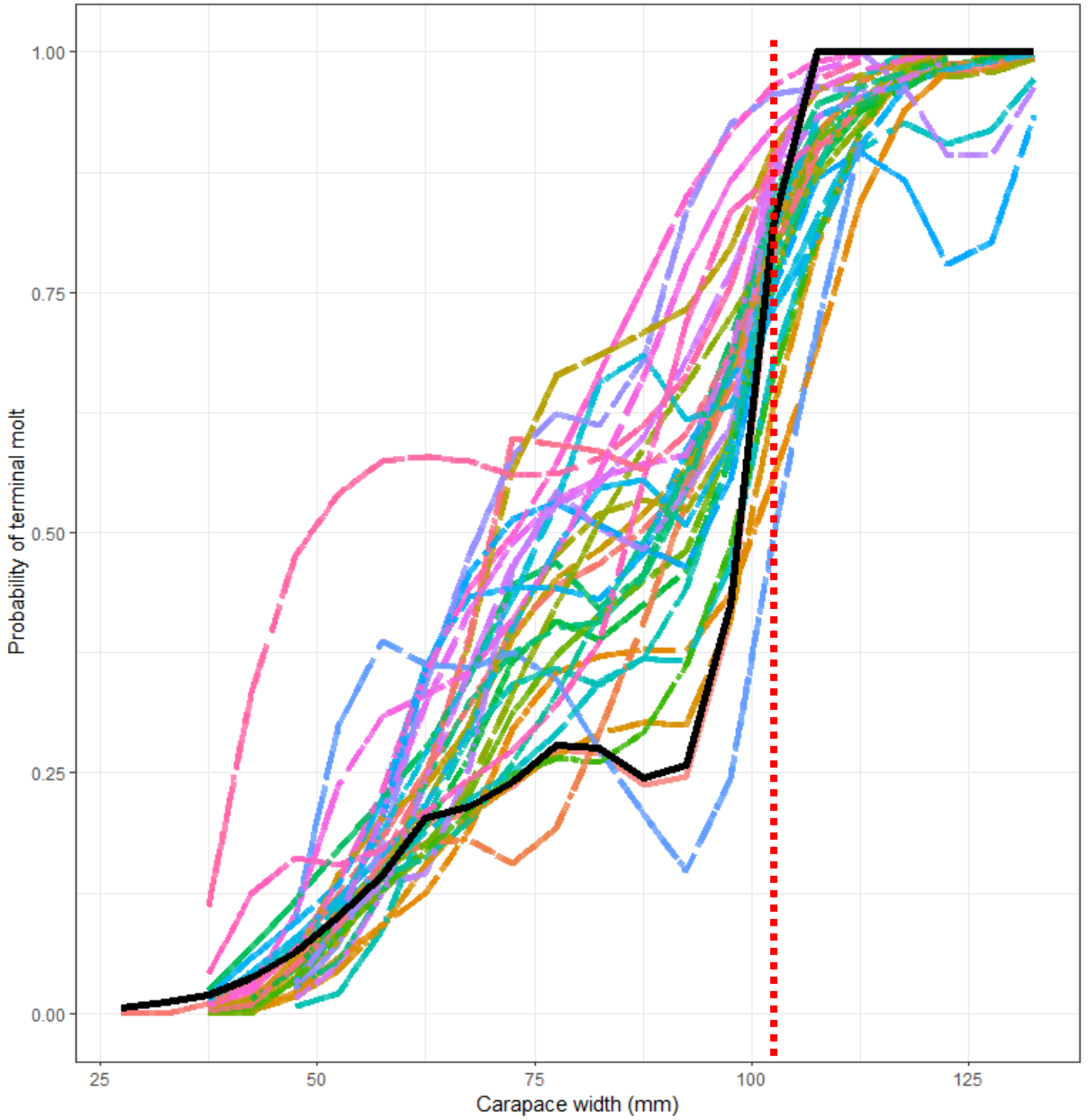
- **SSC comment: The SSC strongly supports the plans of the CPT to evaluate other metrics for reproductive output. The CPT may want to consider a multi-attribute measure of reproductive output. For example, both percent reduction in mature male biomass and percent reduction in large males could be evaluated as a function of fishing mortality.**
- **SSC comment: Figure 23 on page 73 of the SAFE report shows the decline in CPUE over a season by statistical area and year. This represents a kind of depletion experiment, suggesting that total mortality (Z) could be estimated from the linear parameters representing each line. This might help determine spatial patterns in F, indicate the natural bounds for F and M, and assist in determining stock status.**
- **SSC comment: Investigate whether there is information outside the assessment model (e.g., larval or post-settlement data) or in the model supporting estimated skewed sex-ratios at recruitment.**

Recent assessment changes

- Probability of undergoing terminal molt updated to reflect biology

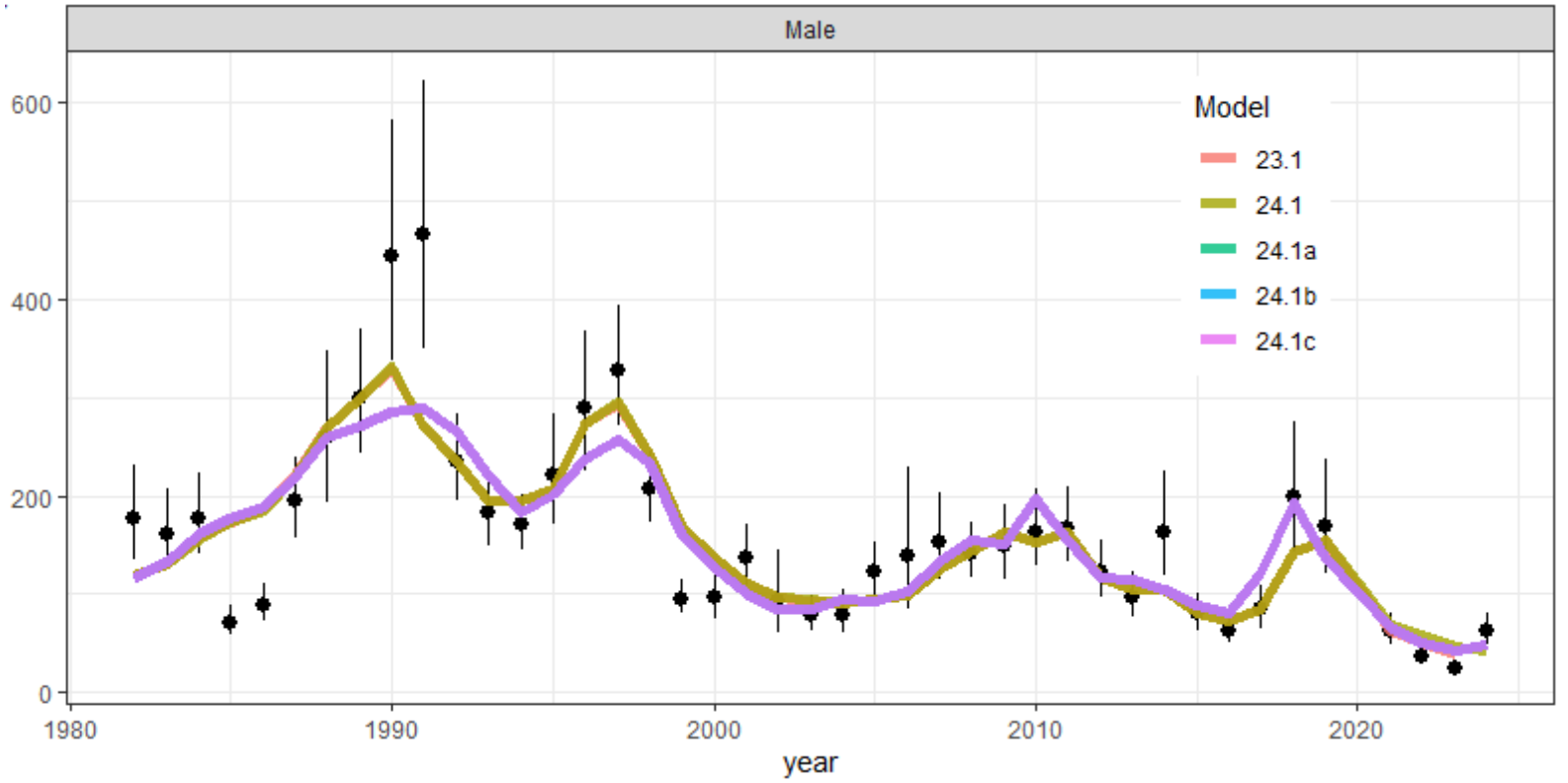
- Status quo reference points and currency of management definitions would allow the capture of all large males.

- This happens because a small mature male is assumed equivalent to a large mature male.

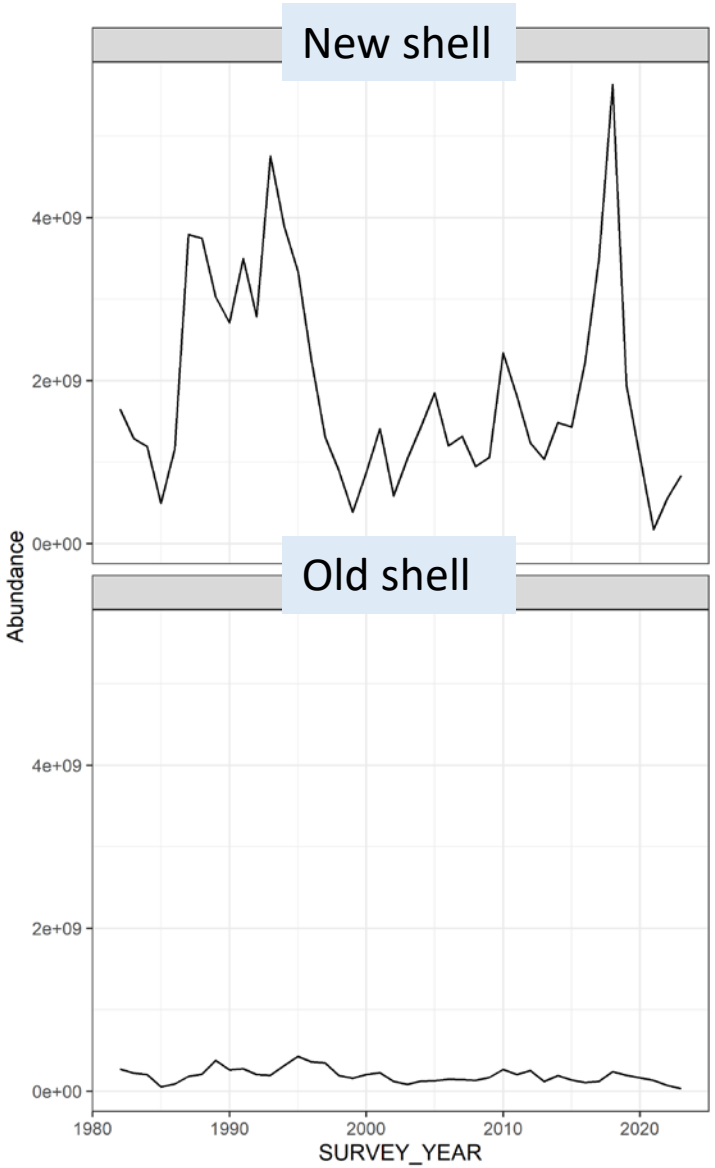


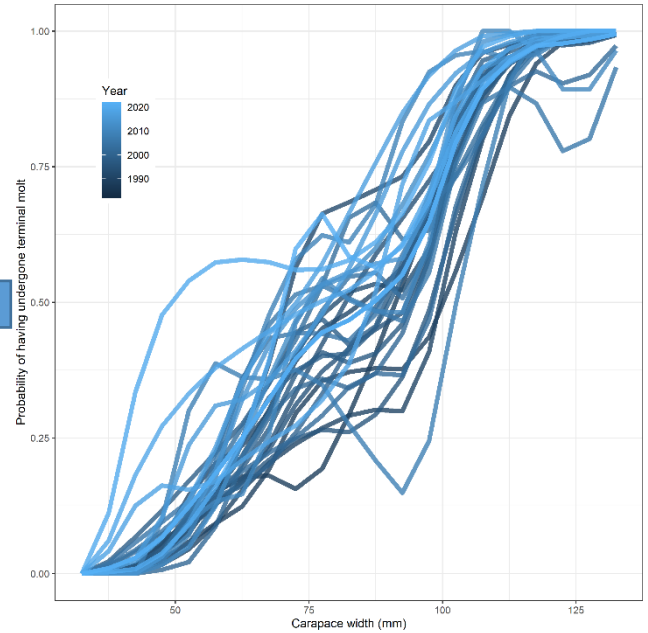
- MMB time series to which the models are fit are the same and reflects morphometrically mature male biomass

- The distributions of the underlying population of numbers of mature males at size is drastically different



Preparing assessment data (MMB)



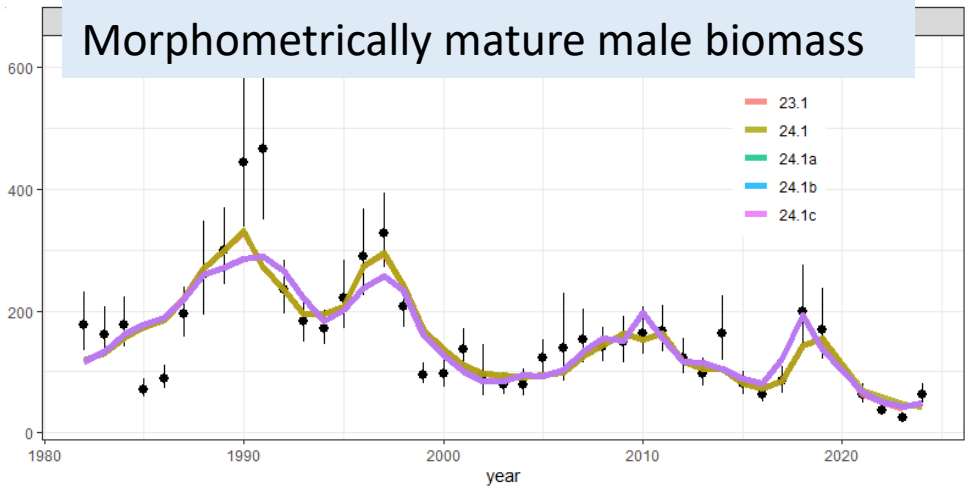


Index of immature animals not fit

Immature size composition data are fit

Weight at size

Weight at size



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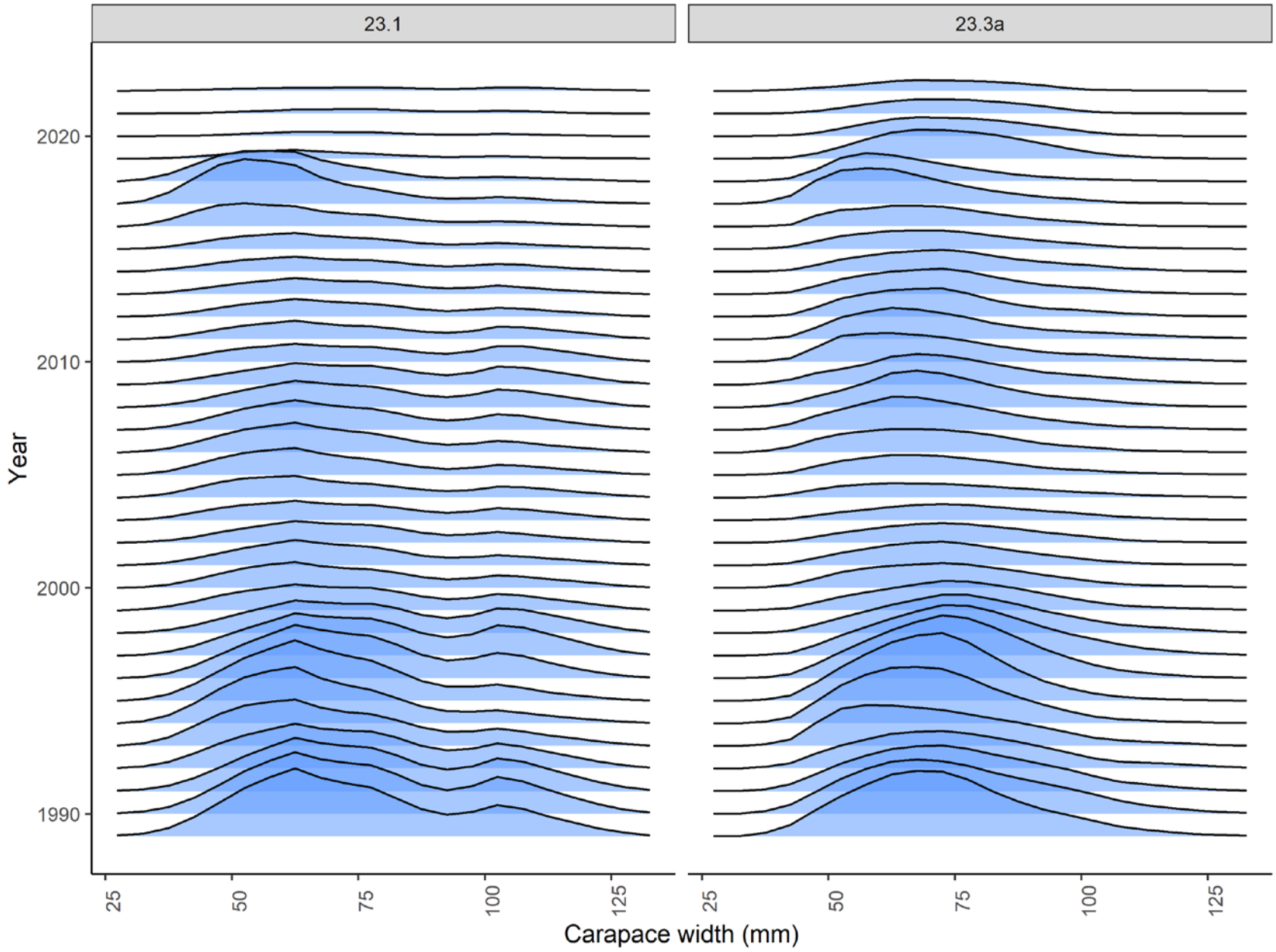
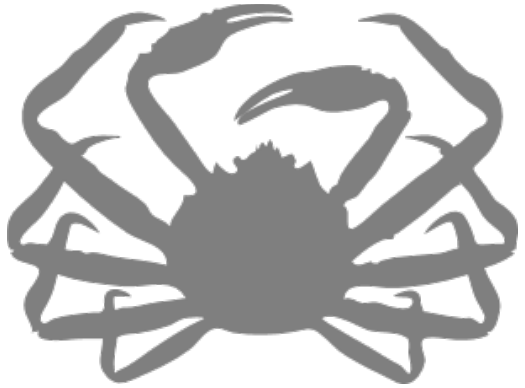


Are small mature males equivalent to large mature males in reproduction?



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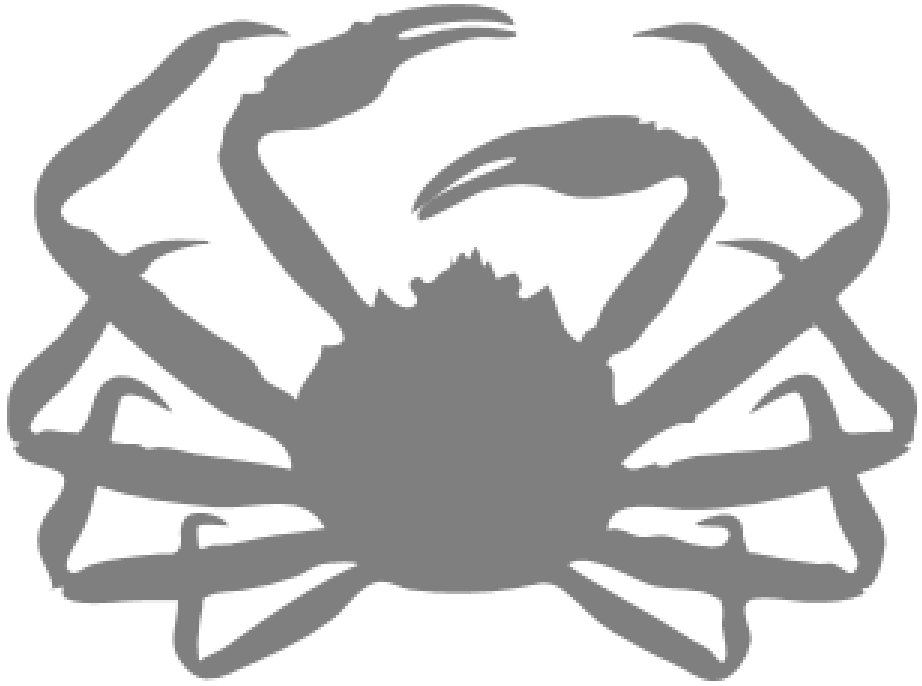


Is it ok to take all the large males because the small males will get the job done?

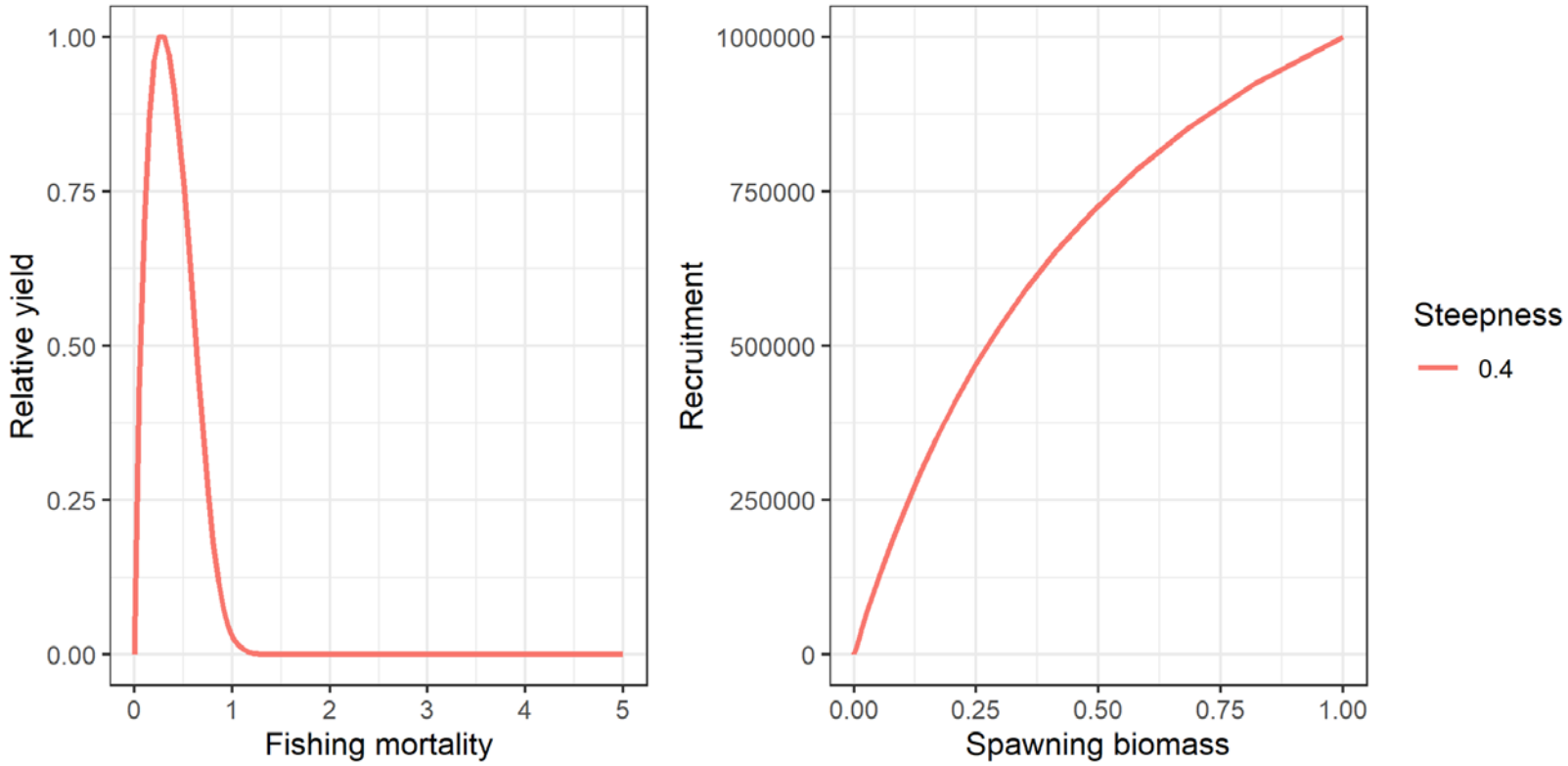
What we know

- Laboratory: Small males can mate with larger females (Watson, 1979)
- Laboratory: Small males are always outcompeted if large males are present (Comeau et al., 1998)
- In situ: Only males larger than 95mm carapace width were observed participating in mating in eastern Canadian waters (Conan and Comeau, 1986).

Given conflicting information, can we incorporate this uncertainty into management?

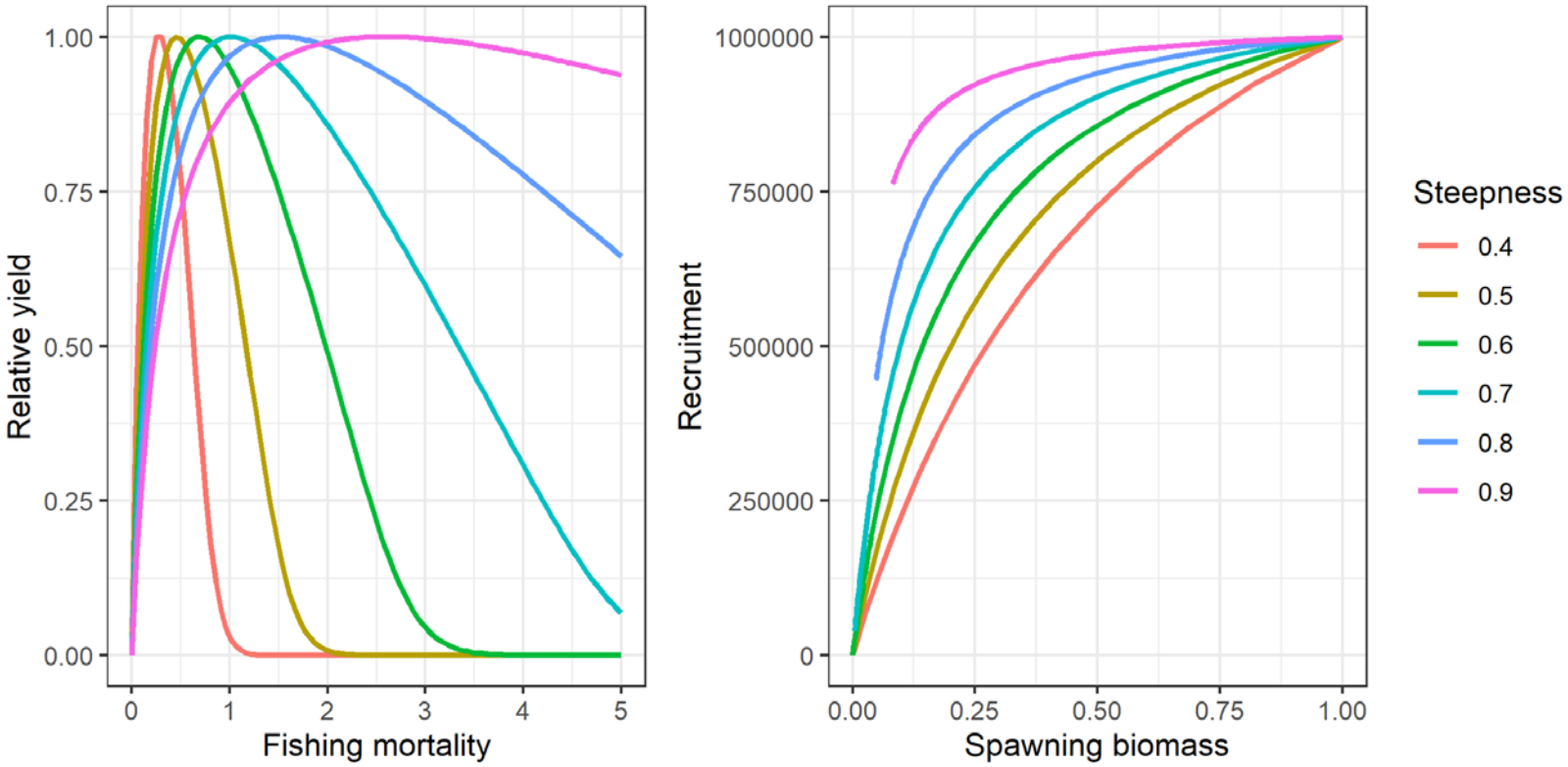
Maximum sustainable yield

- Given life history and equilibrium dynamics, a fishing mortality exists that will provide the maximum yield.
- Stock recruit relationships directly determine MSY.



Maximum sustainable yield

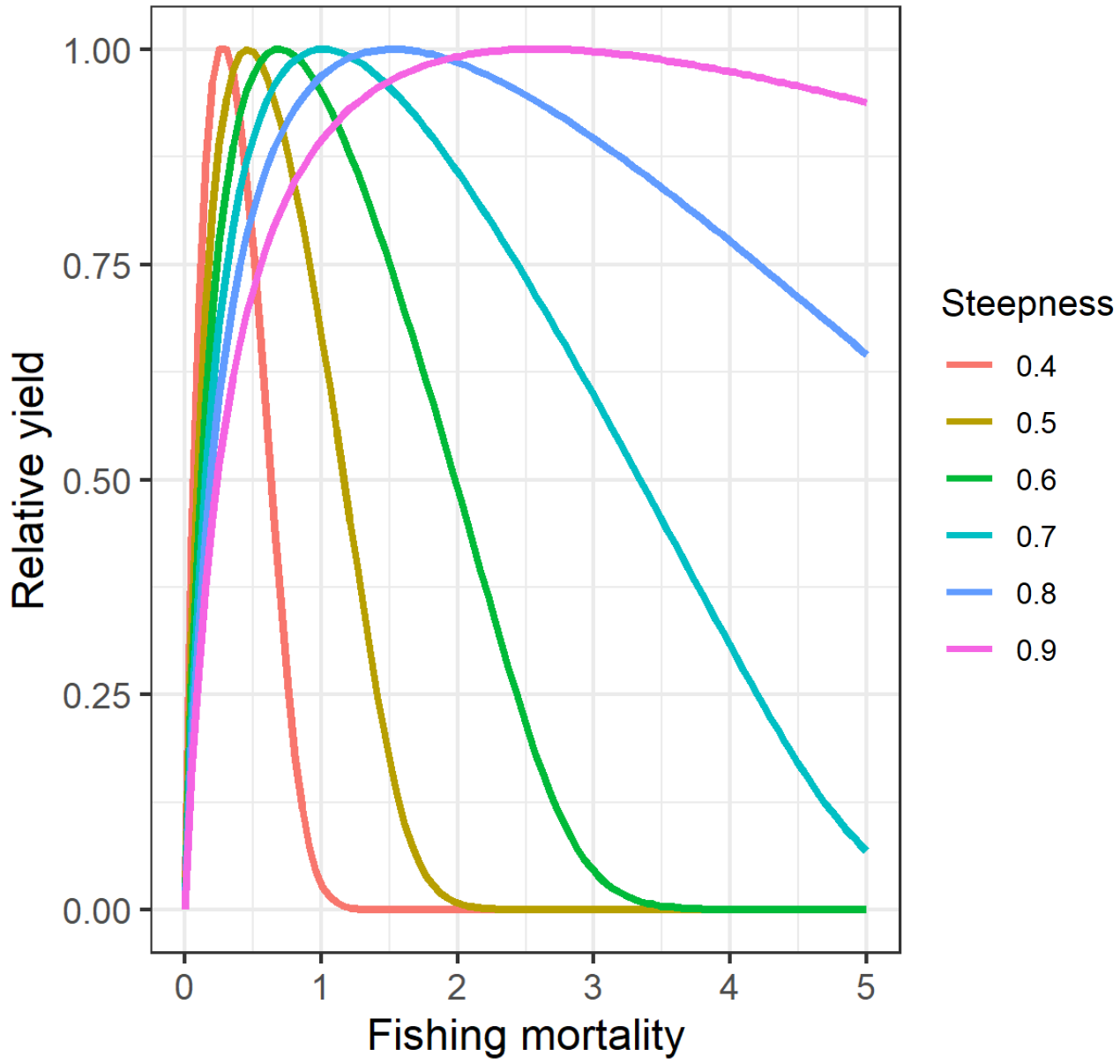
- Given life history and equilibrium dynamics, a fishing mortality exists that will provide the maximum yield.
- Stock recruit relationships directly determine MSY.
- The more recruitment provided for a given spawning biomass, the harder the stock can be fished.



Most stocks (including crab) do not display a stock recruit relationship

Bill Clark's good idea

- Identify a fishing mortality (and therefore spawning biomass) that produces 'pretty good yield' across a range of stock recruit relationship
- Maximize the minimum yield across scenarios



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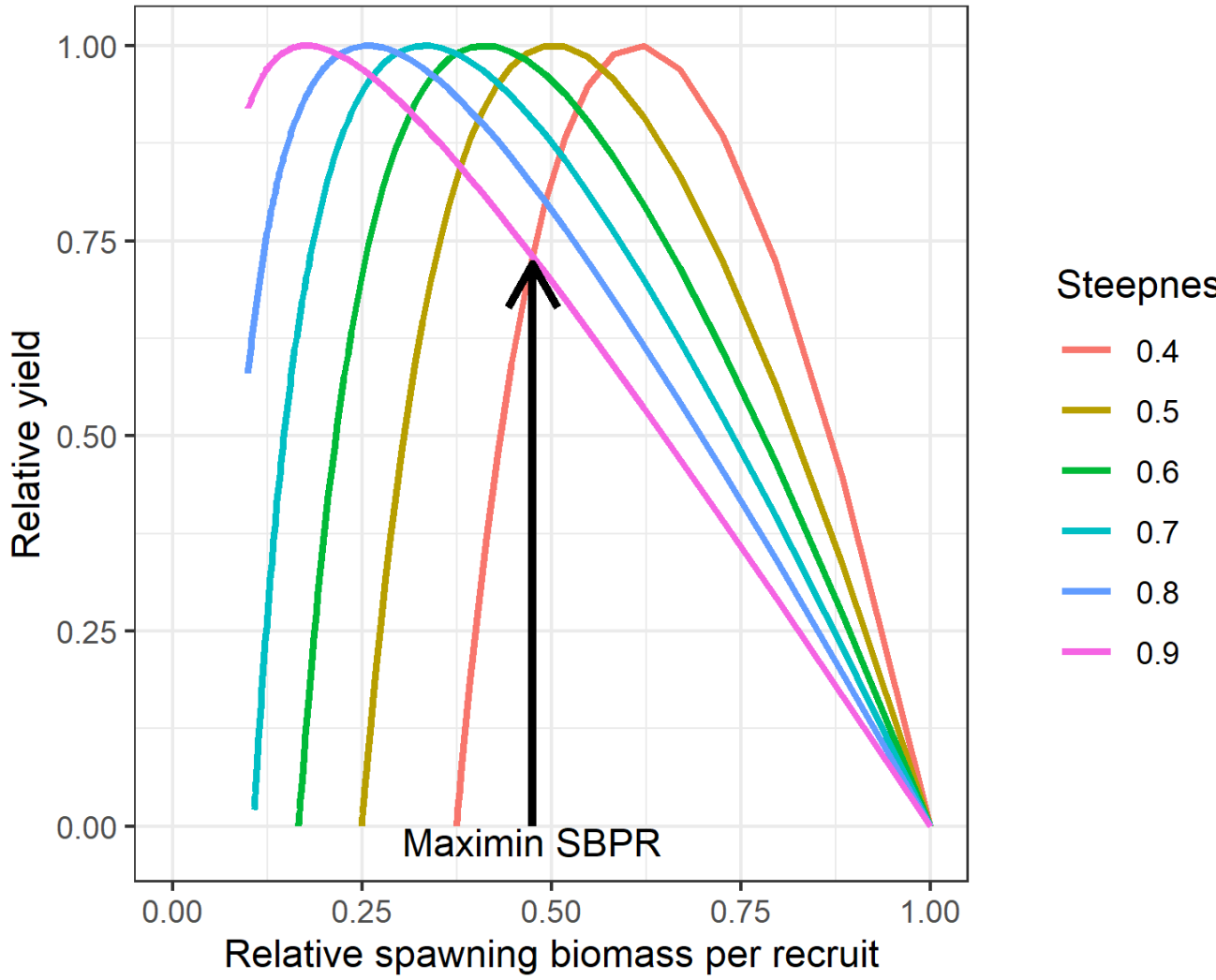


Can we incorporate uncertainty in reproductive activity at size?

Can we incorporate this uncertainty into management?

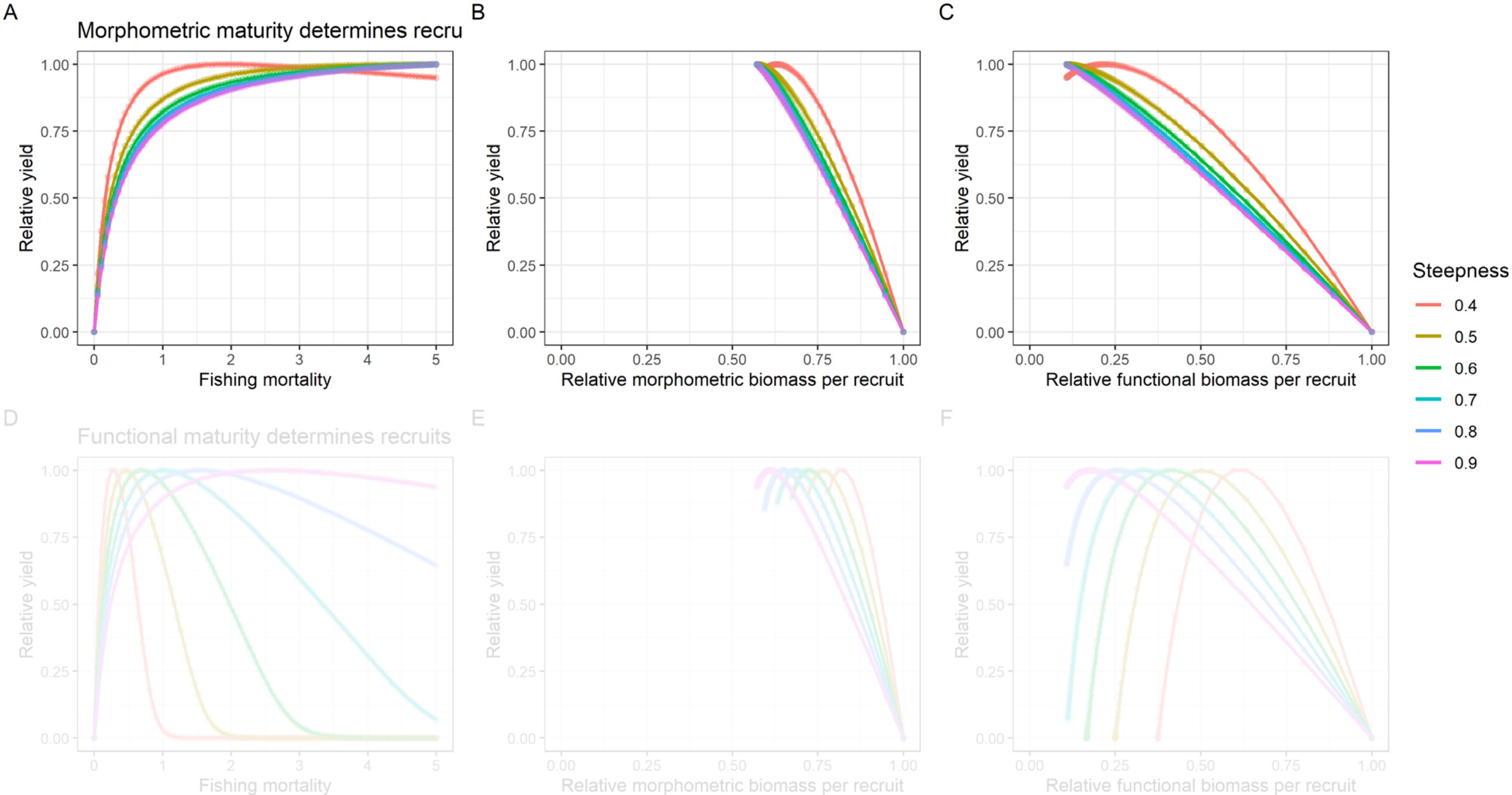
- Repeat Clark's analyses, but with snow crab life history
  - Population dynamics model based on GMACS output
  - Recruitment dynamics based on Beverton Holt curve with steepness ranging from 0.4 to 0.9
  - Project forward to equilibrium for a given fishing mortality
  - Plot equilibrium yield relative to fishing mortality and different currencies of management

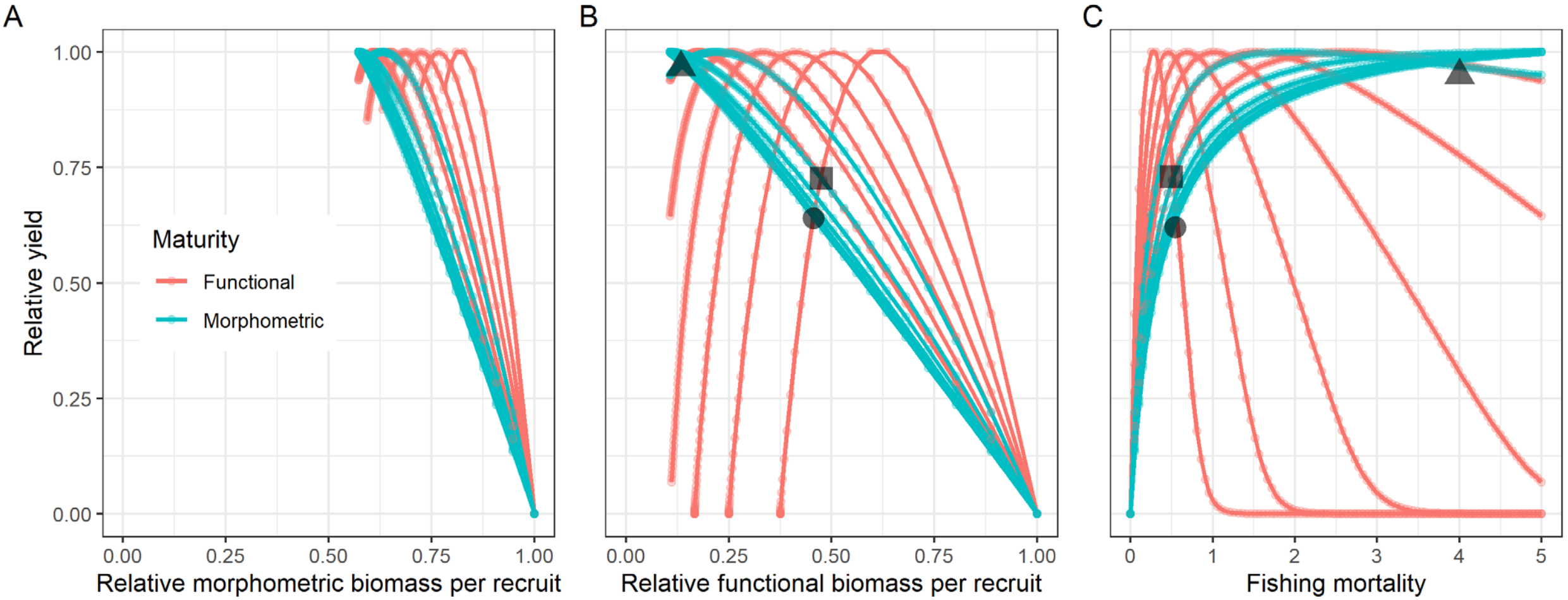
Can we incorporate this uncertainty into management?

- Repeat Clark's analyses, but with snow crab life history
- Add another axis to represent uncertainty in the size at which mature crab contribute to reproduction

- Scenarios differ in what sizes are used for 'spawning biomass' in recruitment and reference point calculations:
  - Morphometric maturity is determined by chela height
  - Functional maturity (>95 mm)

- Looking for a reference point that represents a compromise between these two hypotheses about reproductive dynamics


A
Morphometric maturity determines recru
Relative yield
Fishing mortality
B
Relative yield
Relative morphometric biomass per recruit
C
Relative yield
Relative functional biomass per recruit
Steepness
0.4
0.5
0.6
0.7
0.8
0.9
D
Functional maturity determines recruits
Relative yield
Fishing mortality
E
Relative yield
Relative morphometric biomass per recruit
F
Relative yield
Relative functional biomass per recruit



Triangle represents the maximin solution when morphometric maturity drives dynamics.

Square represents the maximin solution when functional maturity drives dynamics.

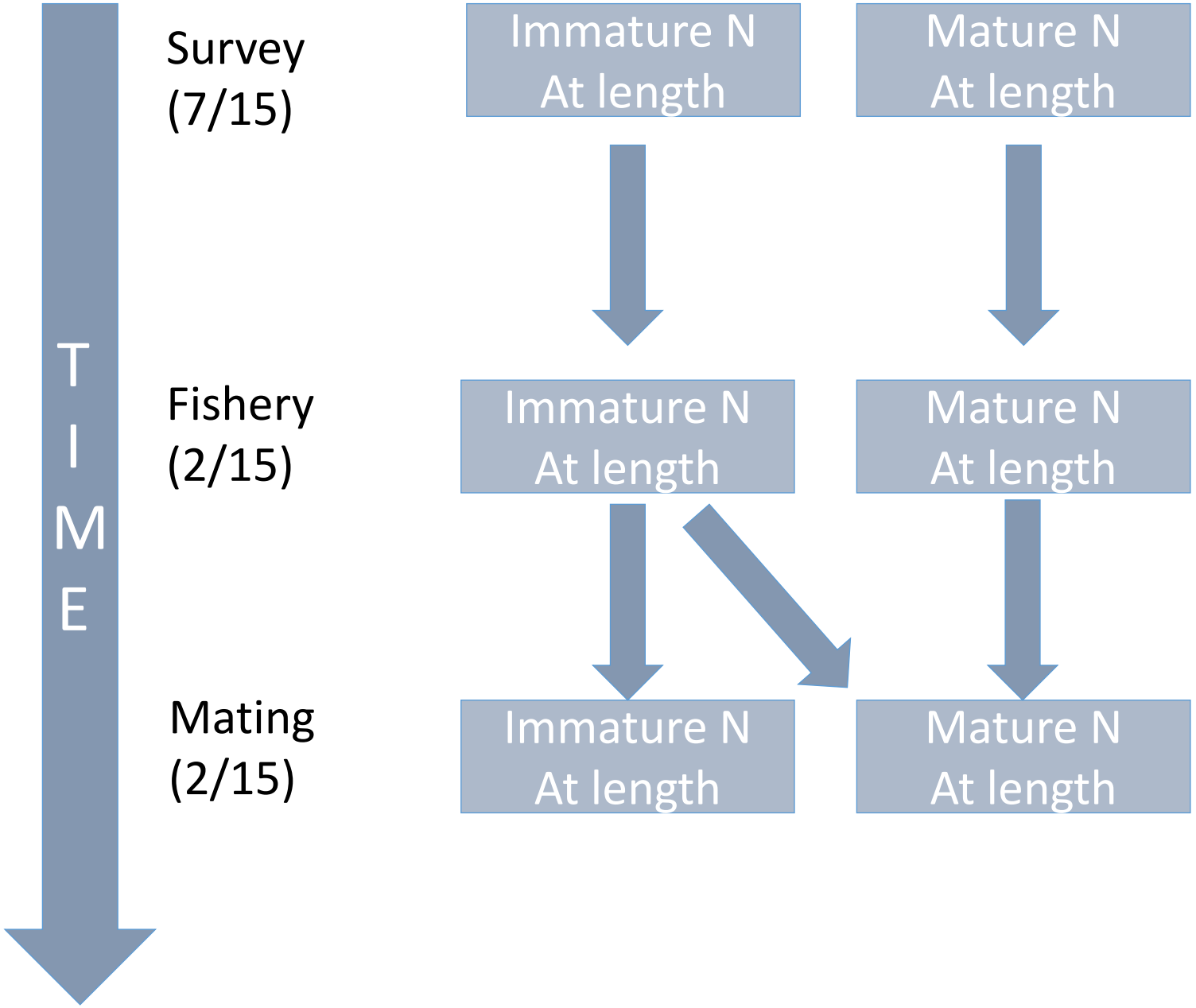
Circle represents the maximin compromise between the hypotheses.

One GMACS model, three HCR configurations for consideration:

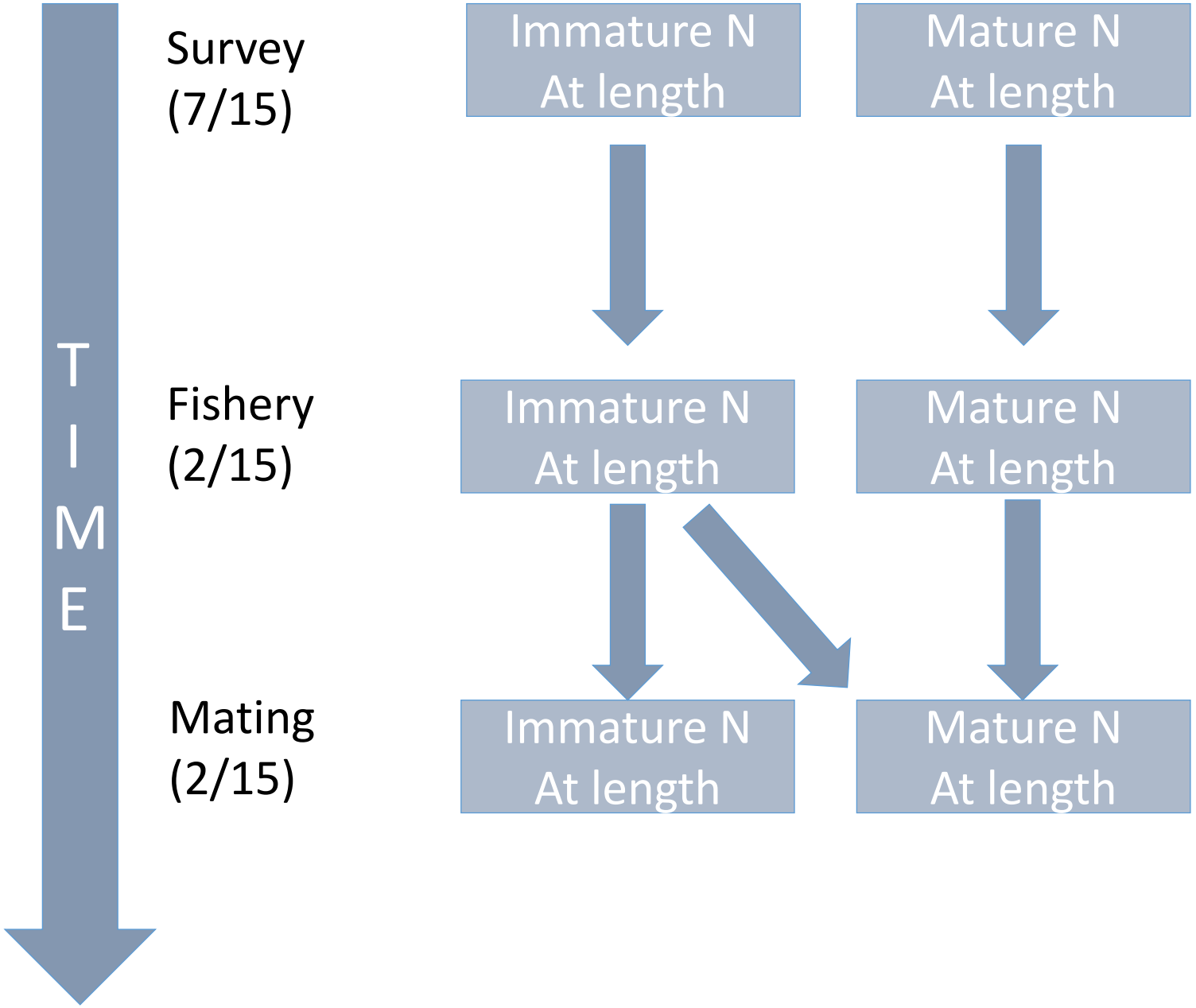
Model	Currency of management	SBPR%
24.1a	Morphometric mature biomass	35%
24.1b	>95mm mature biomass	35%
24.1c	>95mm mature biomass	45%

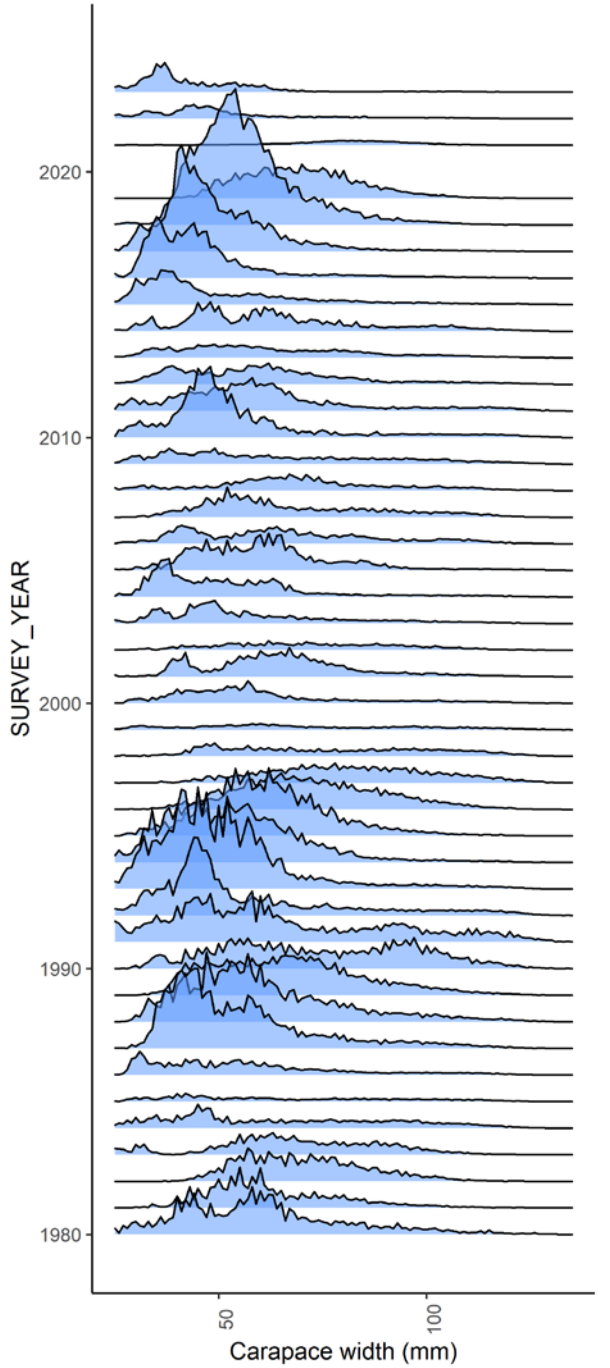
Assessment model

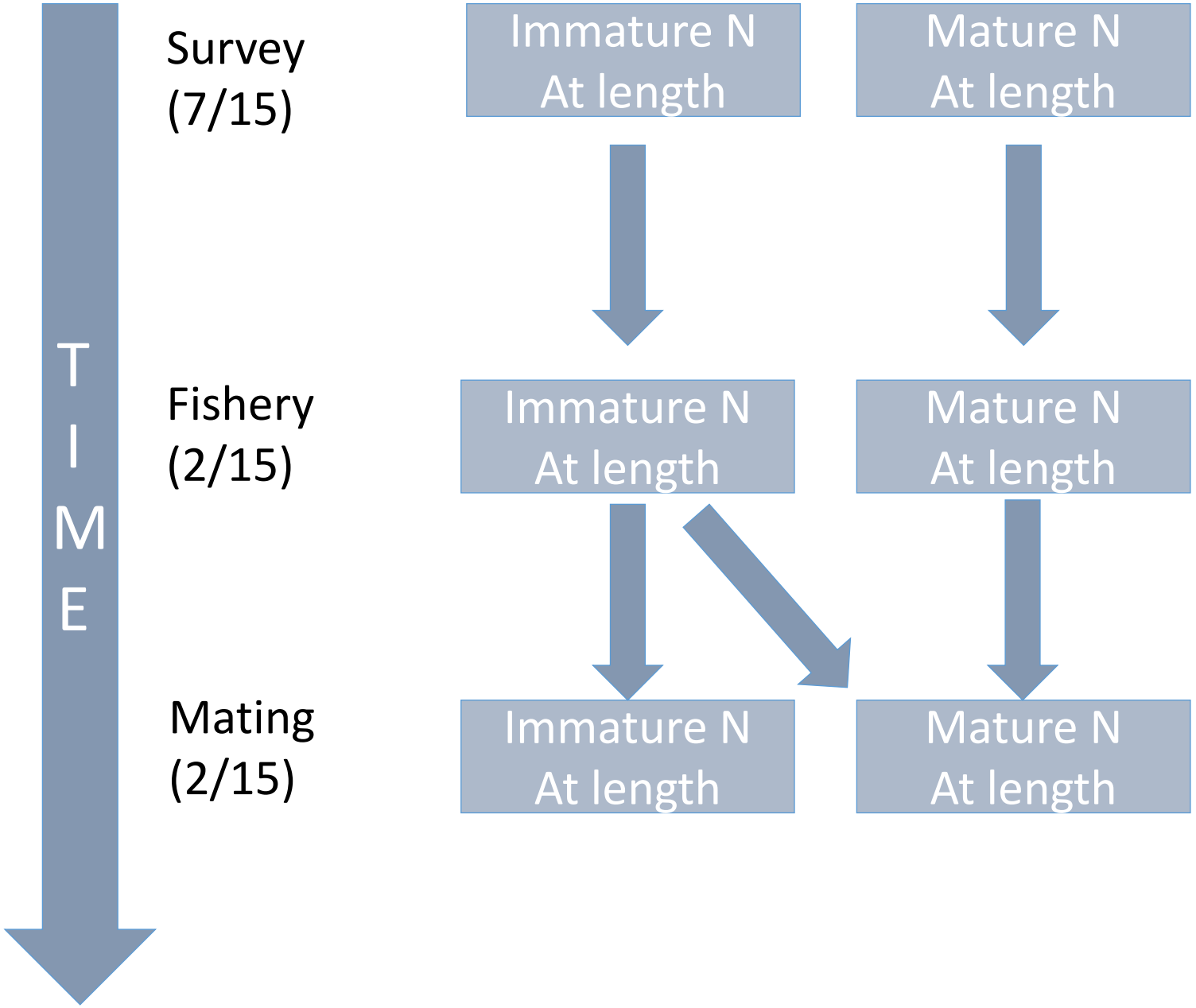
Process	Historical assumptions	Updated assumptions	Rationale
Recruits	Equal sex ratio	Unequal sex ratios	Retrospective patterns
Natural mortality	Constant with strong priors	Strong priors and time-block in 2018-2019	Lack of survey fit
Growth	Piece-wise	Linear	Model instability
Maturity	Single estimated ogive	Input yearly observations	Data interpretation
Fishing mortality	Freely estimated	GMACS changed form	Reproducibility
Fishery selectivity	Freely estimated	GMACS changed form	Reproducibility
Survey selectivity	Logistic, BSFRF as survey	Non-parametric, BSFRF as priors	Data interpretation



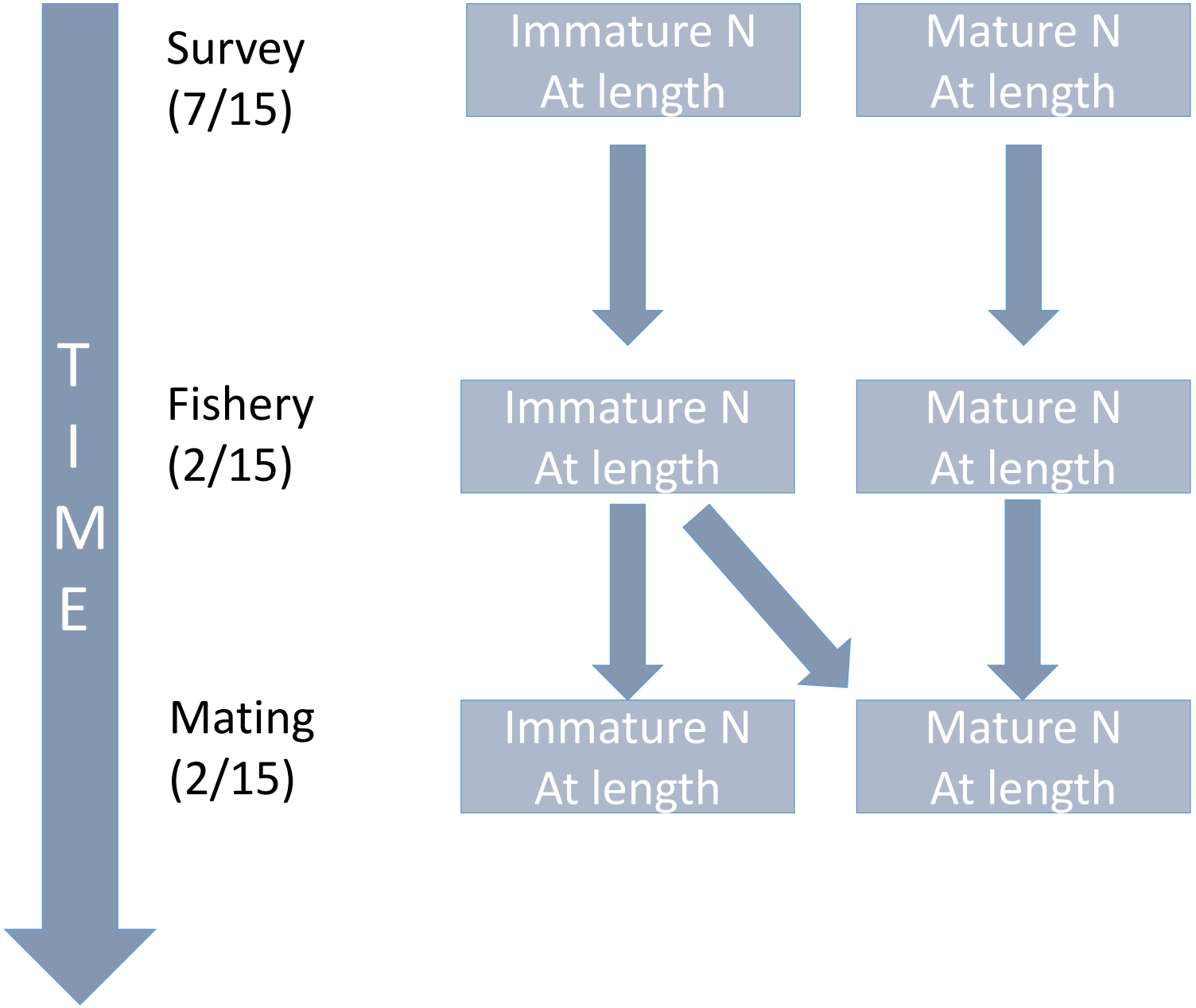
	27.5	32.5	37.5	42.5	47.5	52.5	57.5	62.5	....
1982									
1983									
1984									
1985									
1986									
1987									
....									


TIME
Survey
(7/15)
Immature N
At length
Mature N
At length
Fishery
(2/15)
Immature N
At length
Mature N
At length
Mating
(2/15)
Immature N
At length
Mature N
At length

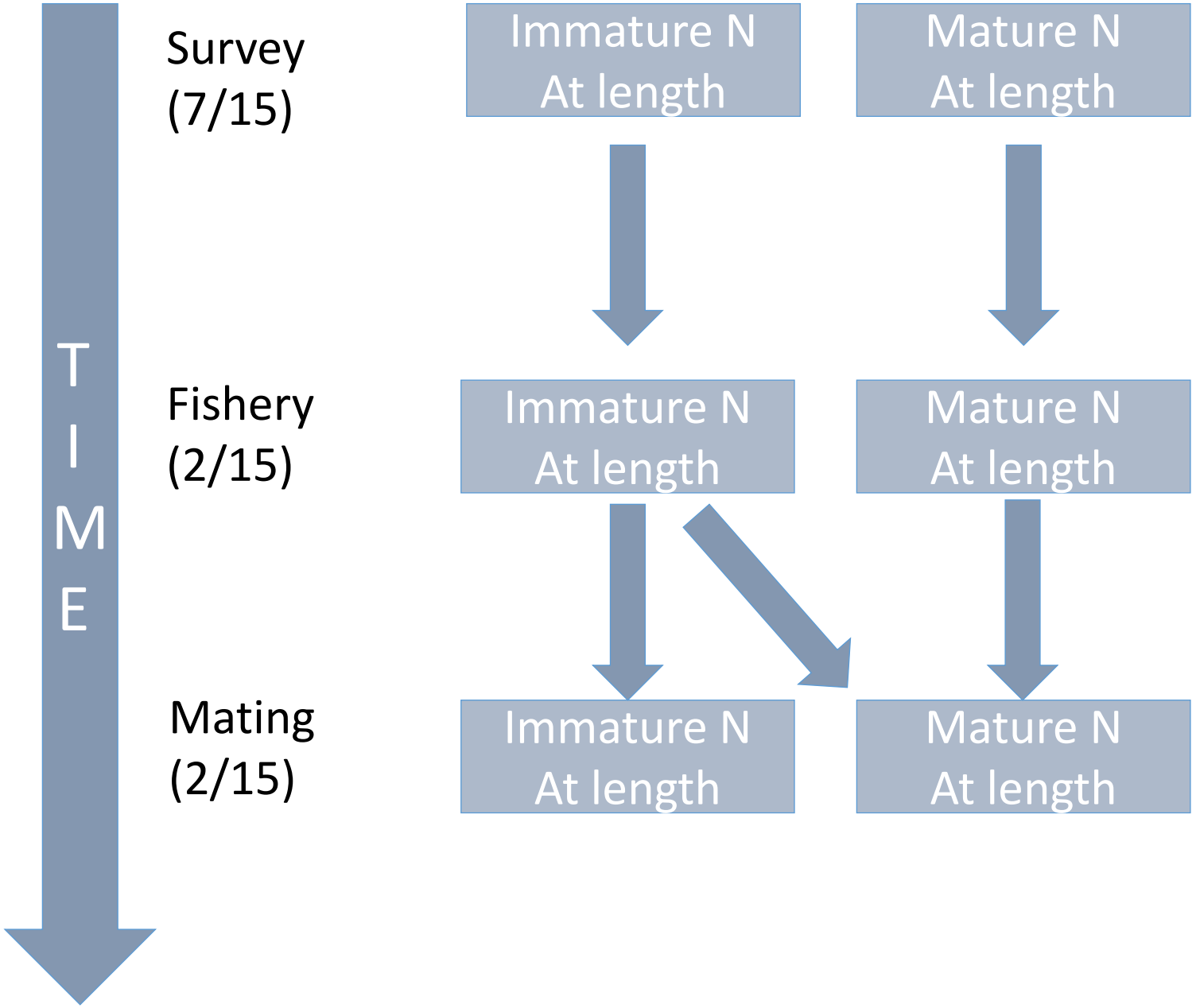

SURVEY_YEAR
2020
2010
2000
1990
1980
50
100
Carapace width (mm)



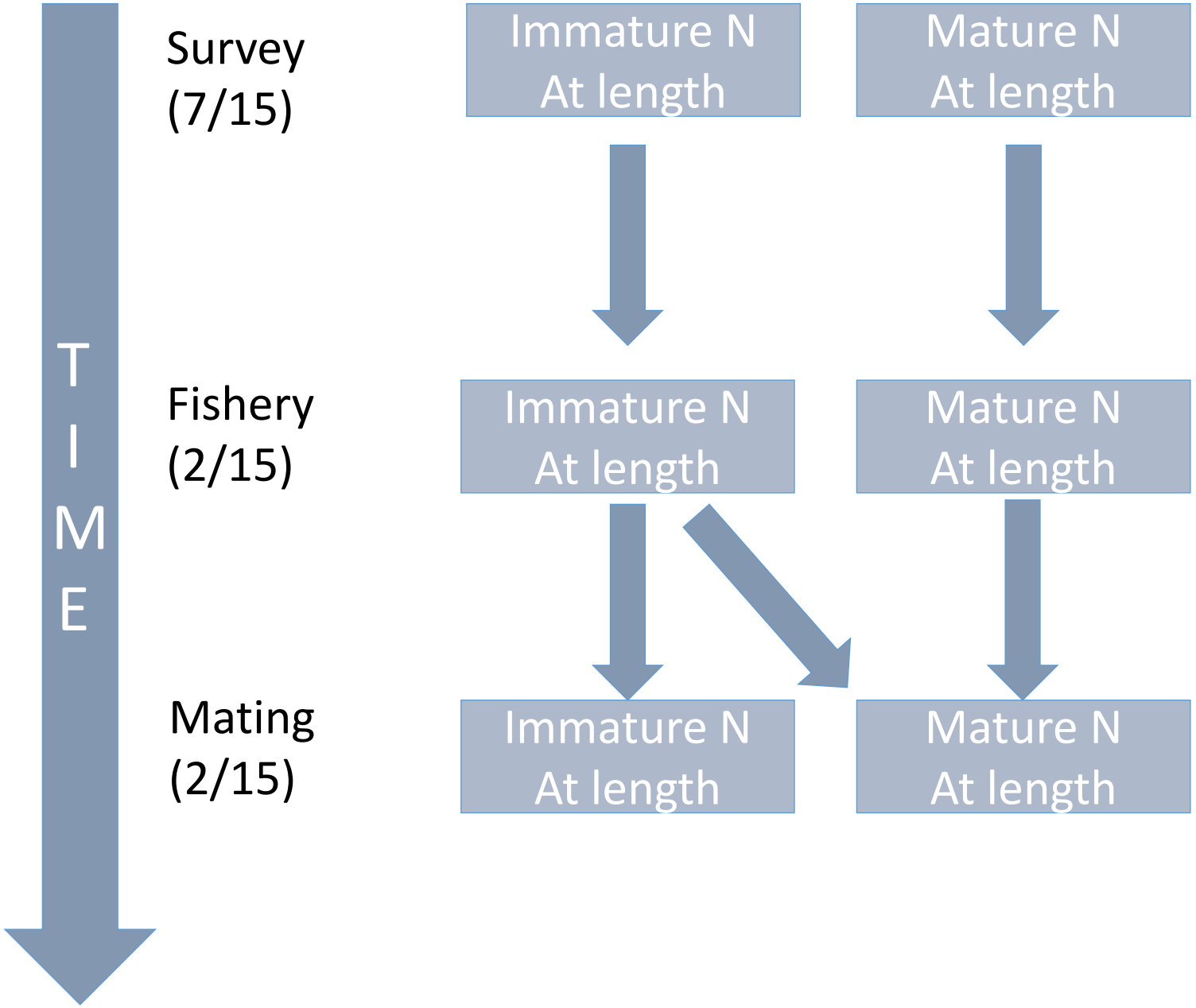
Survey data collected with an estimated selectivity



Natural mortality occurs (estimated by sex and maturity state + events)

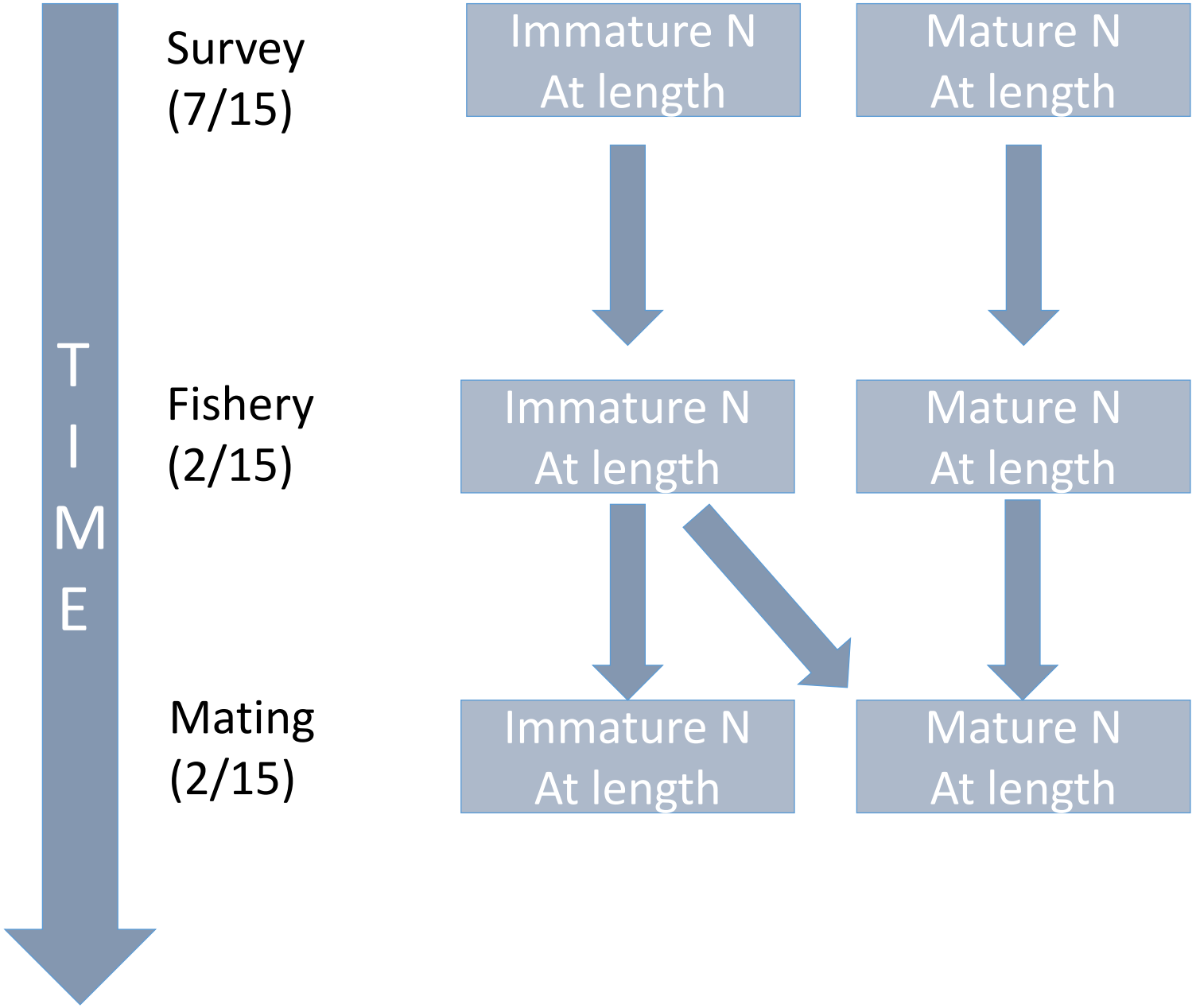


Directed and non-directed fishery occur with sex and fishery specific selectivity.

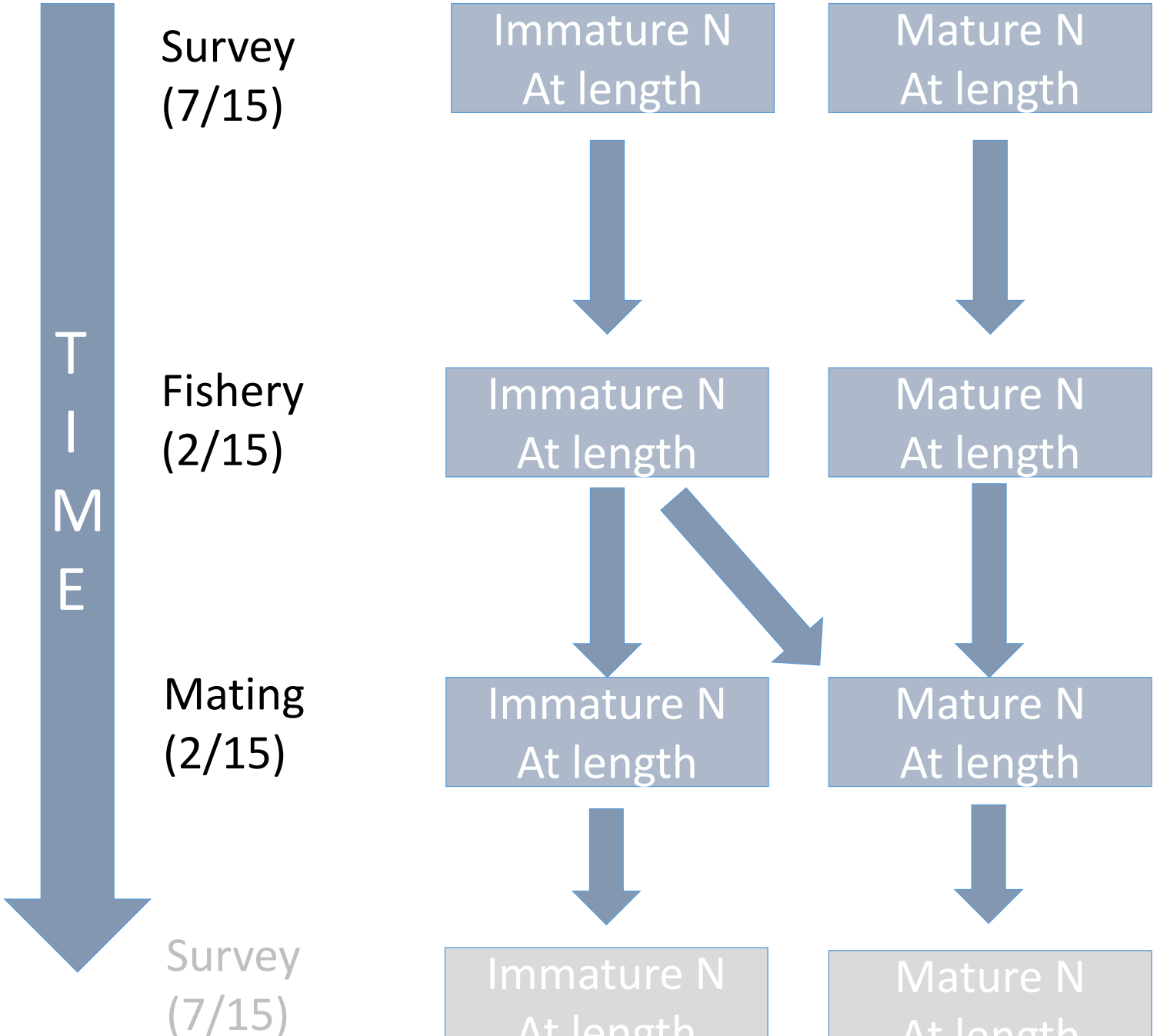


Growth occurs

After growth previously immature animals are allocated to immature or mature size bins based on a probability of having undergone terminal molt.



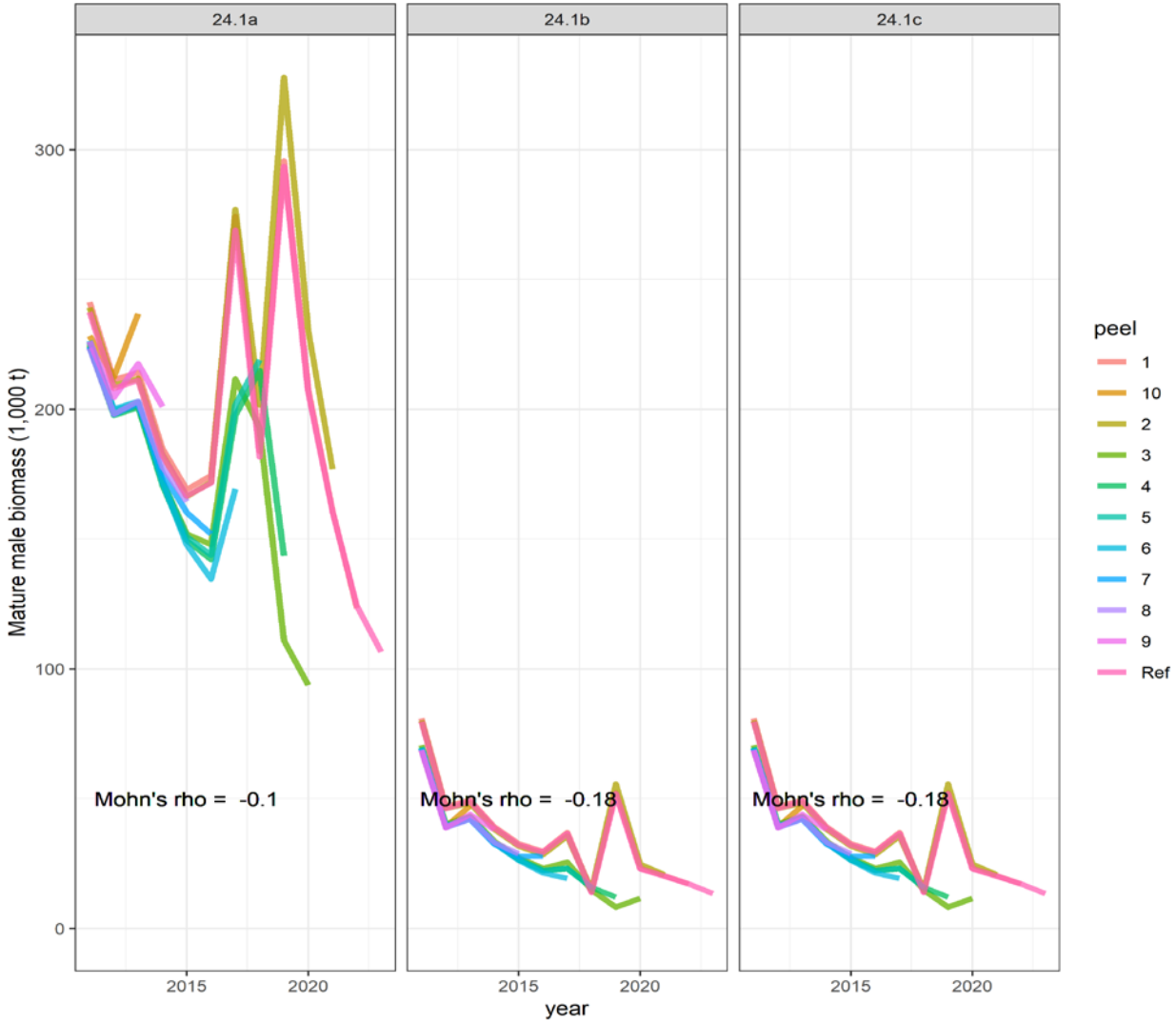
Recruitment occurs and is primarily allocated to the first three size bins.



Remaining natural mortality applied before the next survey.

Model diagnostics

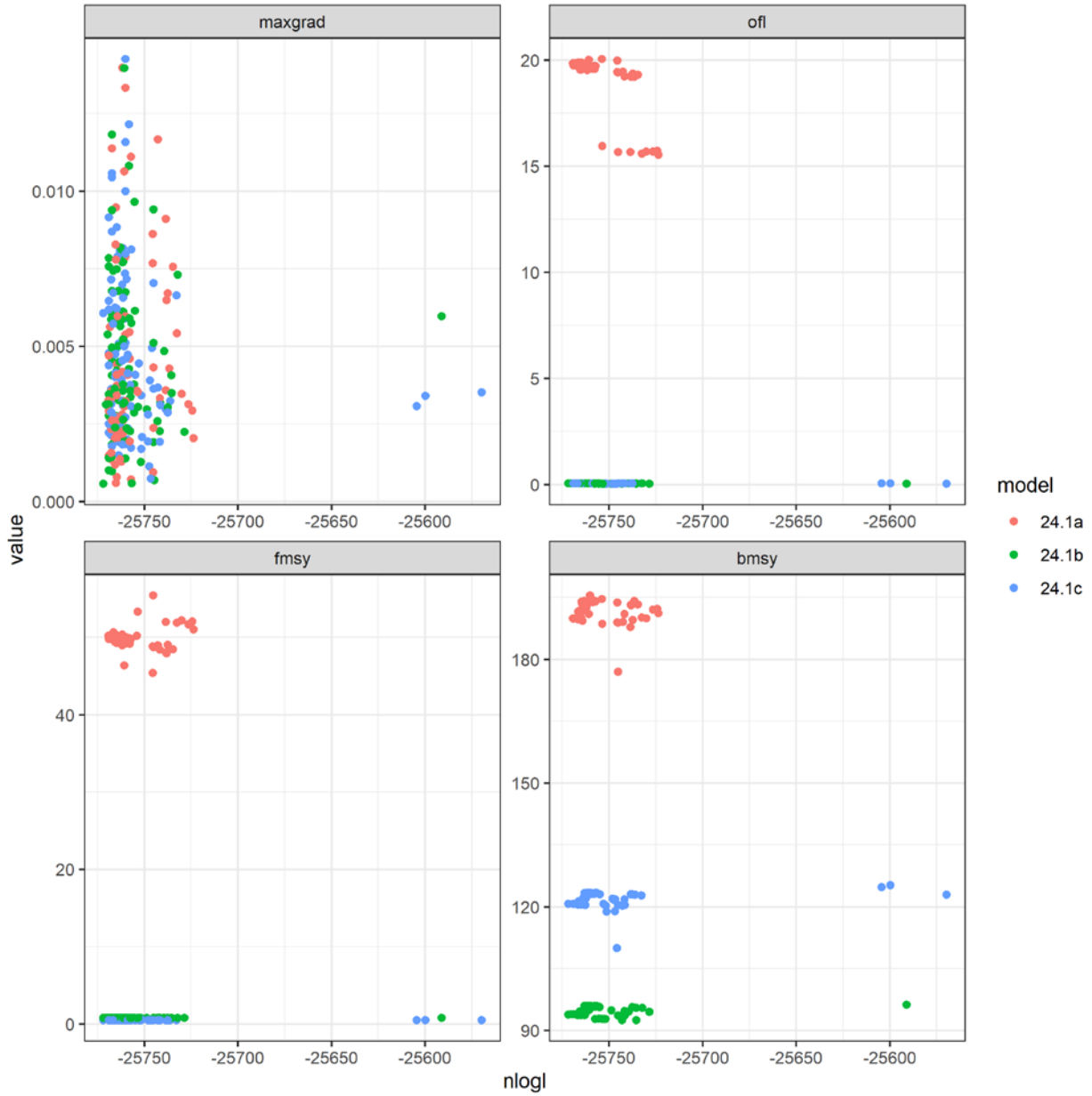
- Retrospective patterns are not concerning



Retrospective patterns in estimated mature male biomass for selected models.

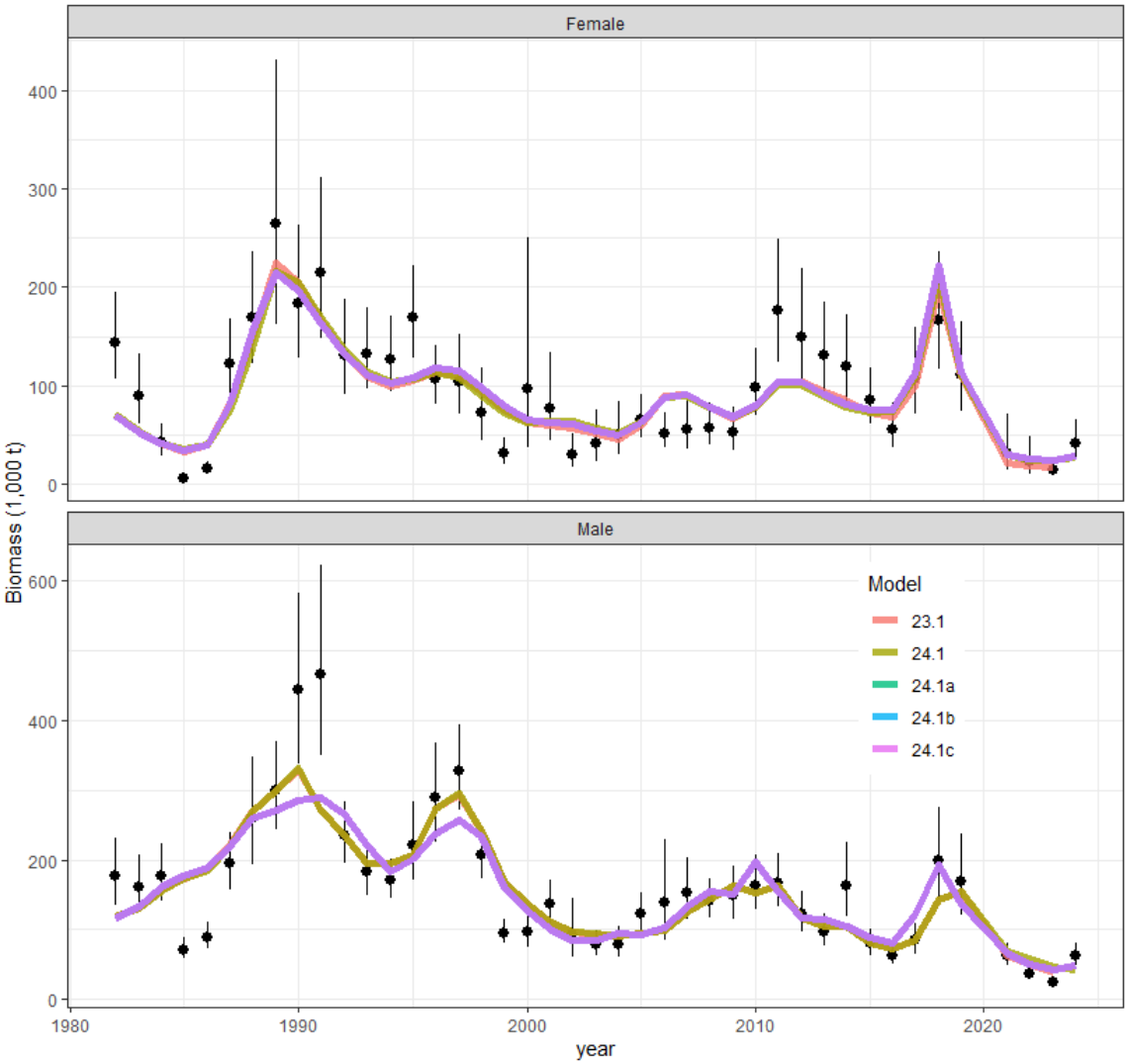
Model diagnostics

- Retrospective patterns are not concerning
- Jittering patterns are concerning



Output of 100 jittered model fittings for selected models. Top left is the maximum gradient component, top right is the overfishing level, bottom left is F35, and bottom right is B35. Each dot represent an instance of a jittered fitted model and are colored based on the OFL resulting from that run.

Data source	comments
FMB index	Reasonable fits with a run of underestimates starting 2010
MMB index	No concerning runs, but large underestimates in high years in the 1990s
Growth	
Catch biomass	
Catch size composition	
Survey size composition	
BSFRF priors	



Model fits to the observed mature biomass at survey.

Data source	comments
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Catch biomass	
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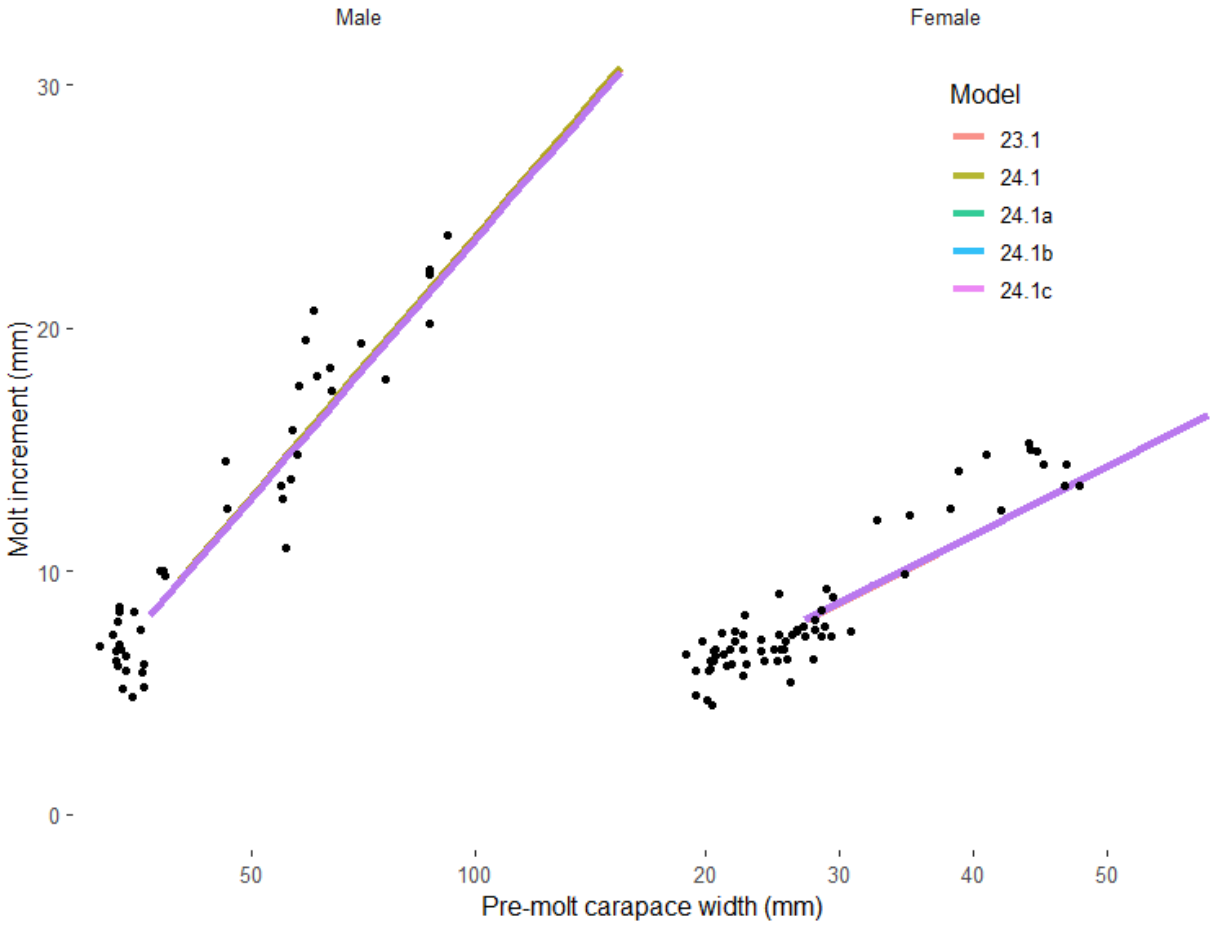

Model fits (colored lines) to the growth data (black dots).

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Catch biomass	All well fit
Catch size composition	
Survey size composition	
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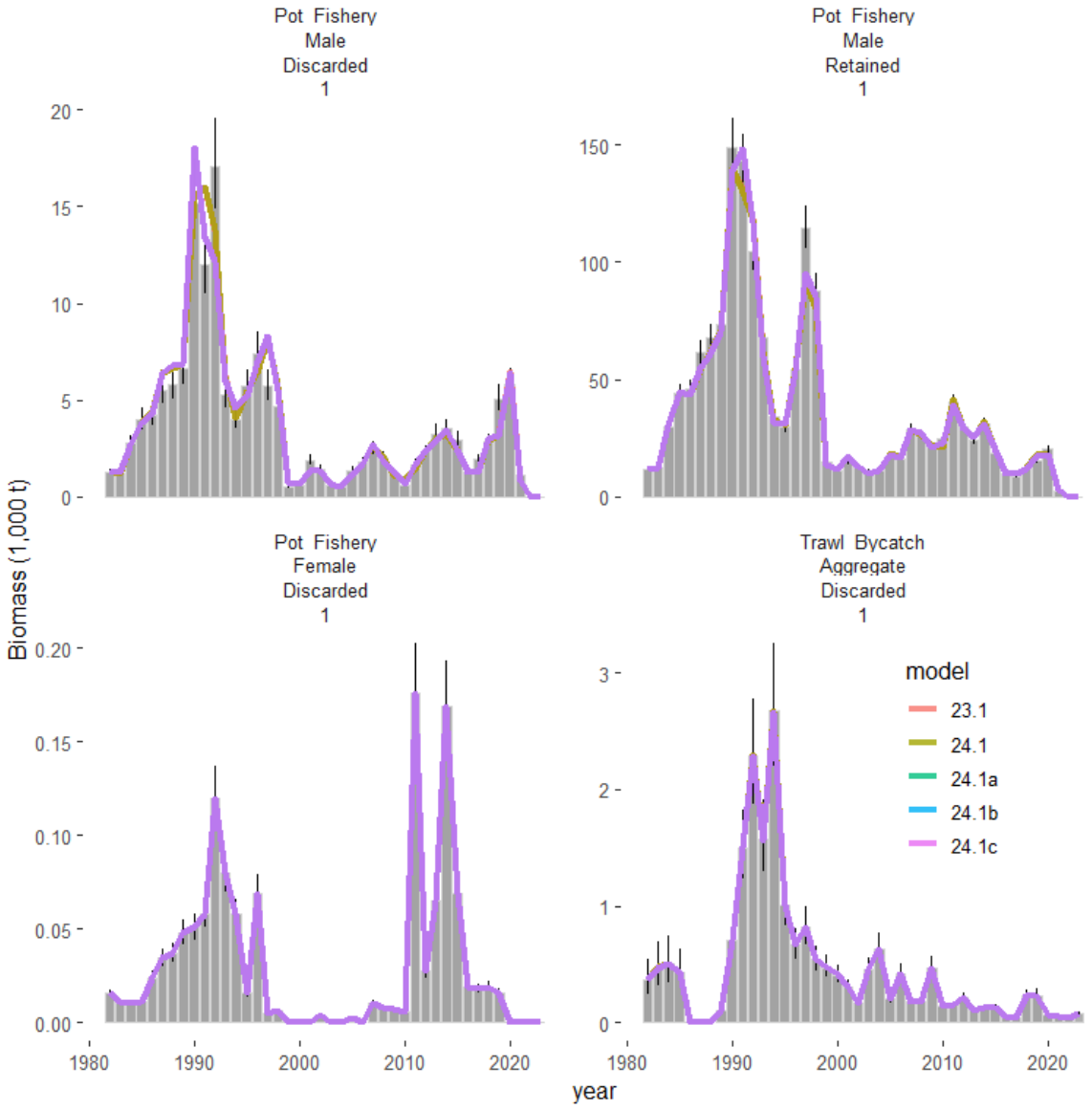

Model fits to catch data.

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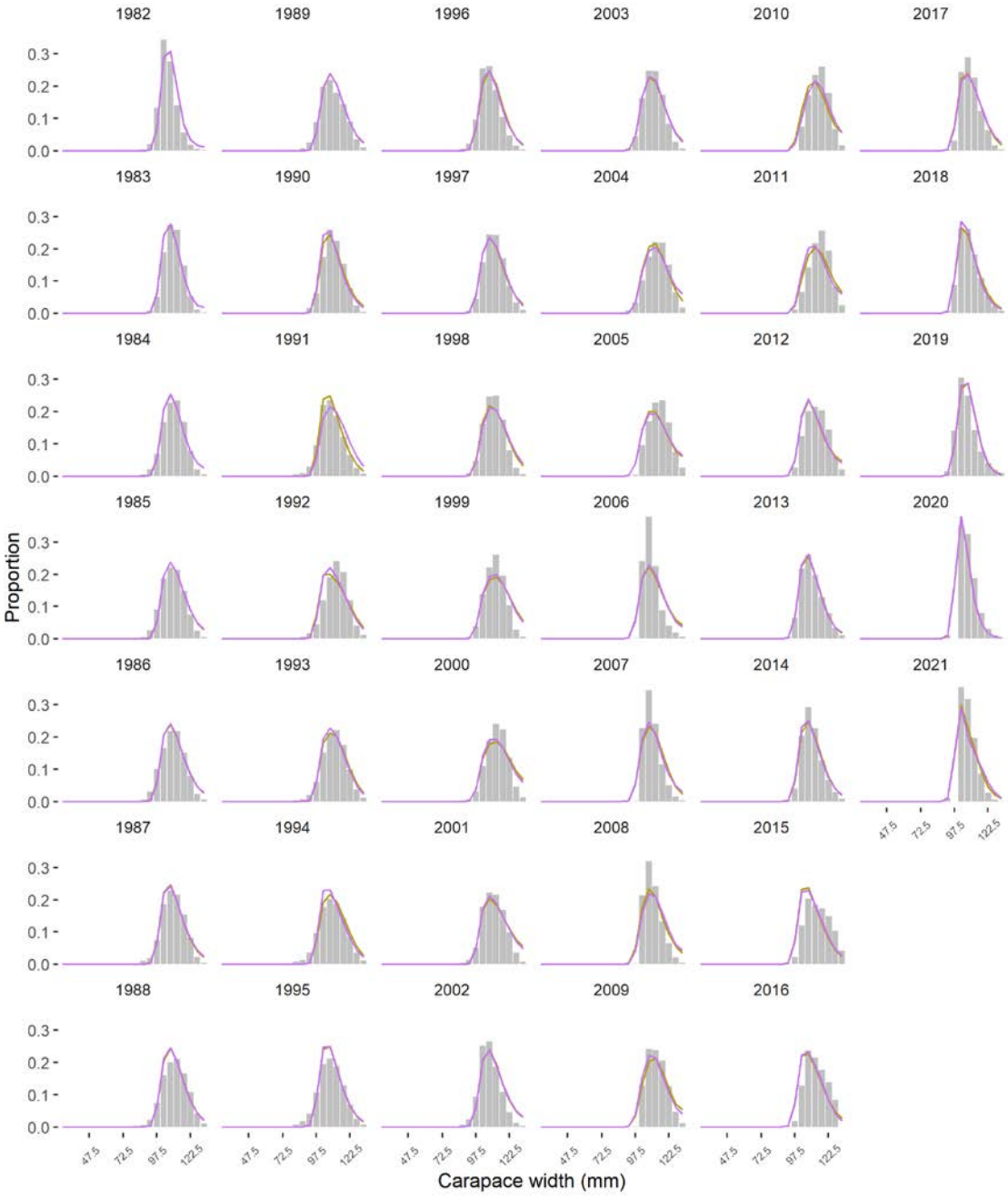
Catch size composition	More large males in retained and total catch than observed
Survey size composition	
BSFRF priors	



RETAINED

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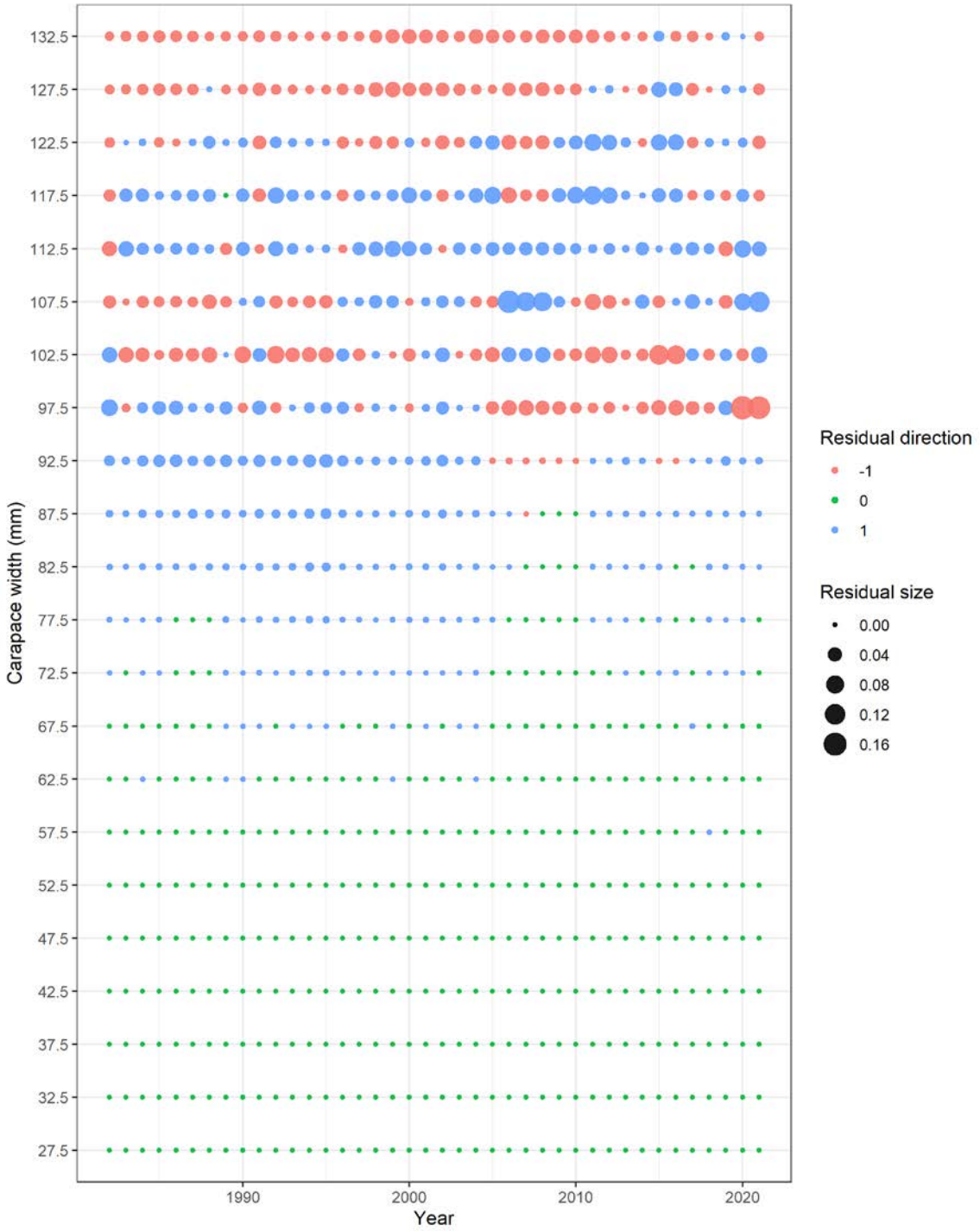

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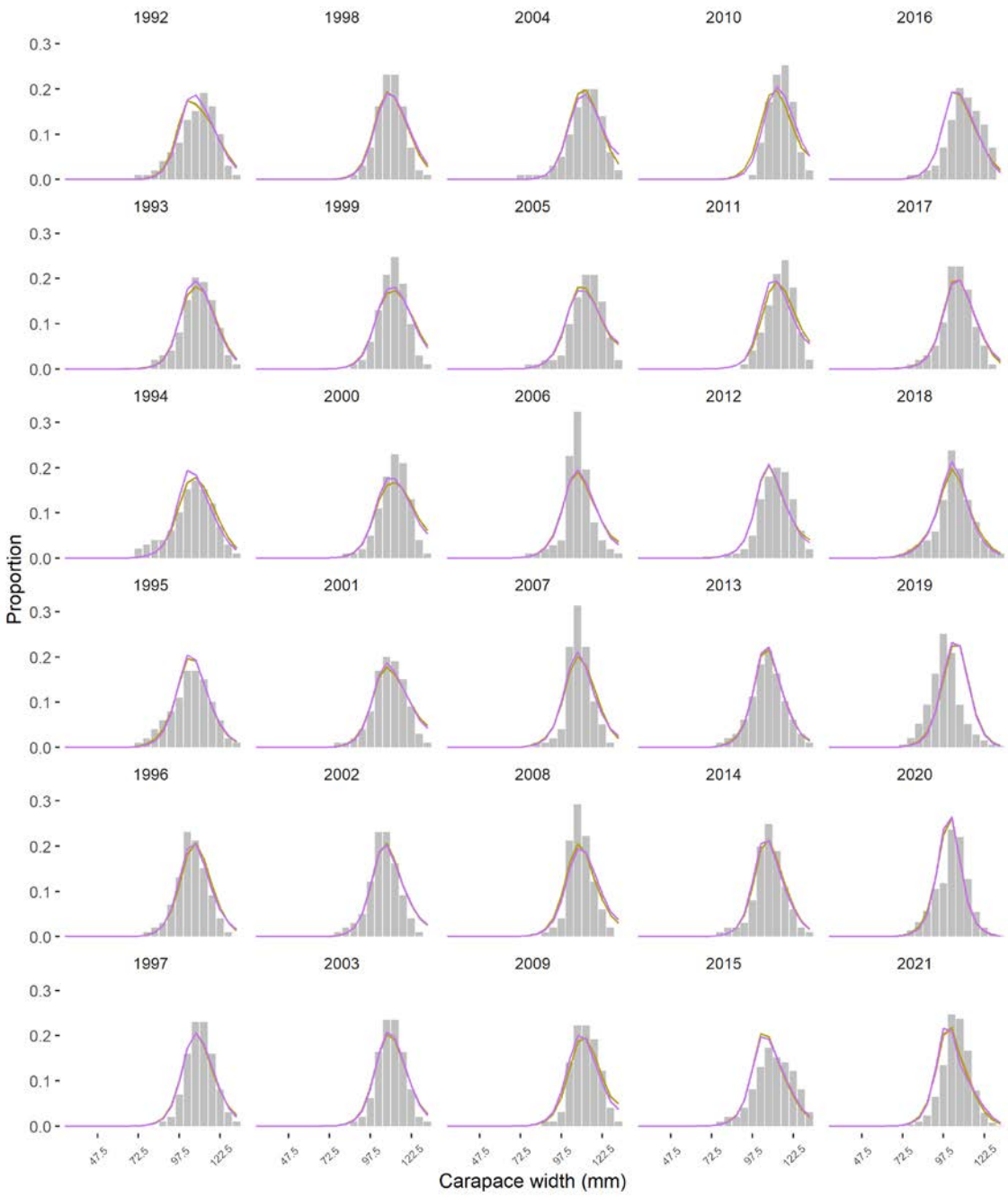
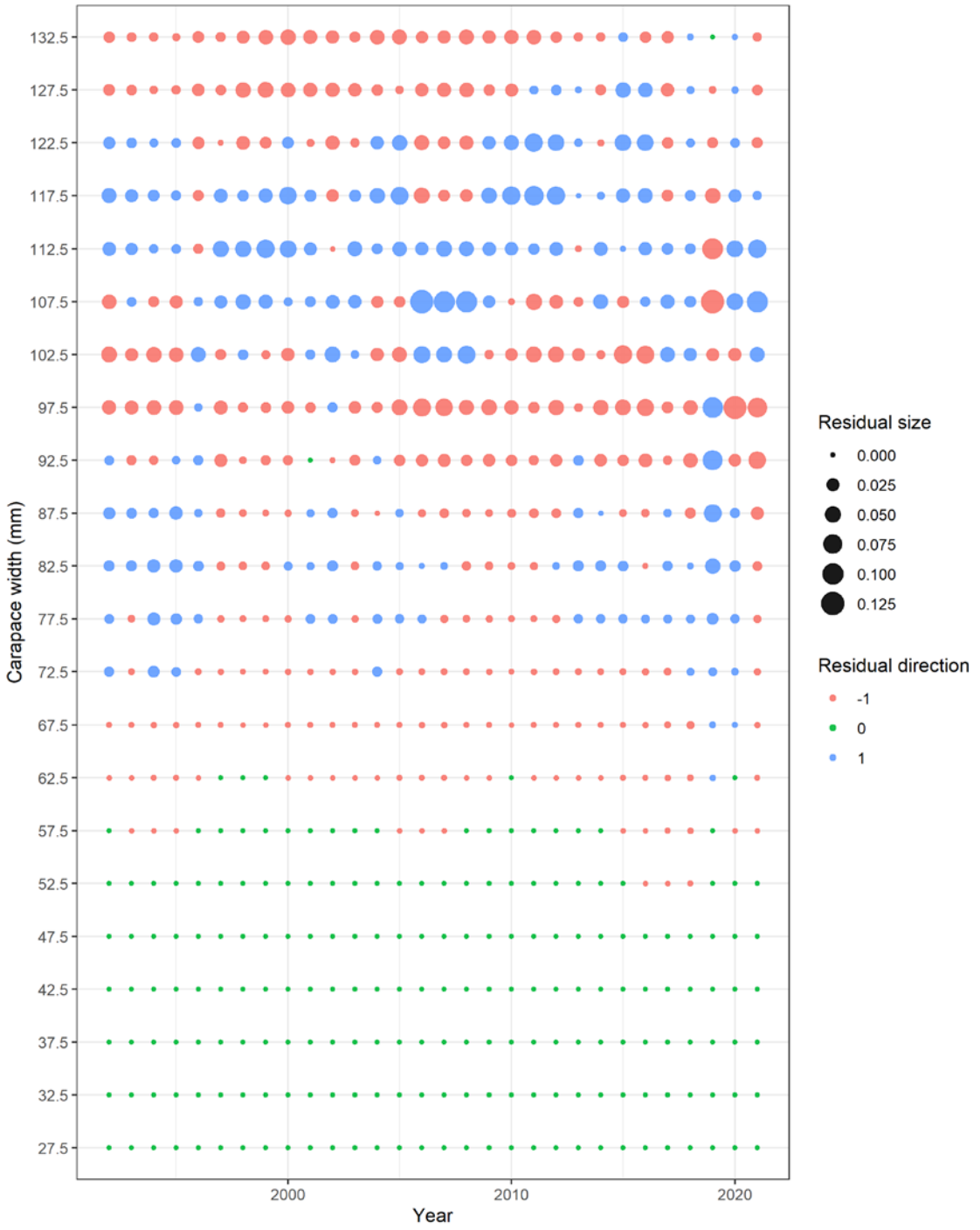
Survey size composition	
BSFRF priors	



TOTAL

Data source	comments
FMB index	Reasonable fits with a run of underestimates starting 2010
MMB index	No concerning runs, but large underestimates in high years in the 1990s
Growth	Males fit well, females underestimated at large sizes. Data for large males would be useful
Catch biomass	All well fit
Catch size composition	More large males in retained and total catch than observed
Survey size composition	
BSFRF priors	



Data source	comments
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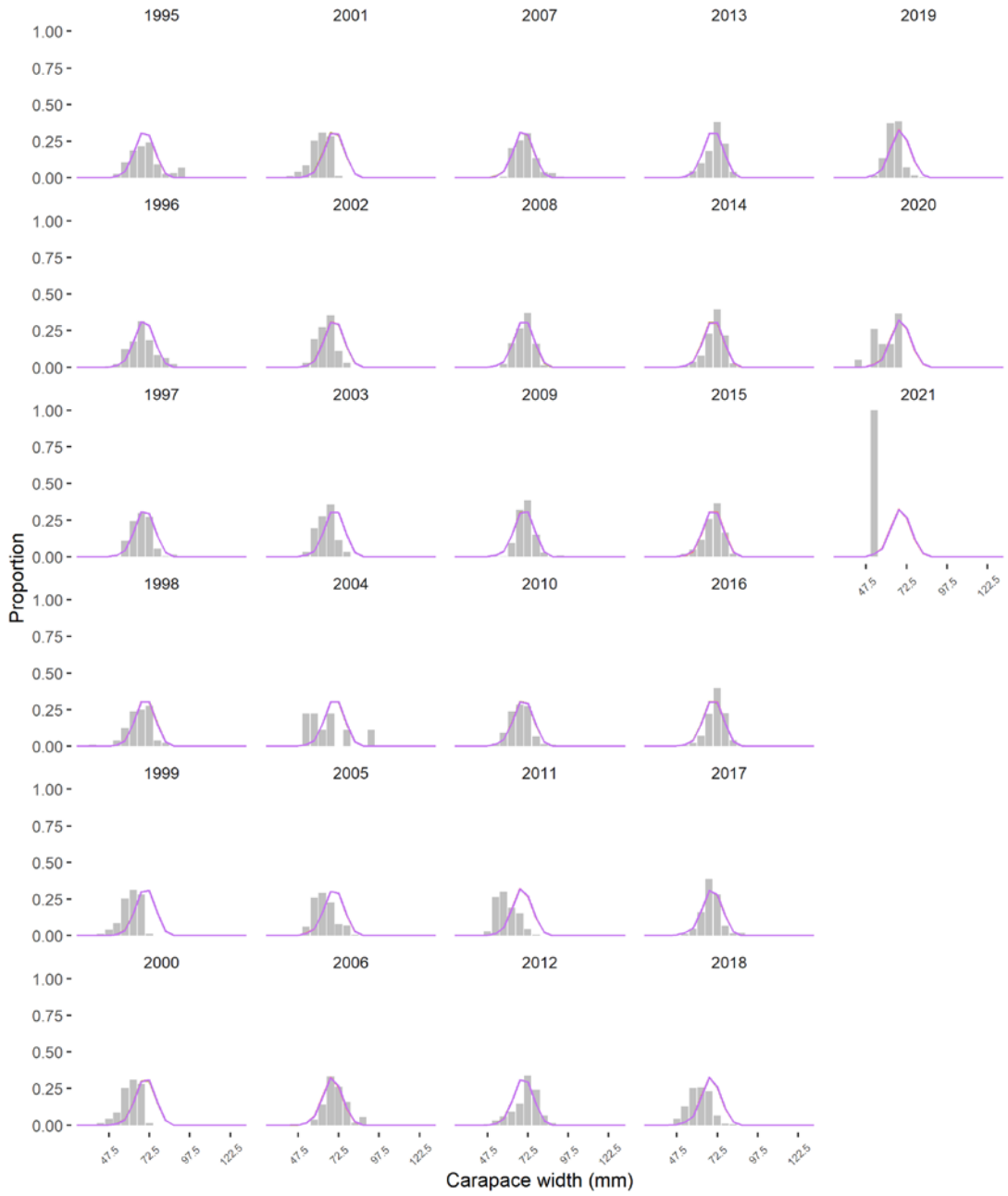
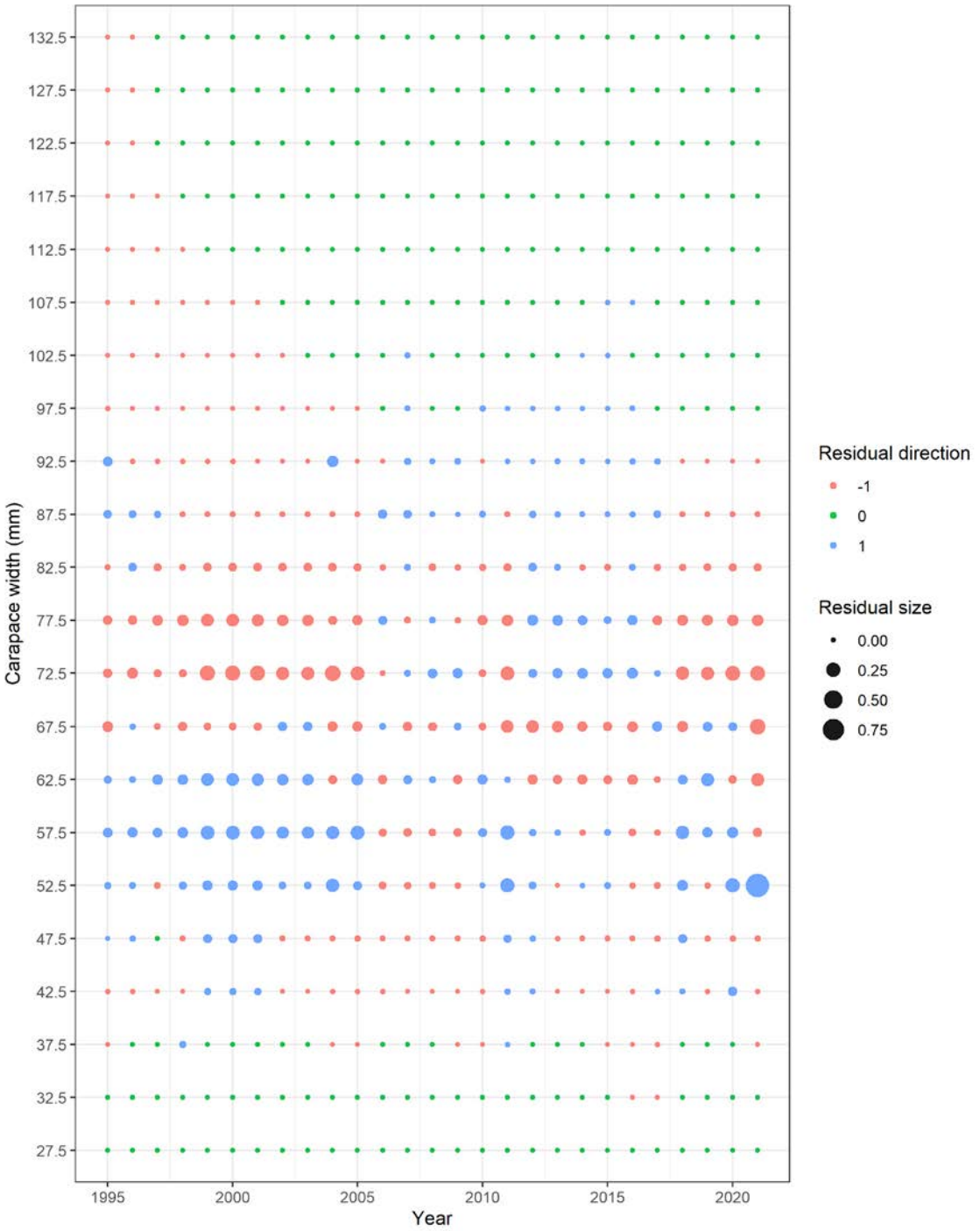
MMB index	No concerning runs, but large underestimates in high years in the 1990s
Growth	Males fit well, females underestimated at large sizes. Data for large males would be useful
Catch biomass	All well fit
Catch size composition	More large males in retained and total catch than observed. Some years female discards poorly fit
Survey size composition	
BSFRF priors	

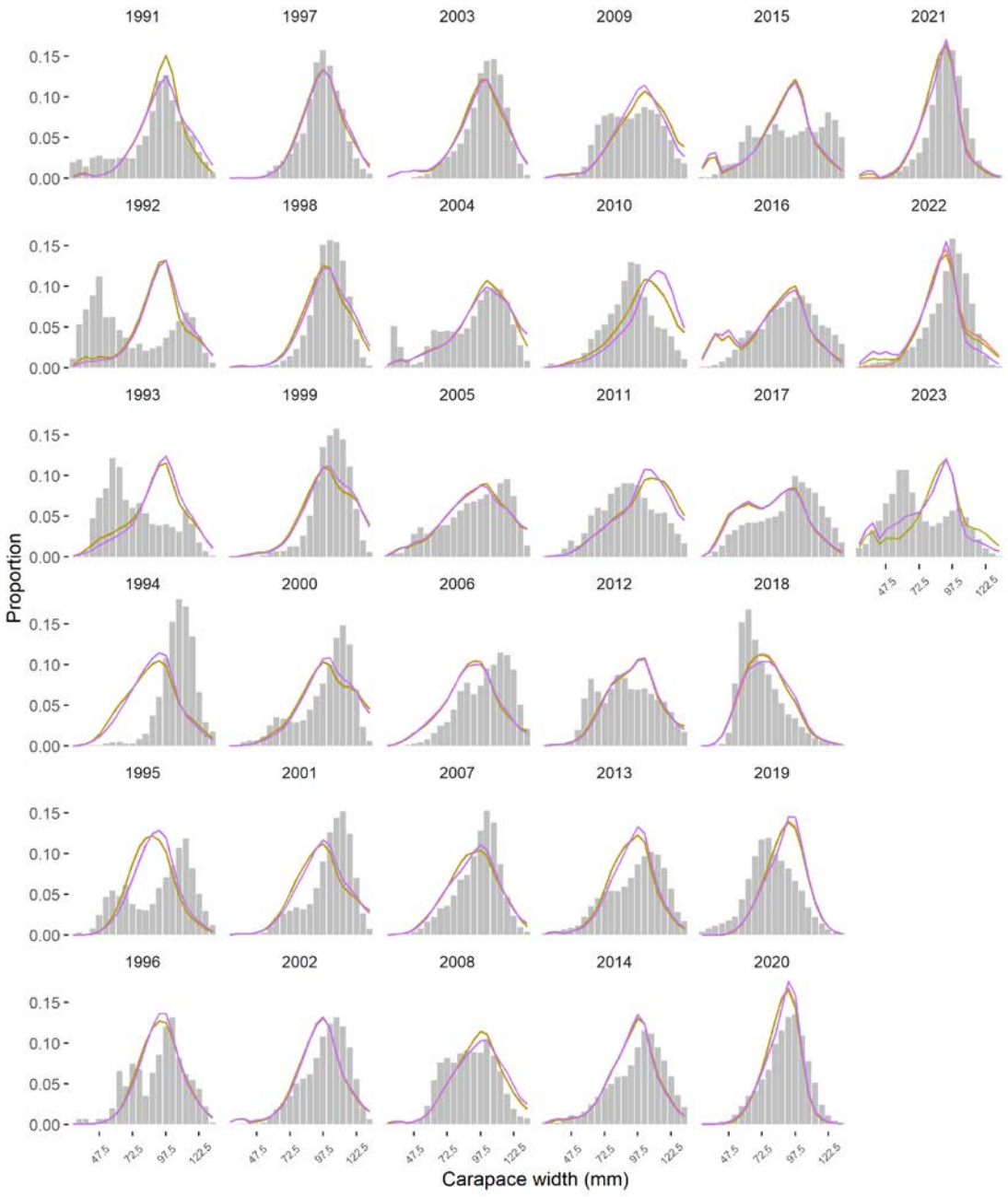


FEMALE (directed)

Data source	comments
FMB index	Reasonable fits with a run of underestimates starting 2010
MMB index	No concerning runs, but large underestimates in high years in the 1990s
Growth	Males fit well, females underestimated at large sizes. Data for large males would be useful
Catch biomass	All well fit
Catch size composition	More large males in retained and total catch than observed. Some years female discards poorly fit
Survey size composition	
BSFRF priors	

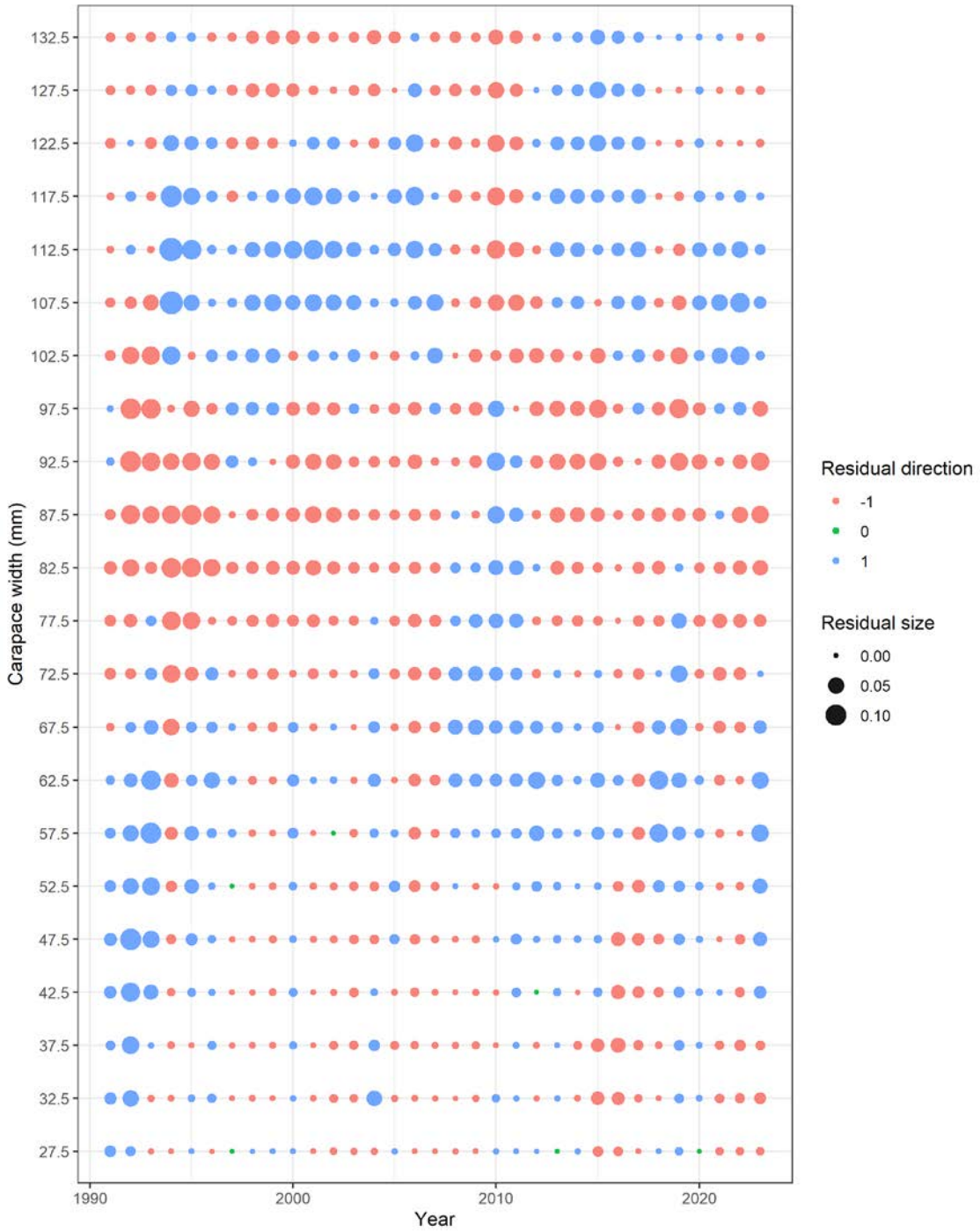


Data source	comments
FMB index	Reasonable fits with a run of underestimates starting 2010
MMB index	No concerning runs, but large underestimates in high years in the 1990s
Growth	Males fit well, females underestimated at large sizes. Data for large males would be useful
Catch biomass	All well fit
Catch size composition	More large males in retained and total catch than observed. Some years female discards poorly fit. Non-directed have worst fits.
Survey size composition	
BSFRF priors	

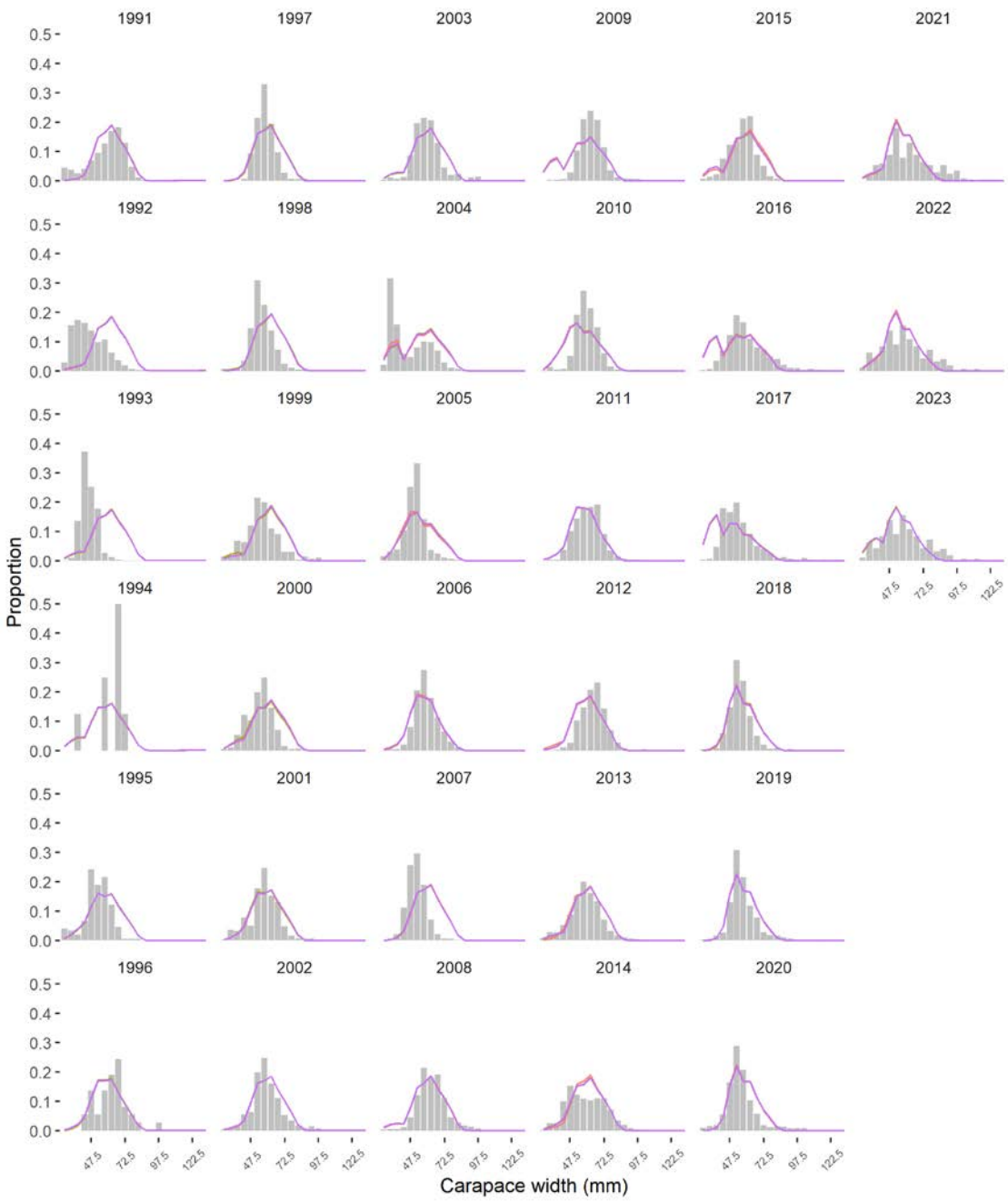


MALE (bycatch)

Data source	comments
FMB index	Reasonable fits with a run of underestimates starting 2010
MMB index	No concerning runs, but large underestimates in high years in the 1990s
Growth	Males fit well, females underestimated at large sizes. Data for large males would be useful
Catch biomass	All well fit
Catch size composition	More large males in retained and total catch than observed. Some years female discards poorly fit. Non-directed have worst fits.
Survey size composition	
BSFRF priors	



Data source	comments
FMB index	Reasonable fits with a run of underestimates starting 2010
MMB index	No concerning runs, but large underestimates in high years in the 1990s
Growth	Males fit well, females underestimated at large sizes. Data for large males would be useful
Catch biomass	All well fit
Catch size composition	More large males in retained and total catch than observed. Some years female discards poorly fit. Non-directed have worst fits.
Survey size composition	
BSFRF priors	



FEMALE (bycatch)

Data source	comments
FMB index	Reasonable fits with a run of underestimates starting 2010
MMB index	No concerning runs, but large underestimates in high years in the 1990s
Growth	Males fit well, females underestimated at large sizes. Data for large males would be useful
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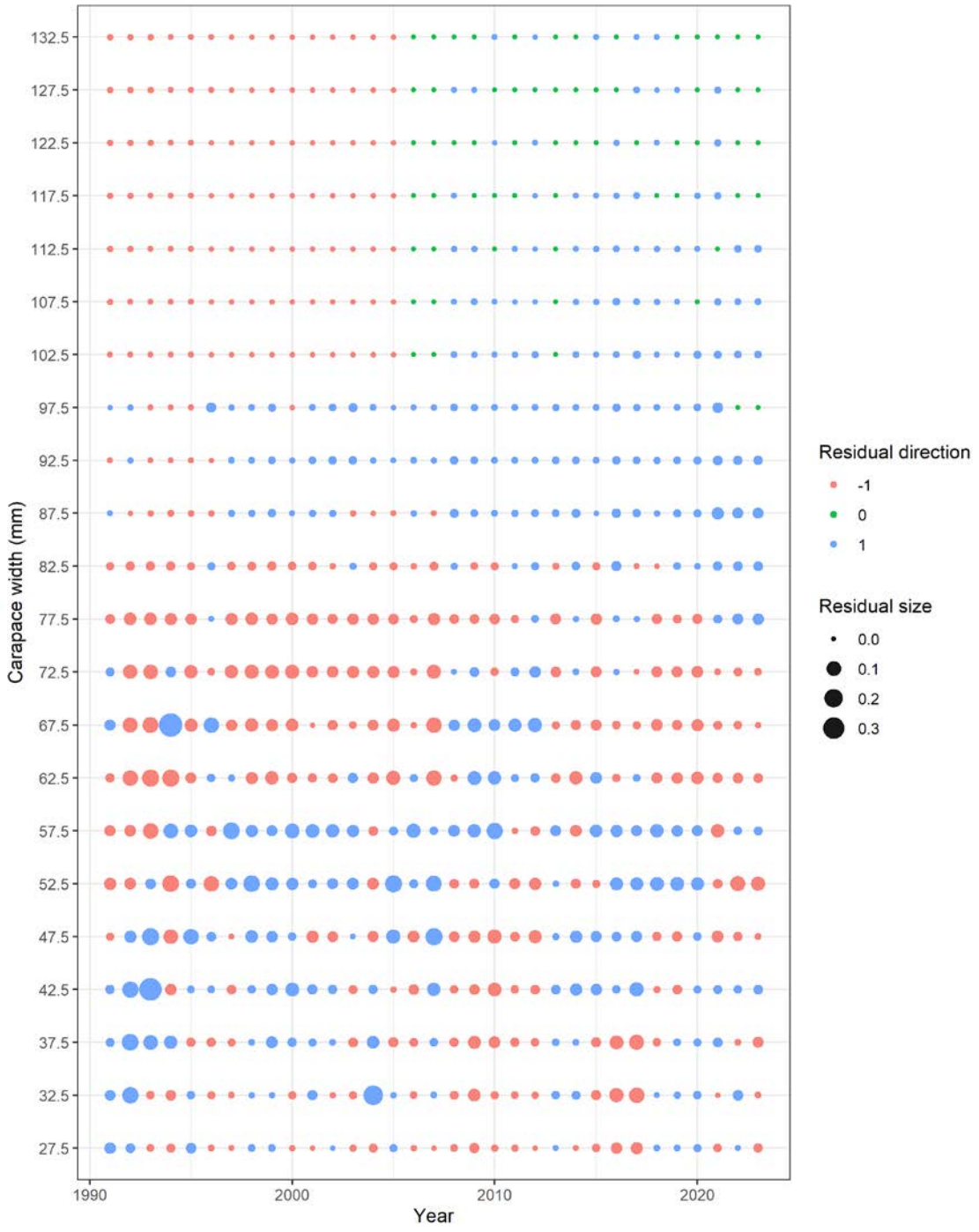
BSFRF priors	



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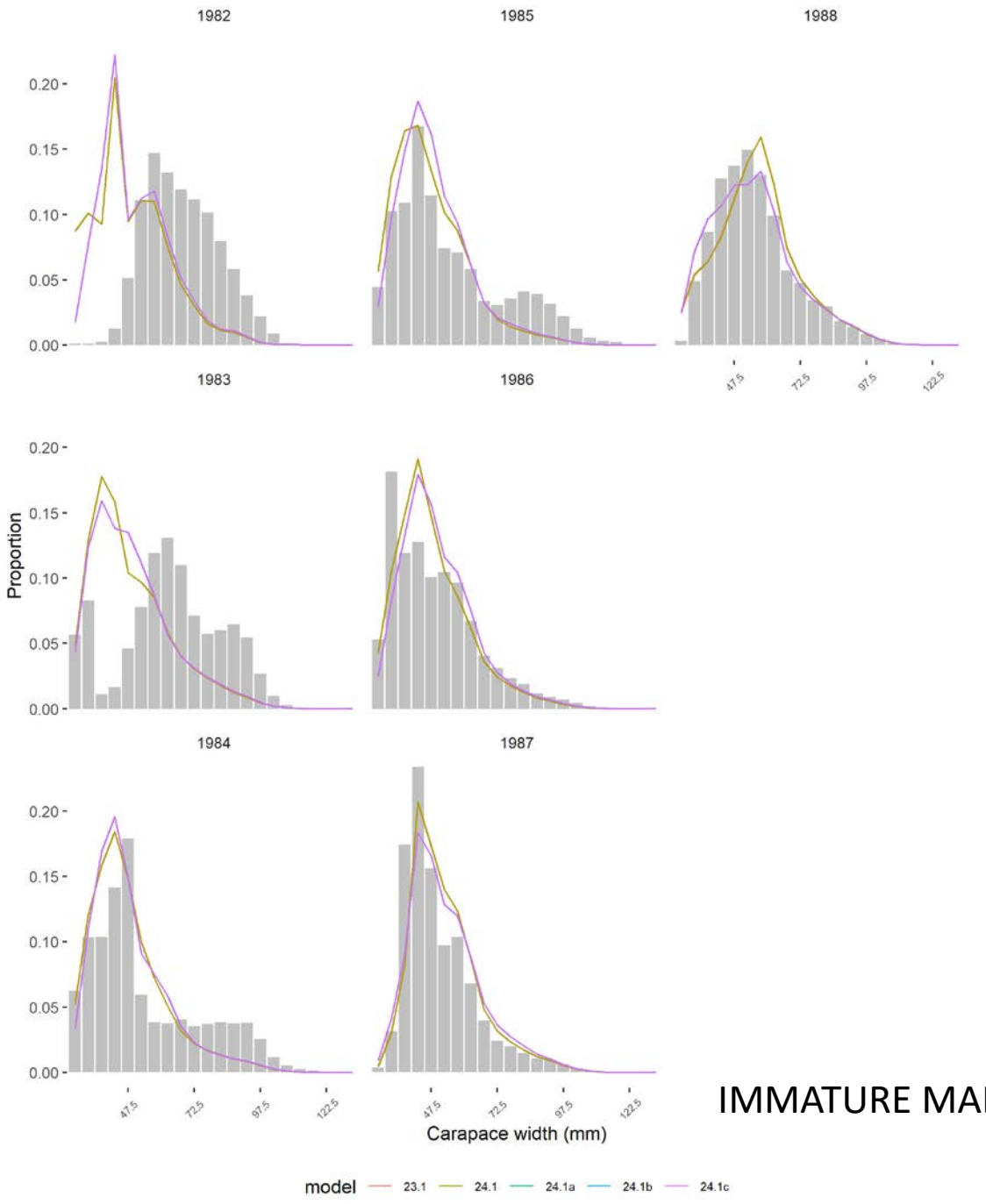
Survey size composition	Early males not well fit; females better.
BSFRF priors	



IMMATURE MALE

Data source	comments
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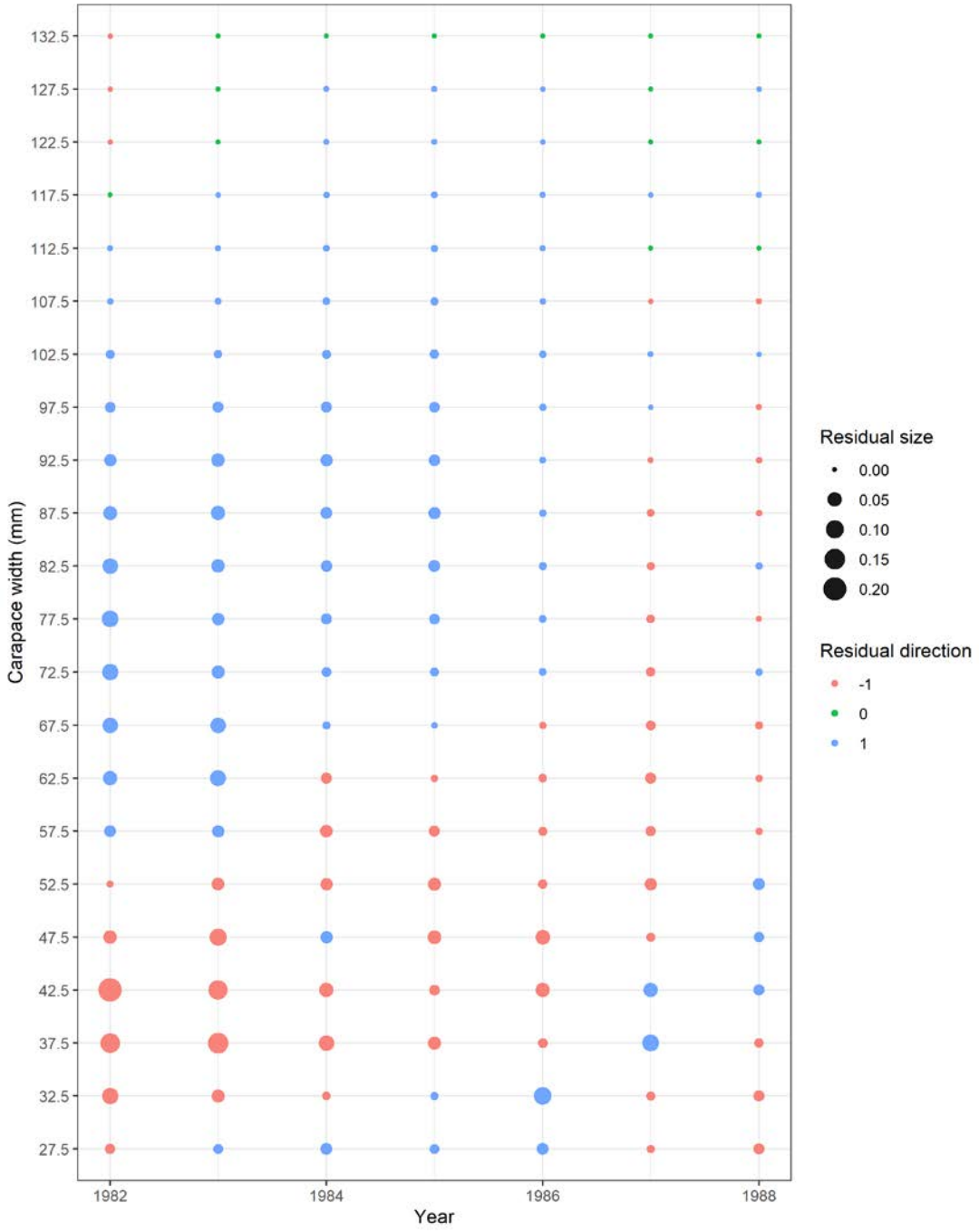
BSFRF priors	



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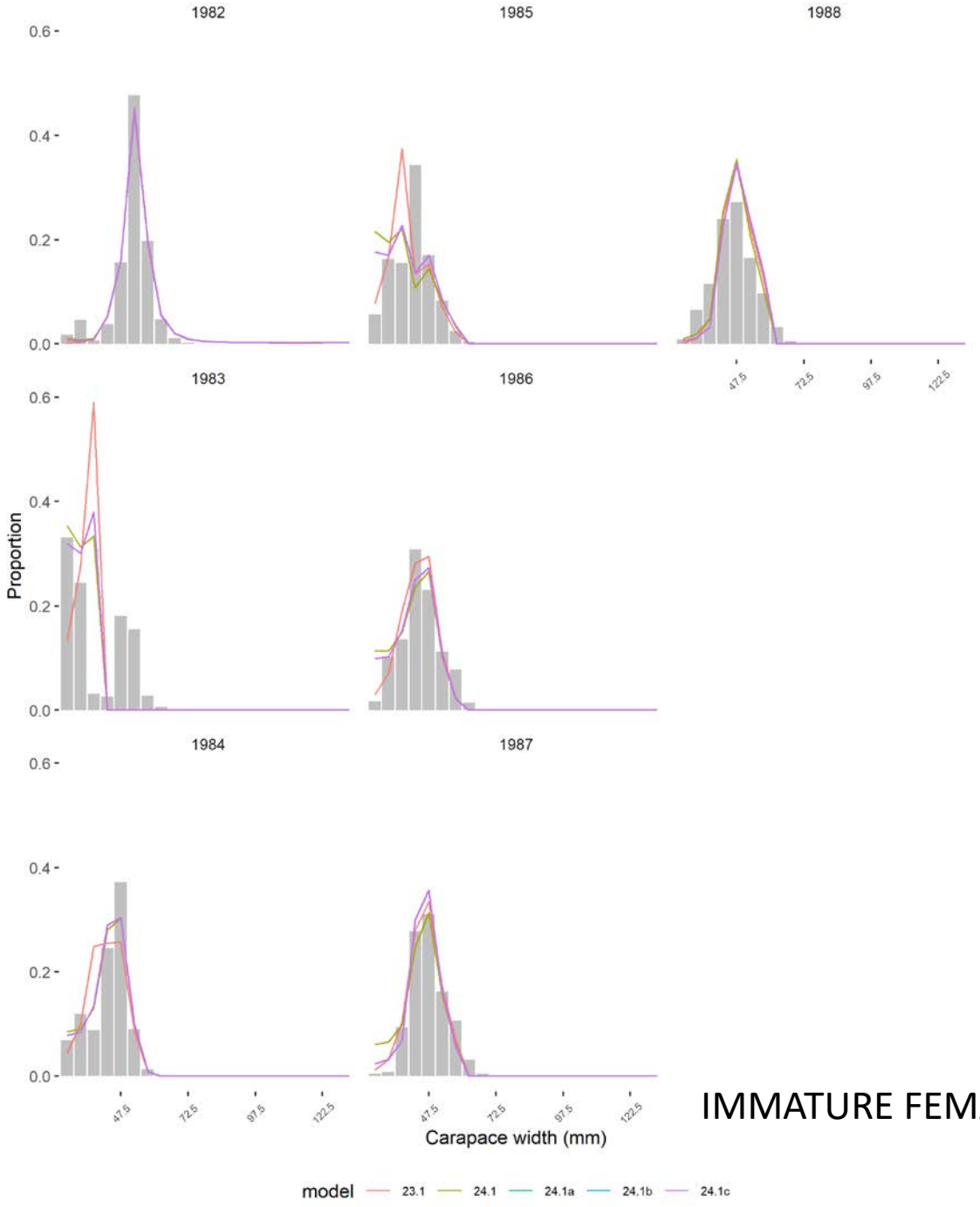

IMMATURE FEMALE

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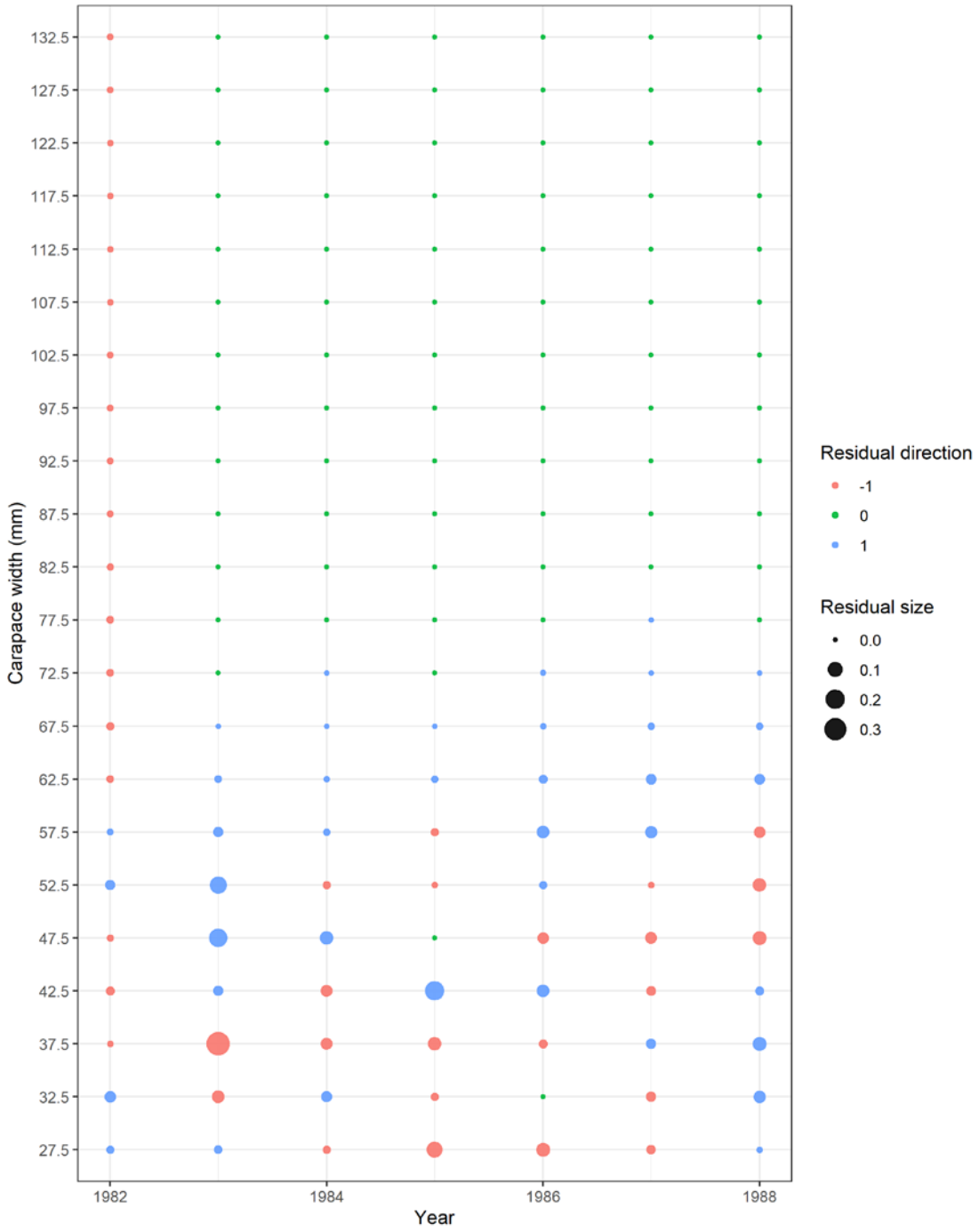

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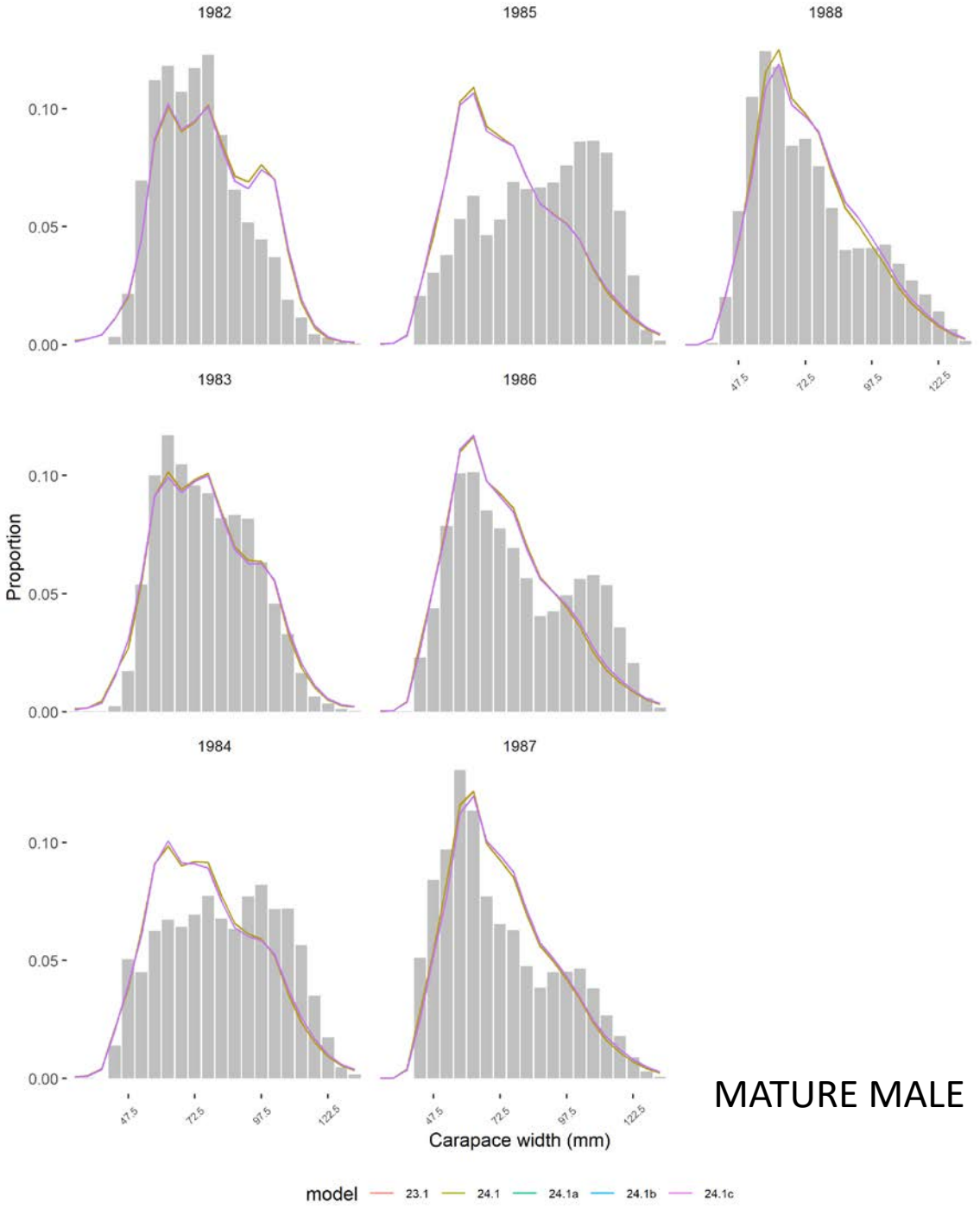

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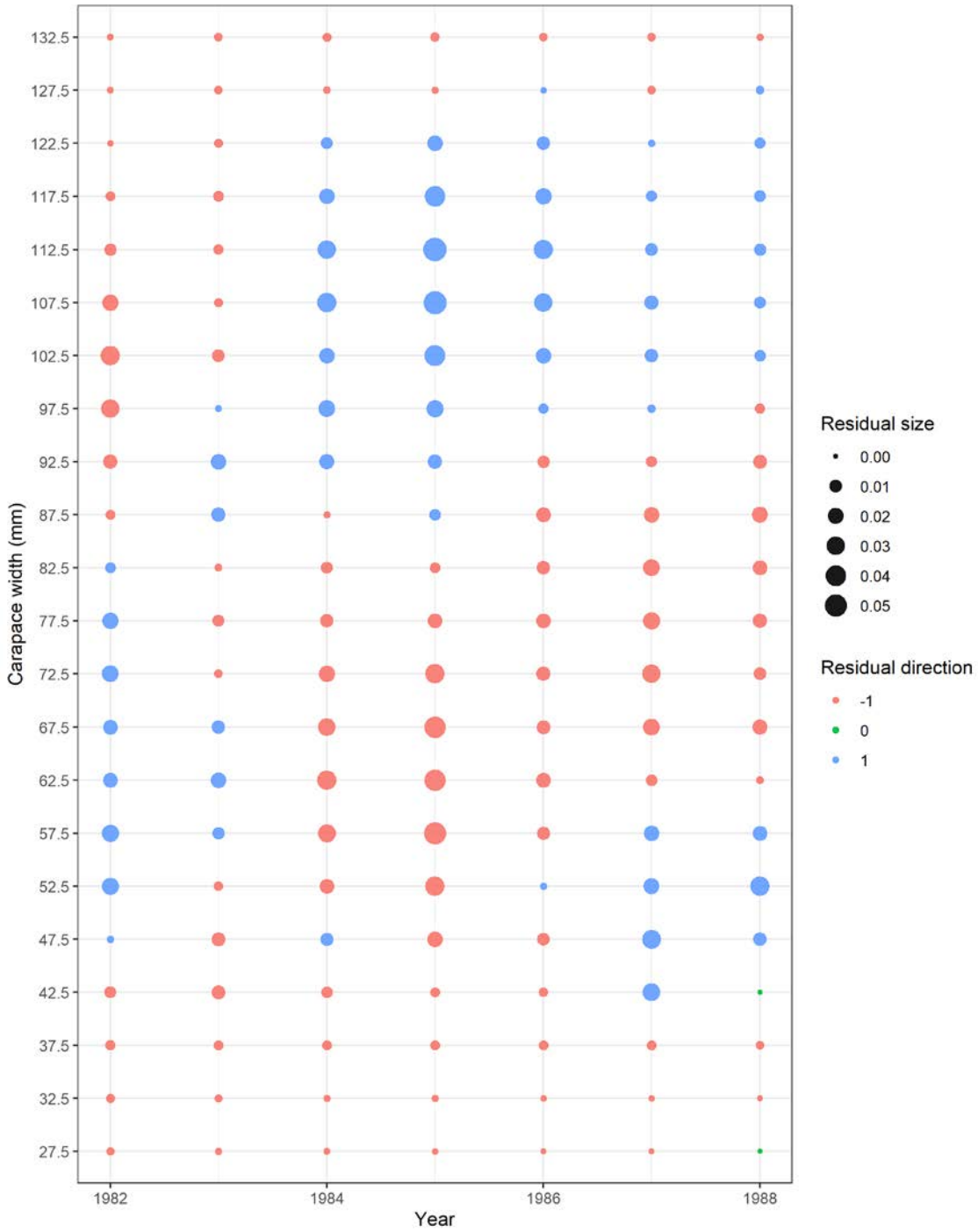

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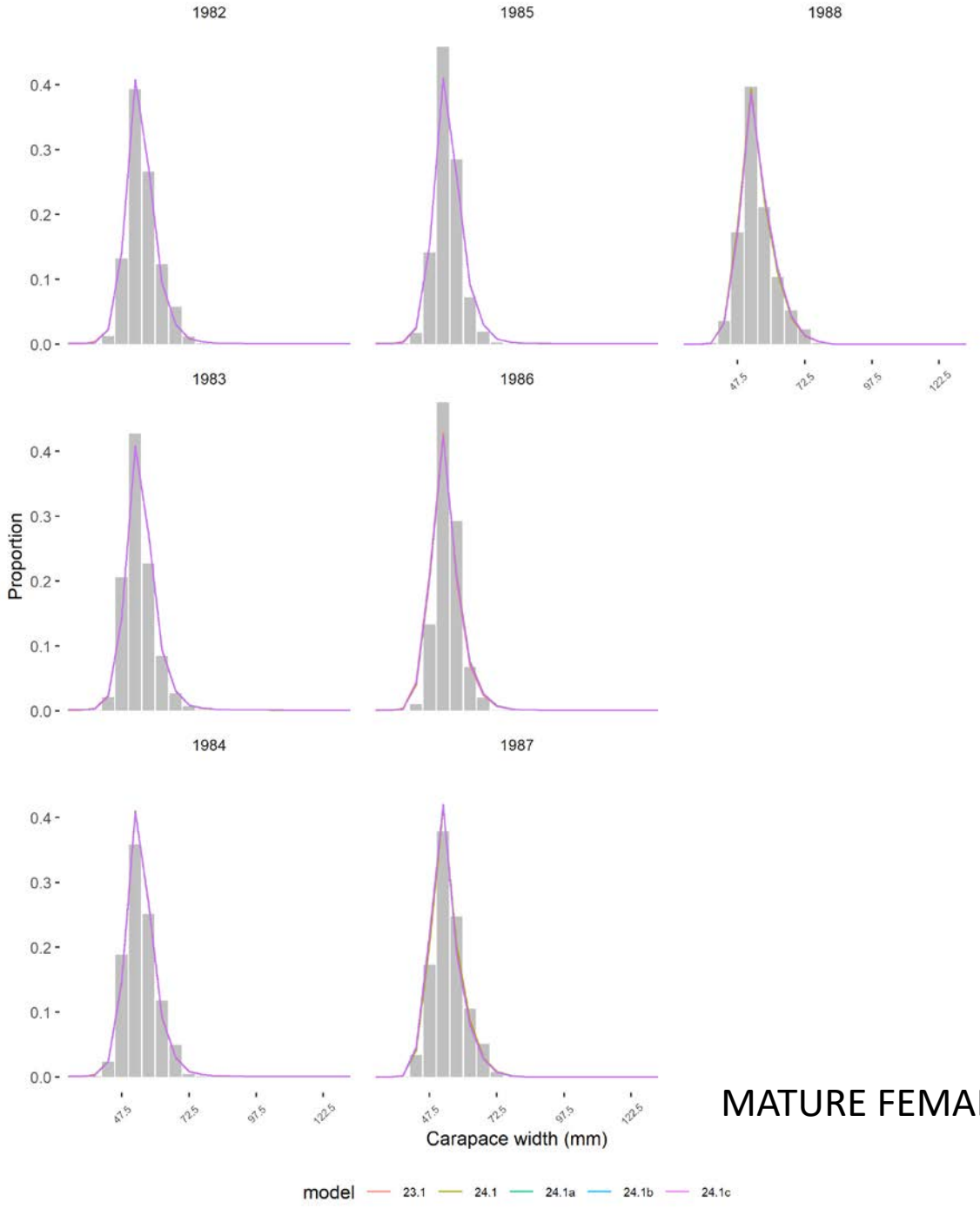

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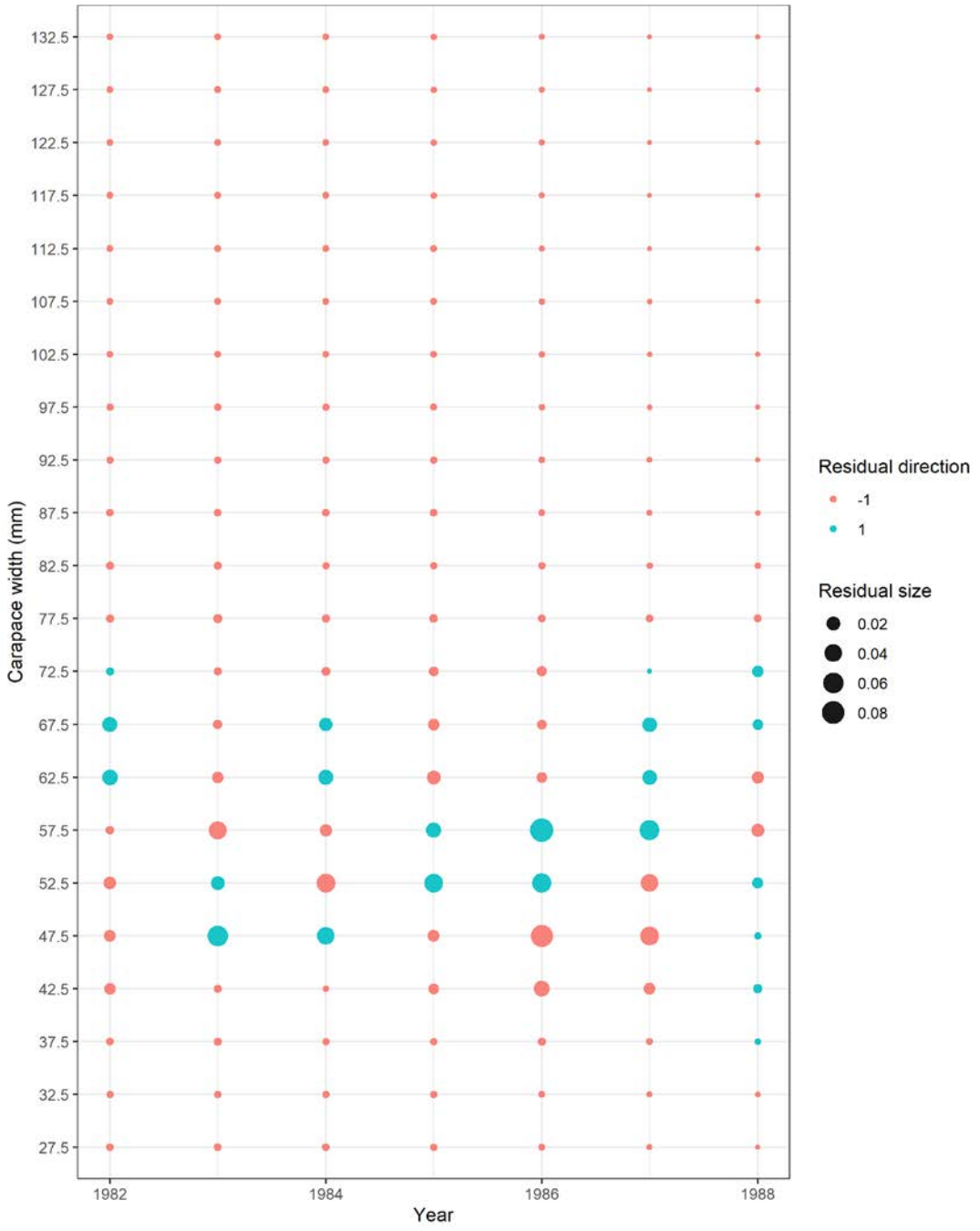

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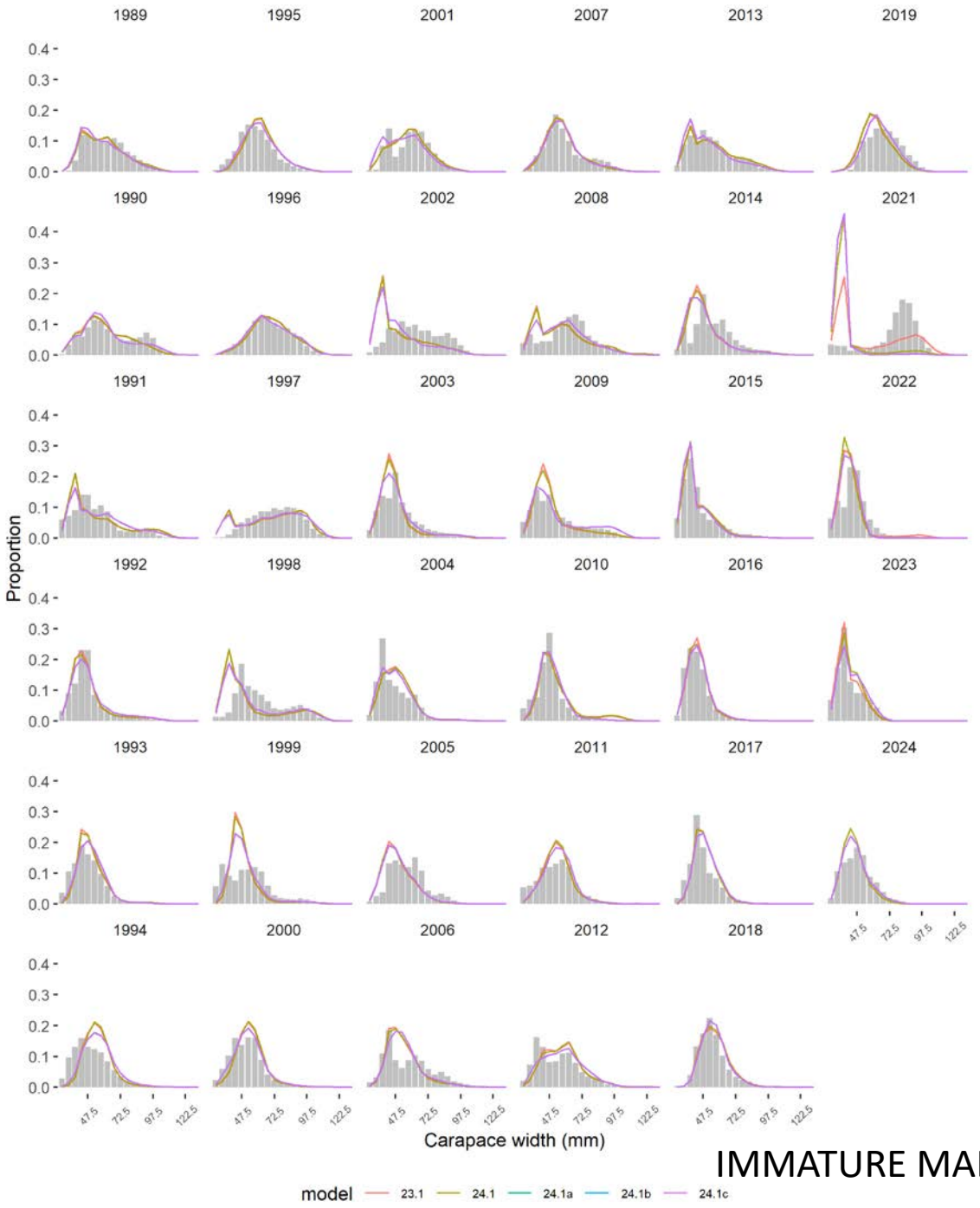

IMMATURE MALE

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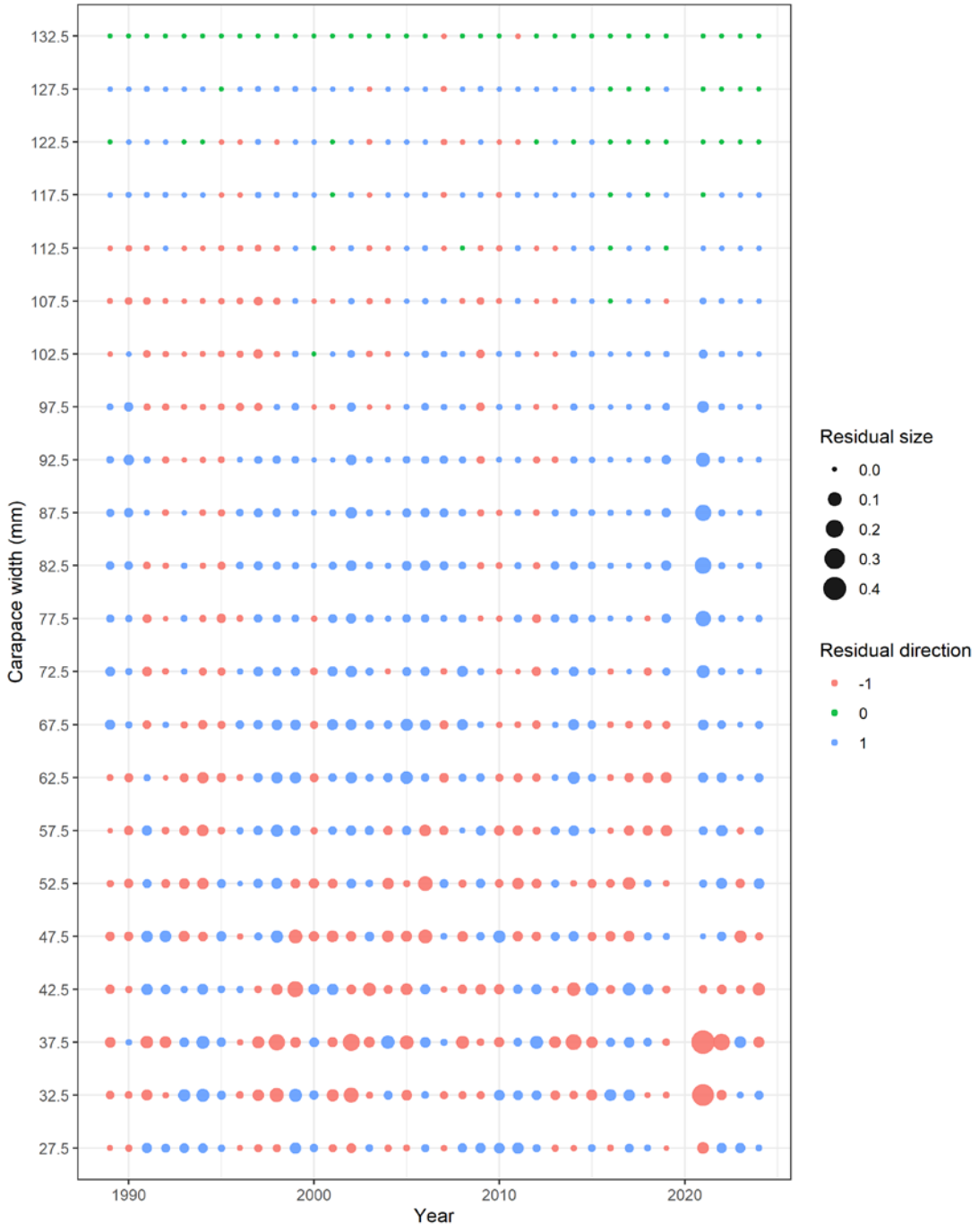

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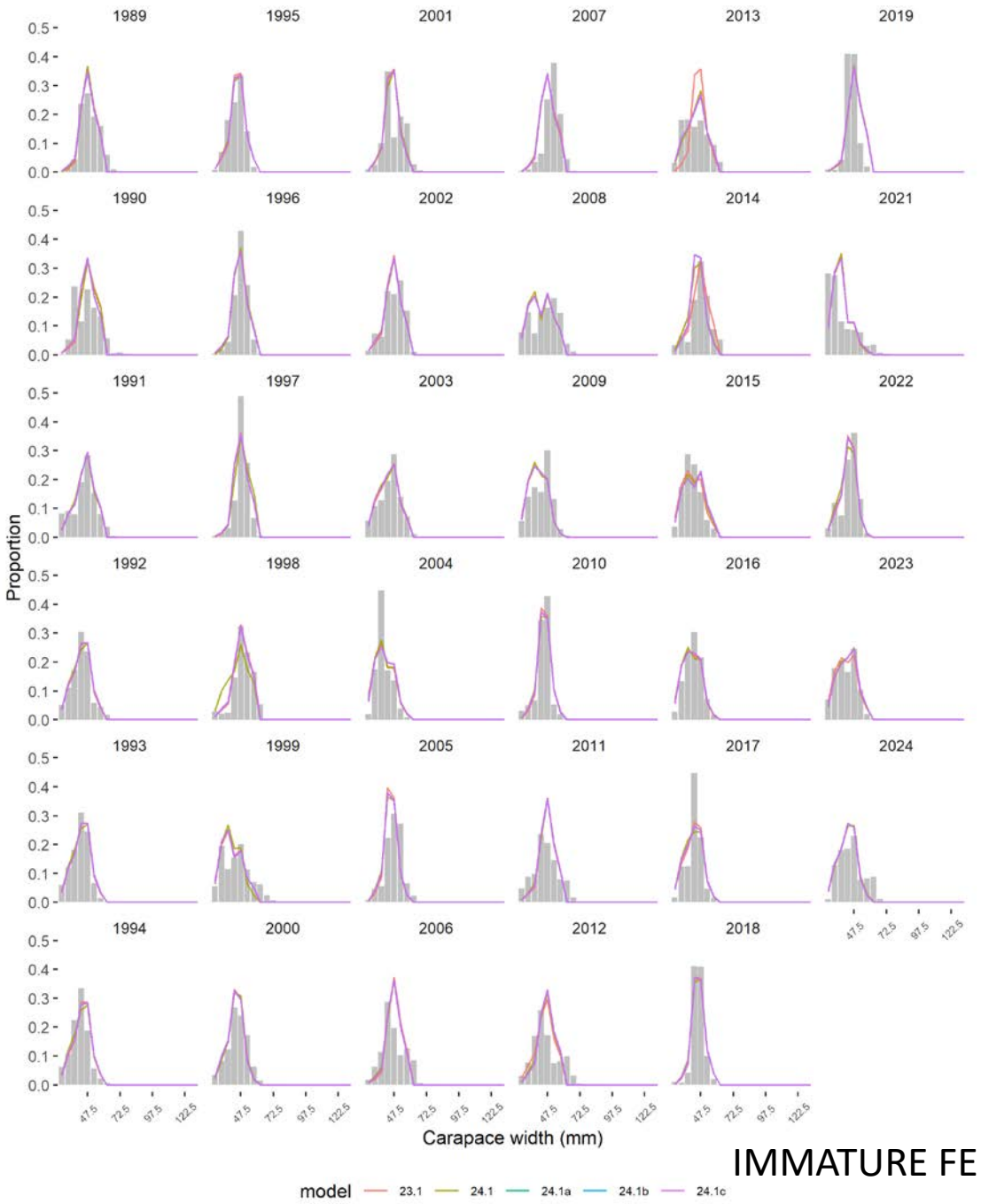

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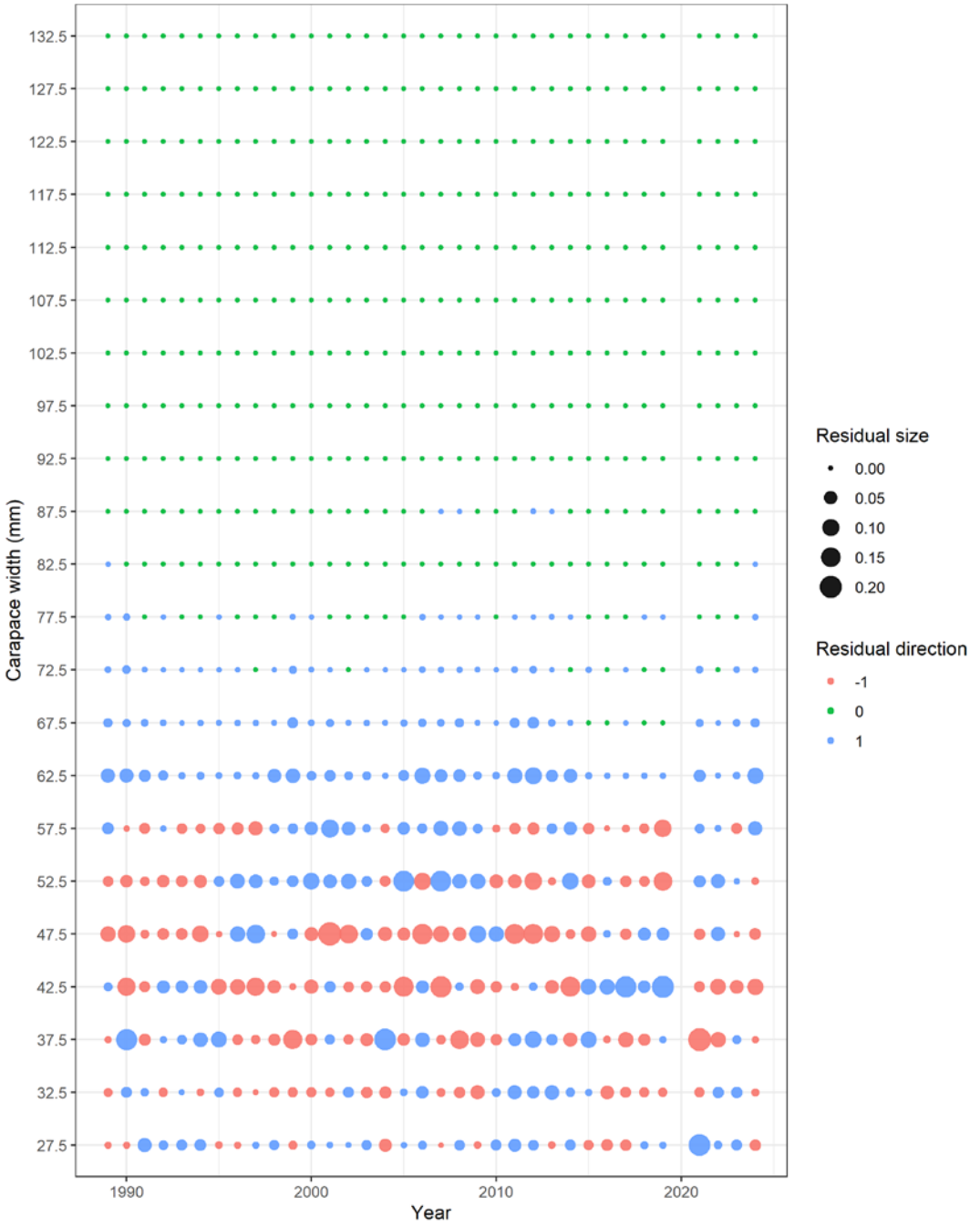

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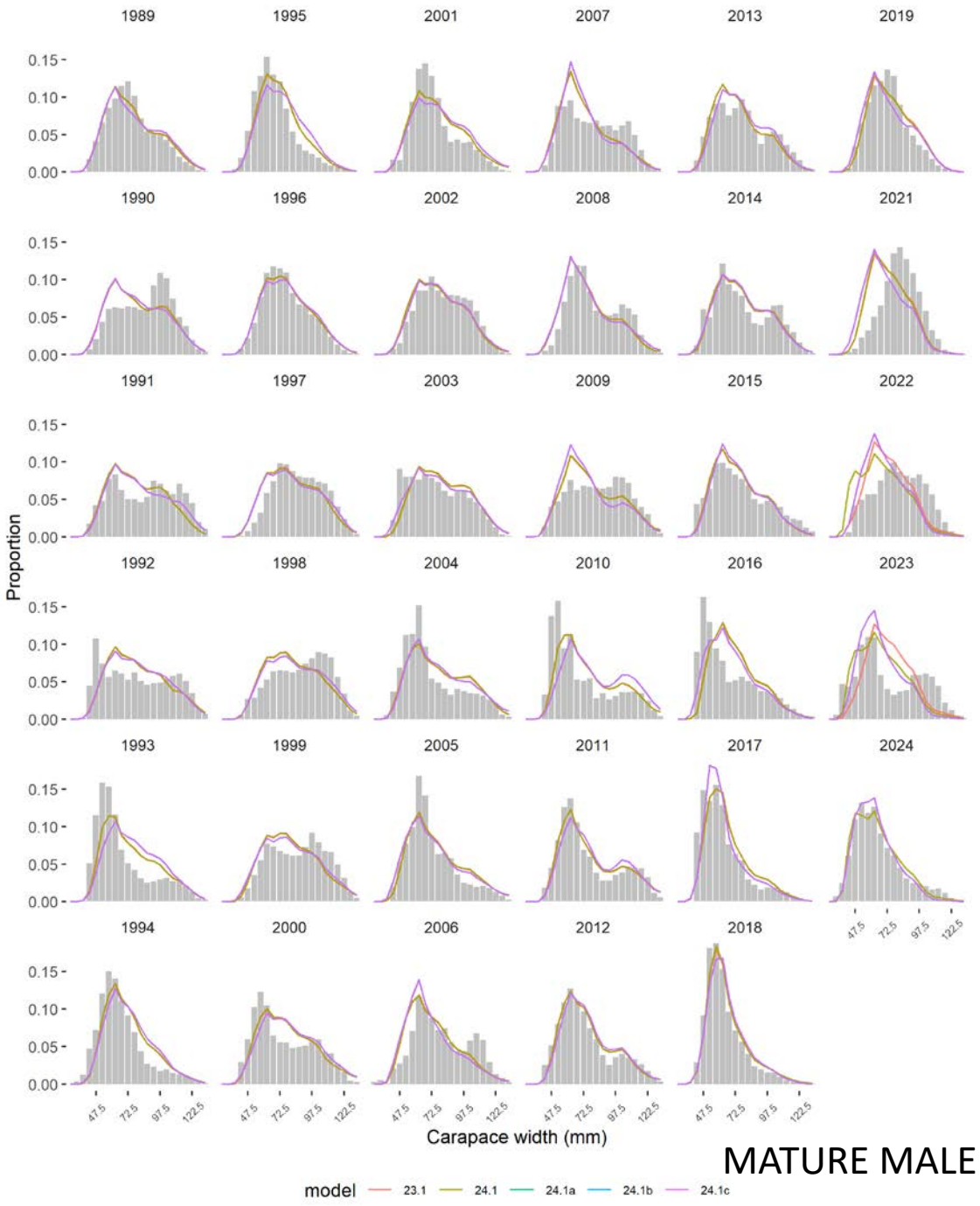

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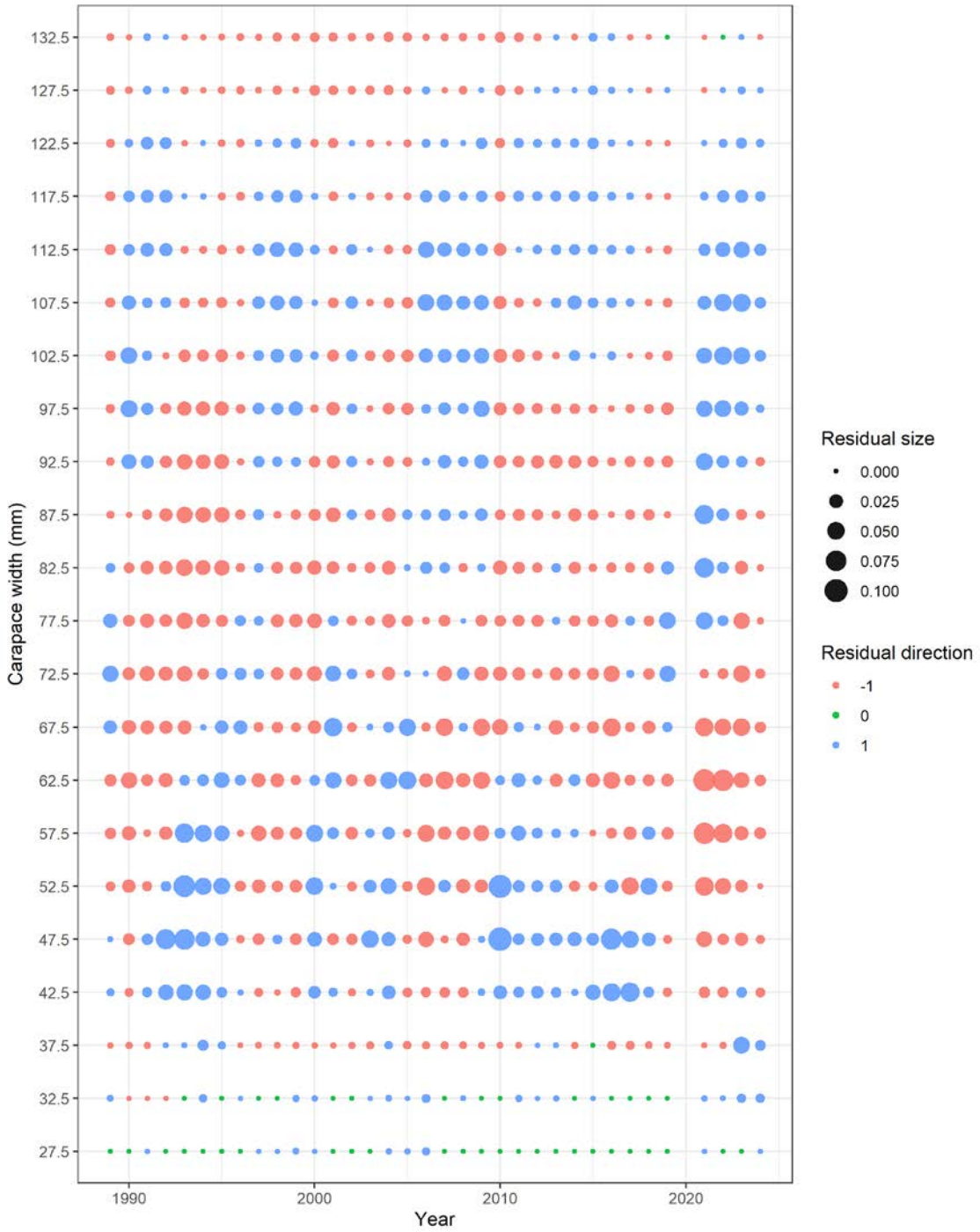

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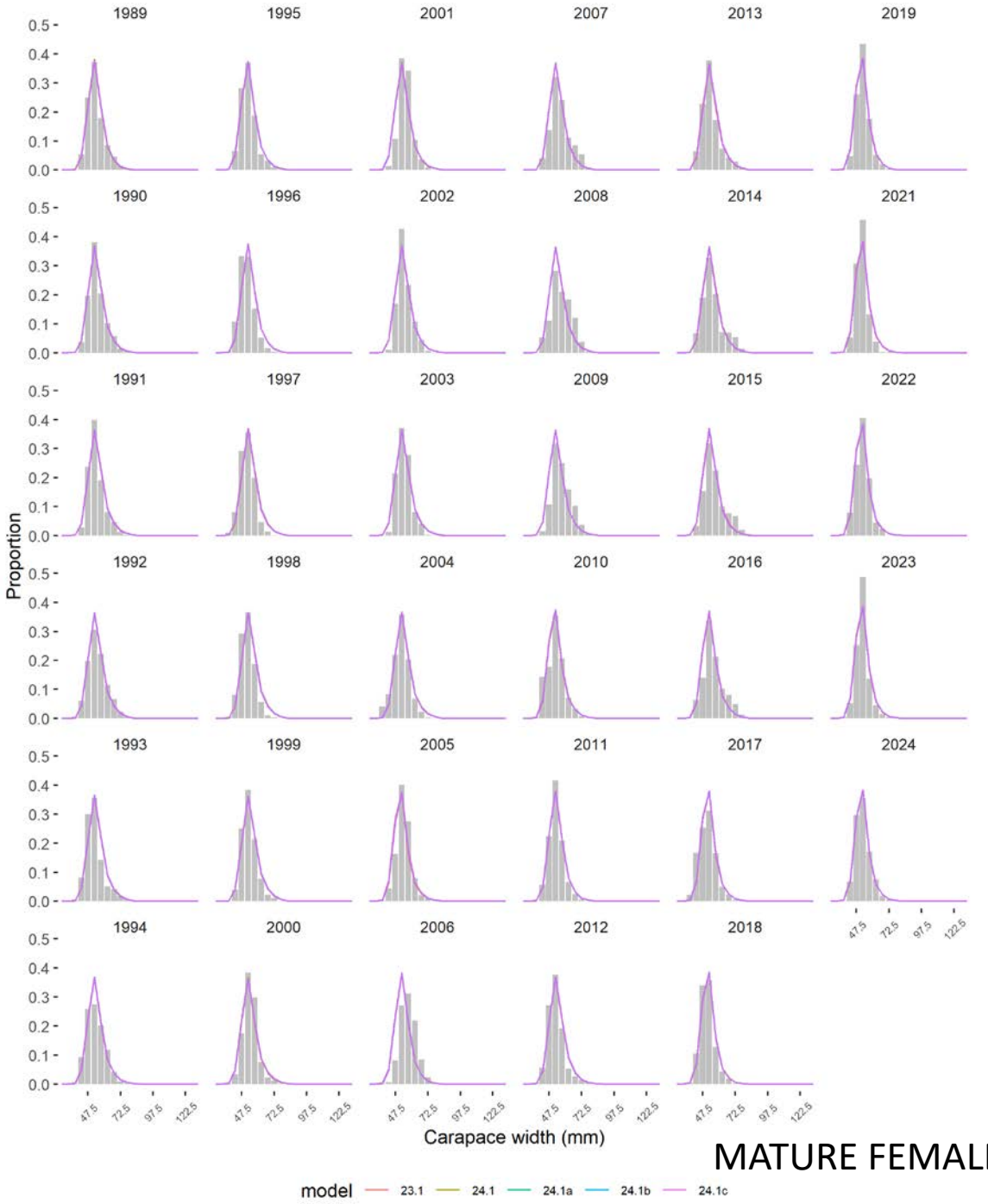
BSFRF priors	



MATURE FEMALE

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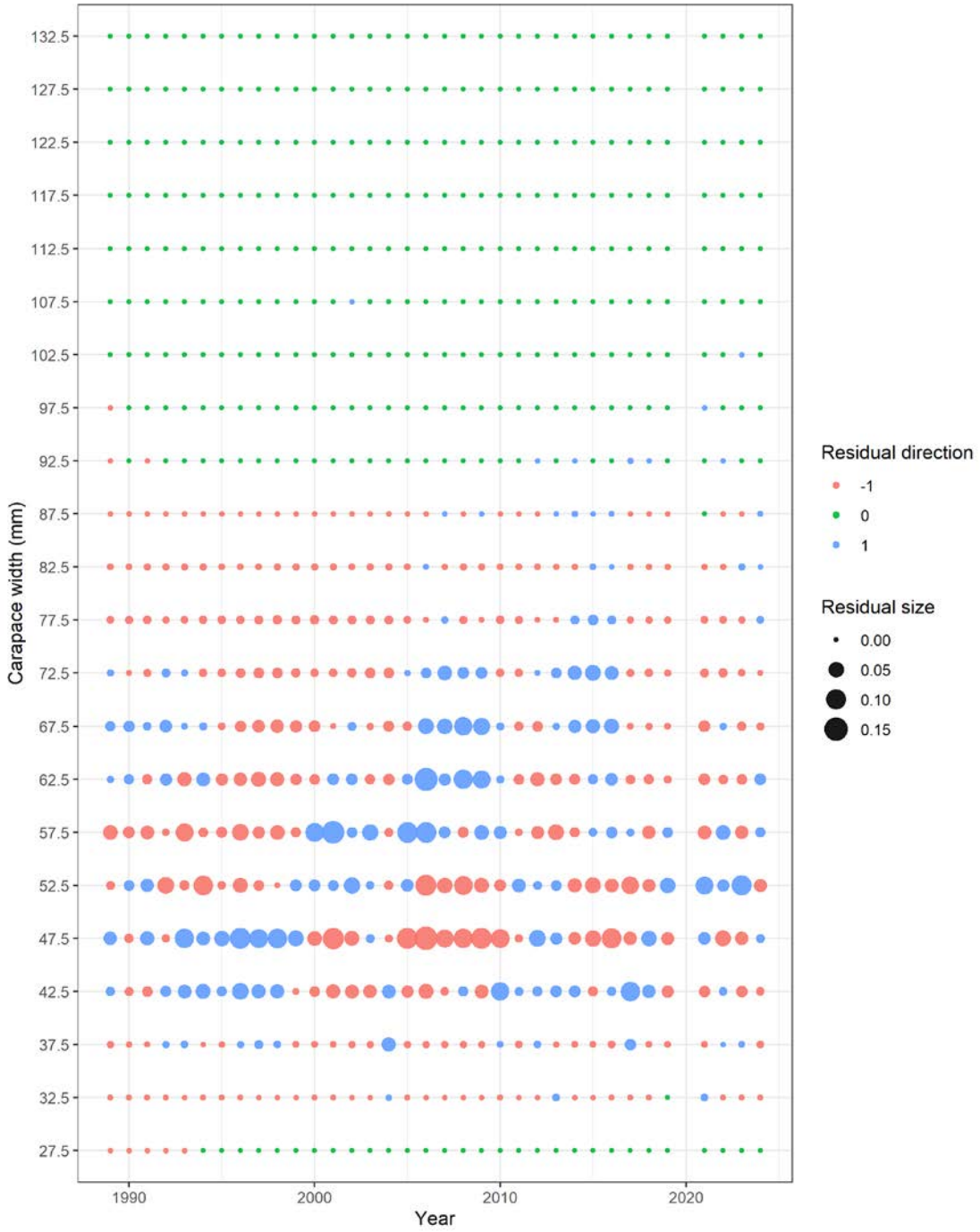

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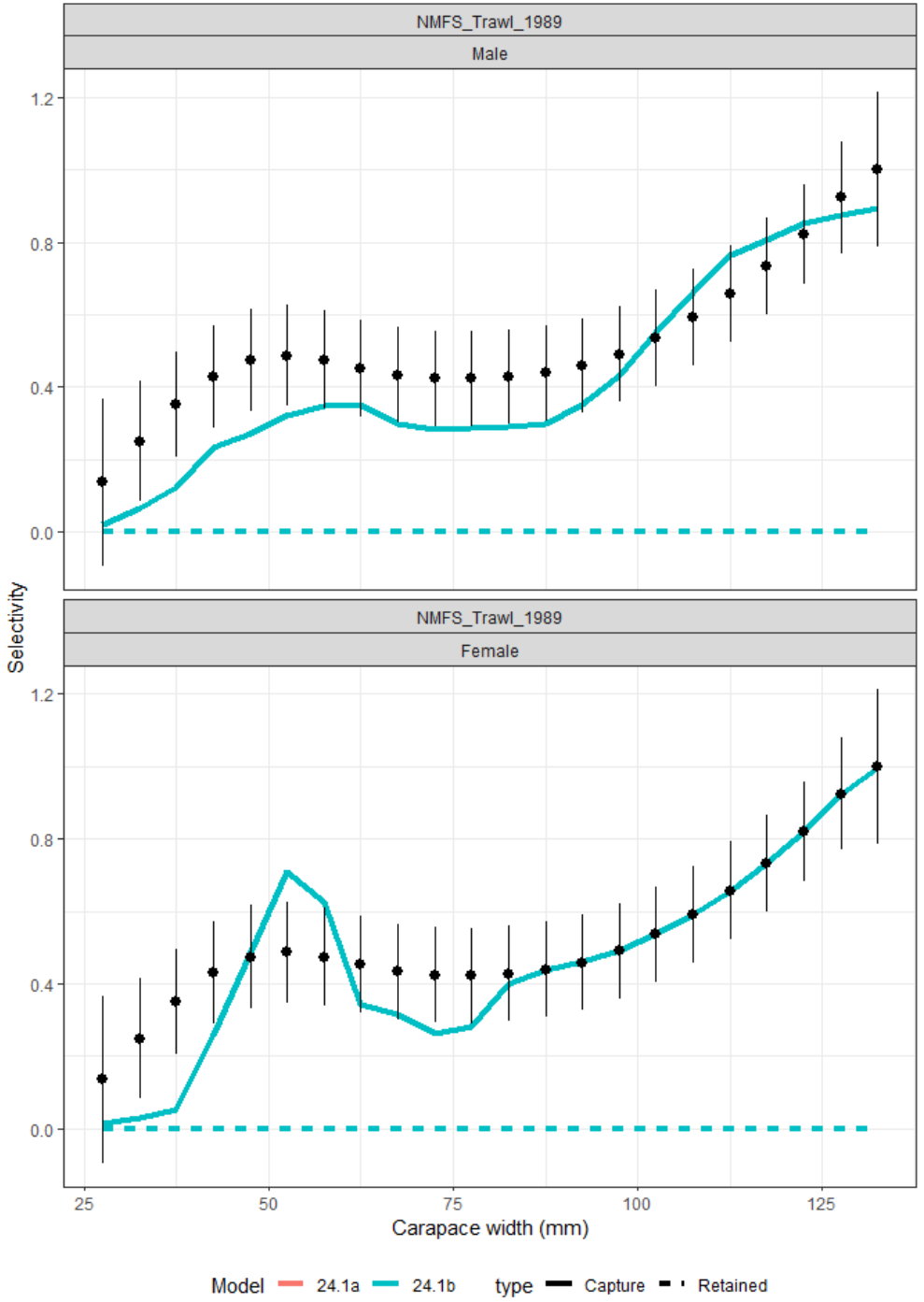
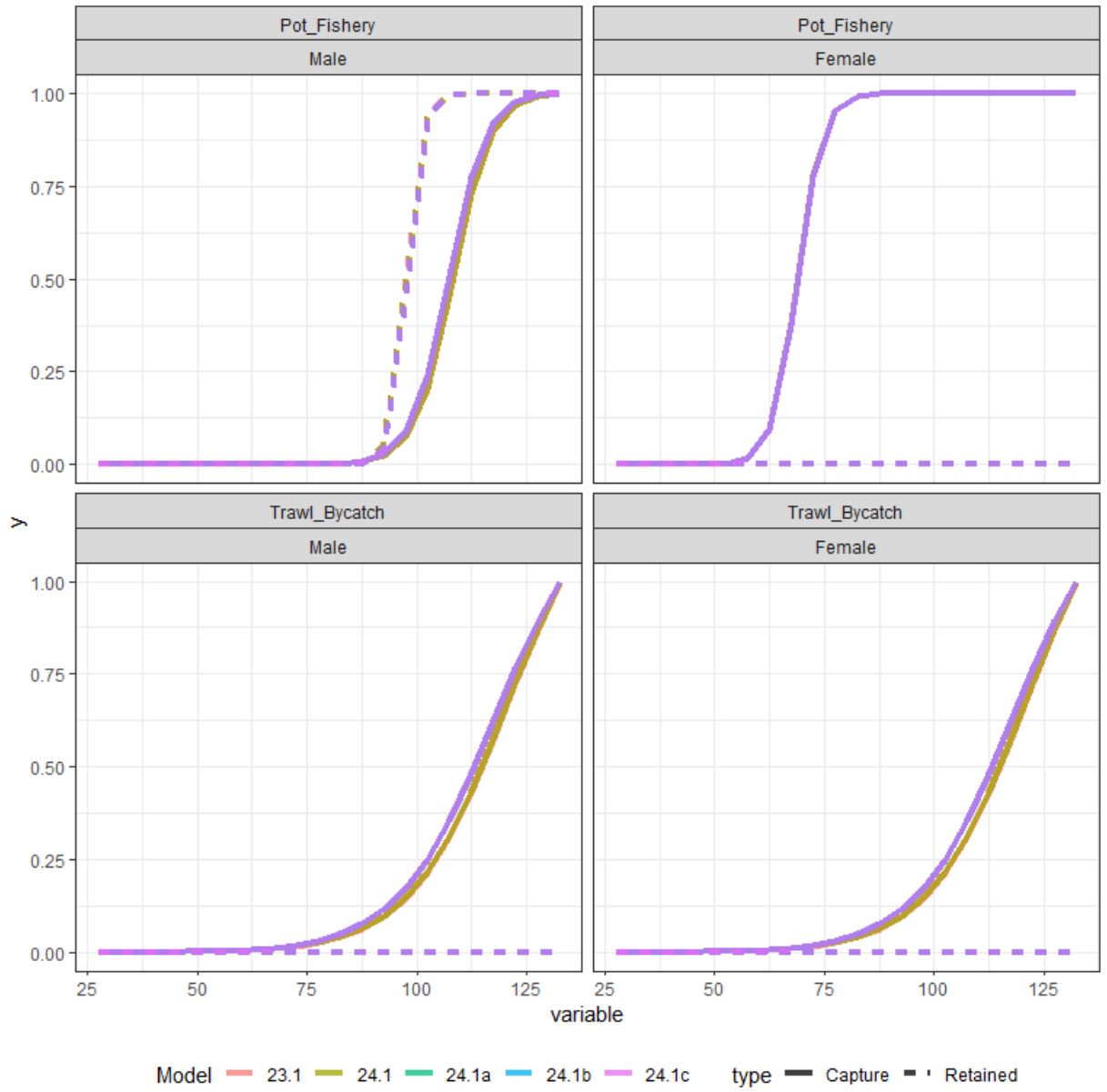
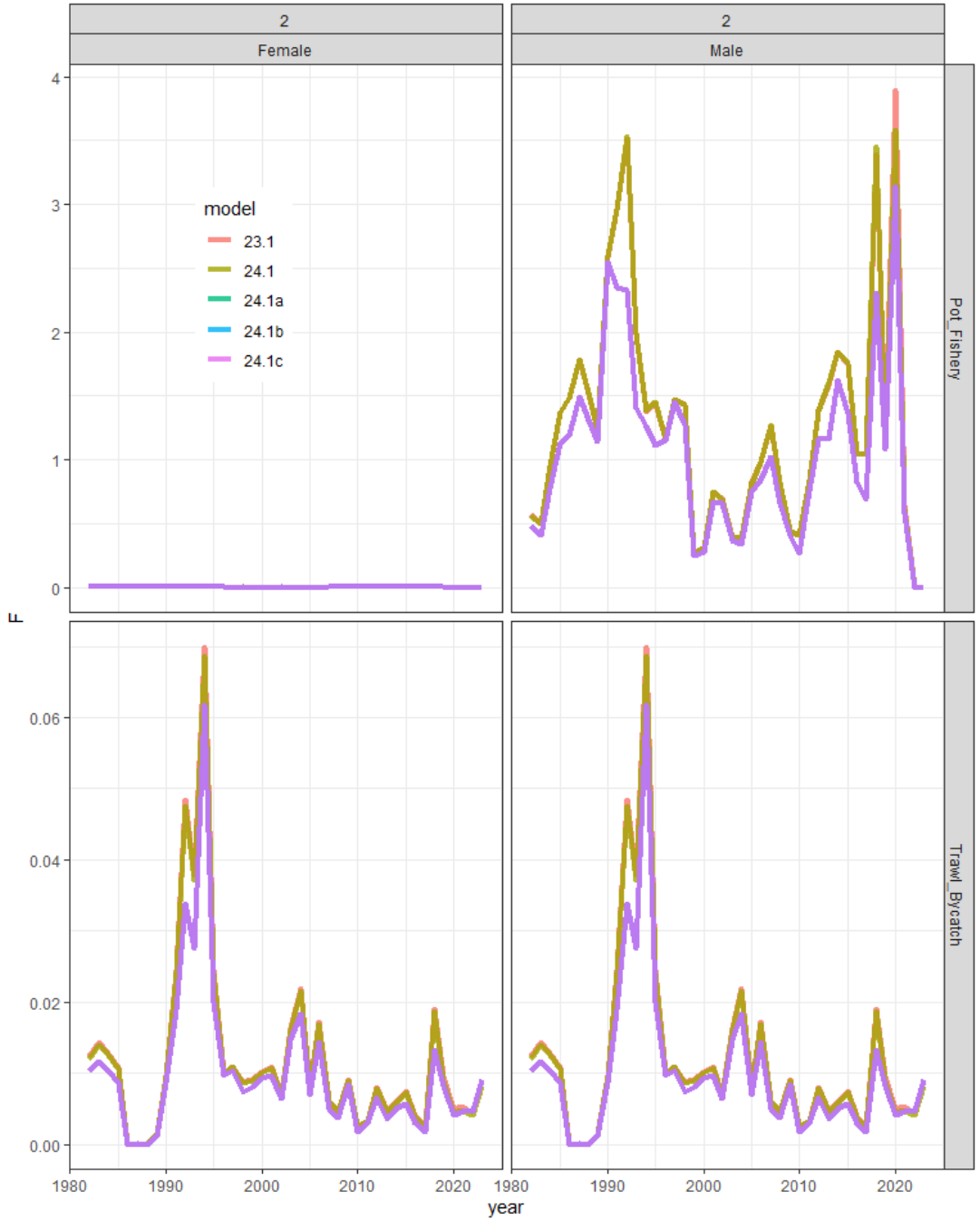
Survey size composition	Early males not well fit; females better. Small imm male lack of fit; notable lack of fit for large males in recent years
BSFRF priors	Males lower than prior; large discontinuity in females over size



Population process	comments
Selectivity	Total fishery selectivity low for smallest of industry preferred males; big difference between selectivity for males and females
Fishing mortality	
Recruitment	
Natural mortality	
Maturity	



Population process	comments
Selectivity	Total fishery selectivity low for smallest of industry preferred males; big difference between selectivity for males and females
Fishing mortality	High estimated fishing mortality in some years; translate to lower, but still high, exploitation rates
Recruitment	
Natural mortality	
Maturity	



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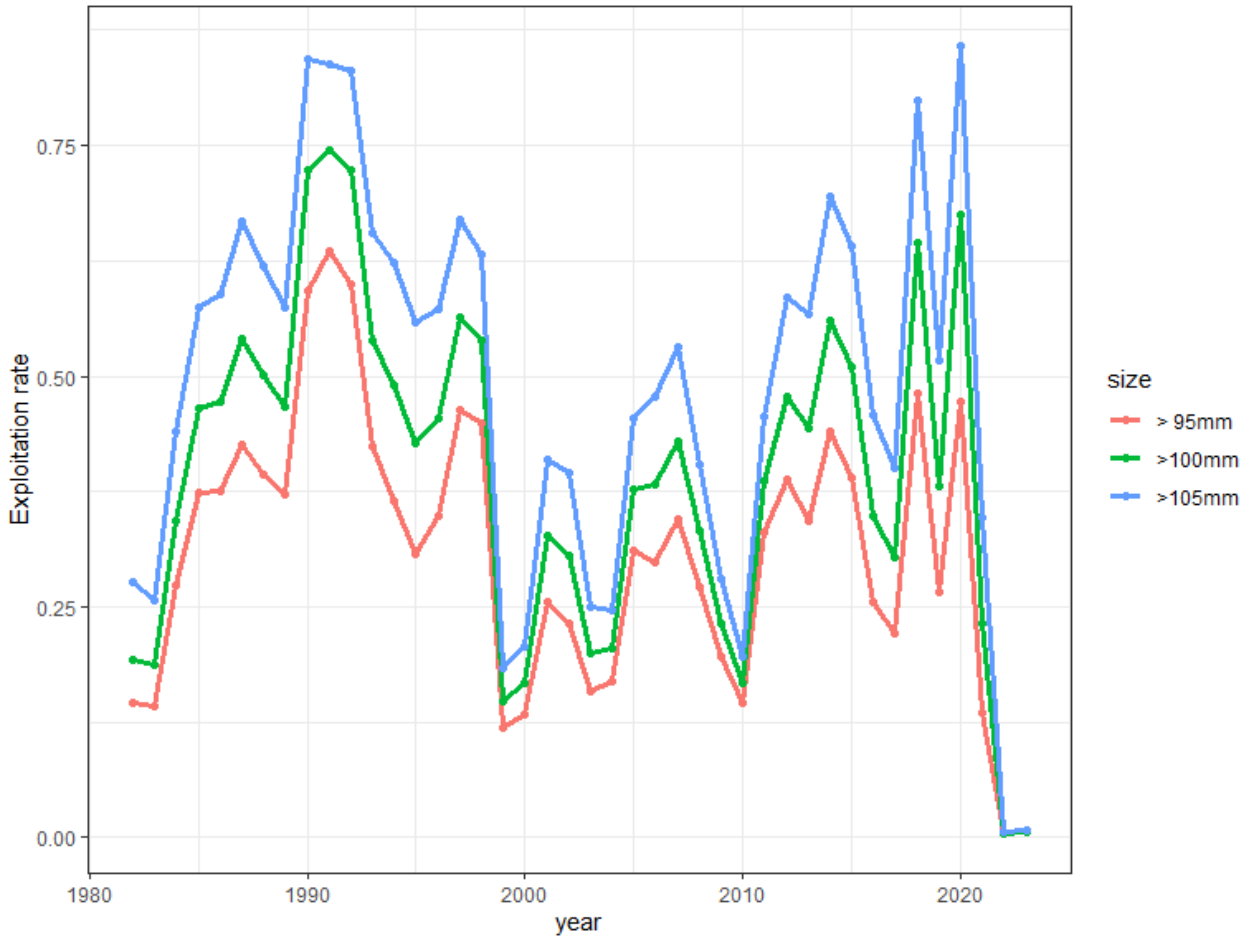

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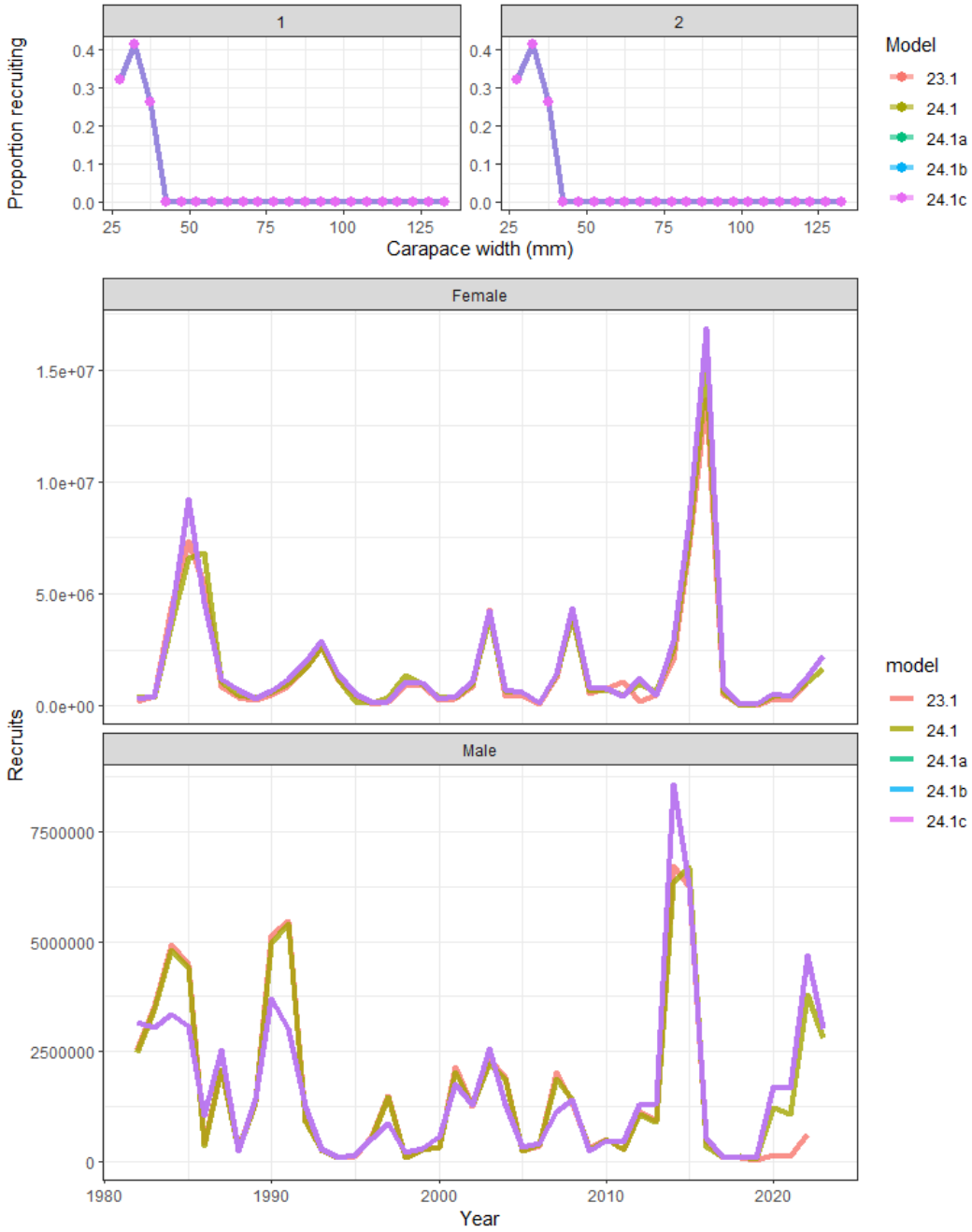
Recruitment	Estimated recruitment different by sex
Natural mortality	
Maturity	



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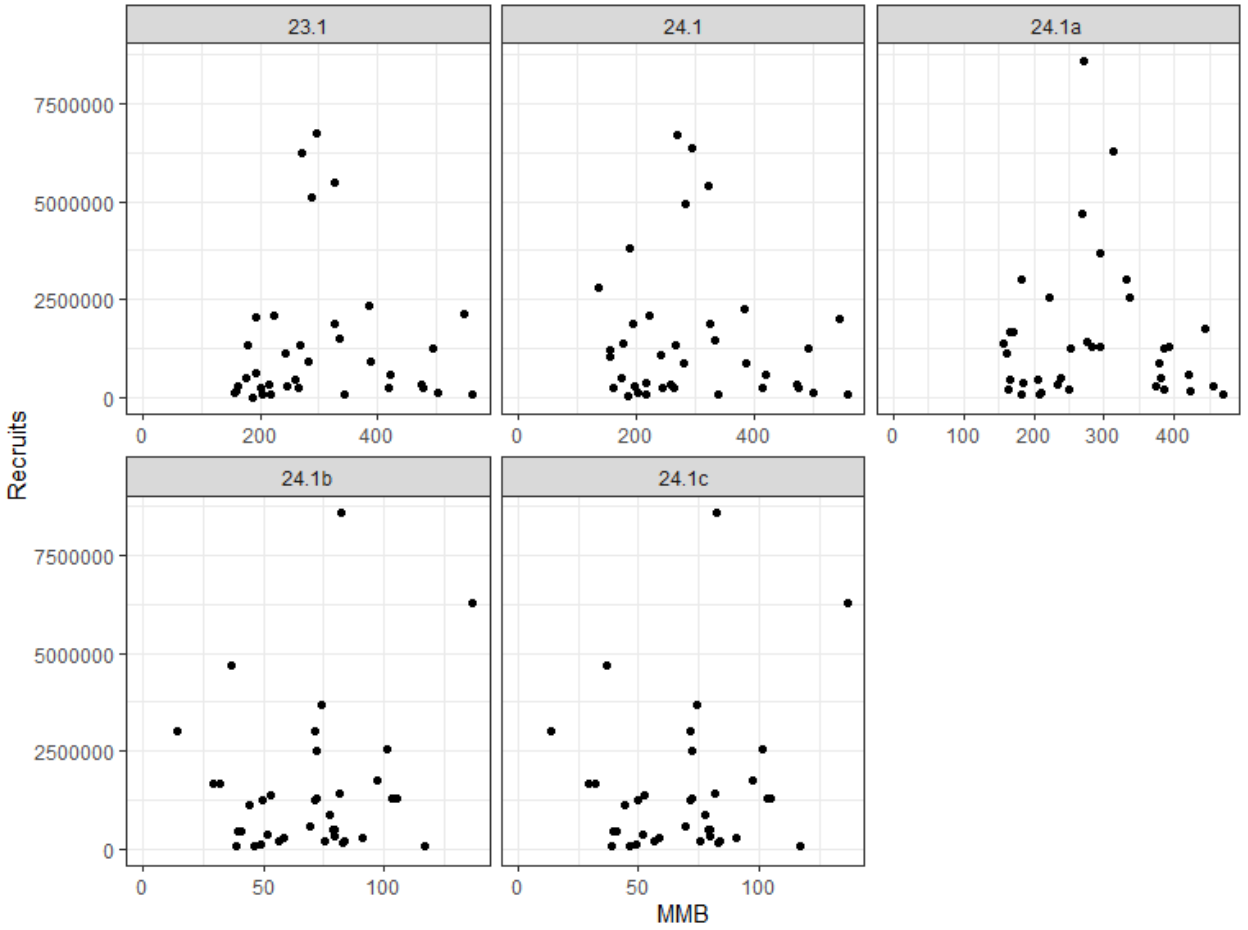
Selectivity	Total fishery selectivity low for smallest of industry preferred males; big difference between selectivity for males and females
Fishing mortality	High estimated fishing mortality in some years; translate to lower, but still high, exploitation rates
Recruitment	Estimated recruitment different by sex; no clear stock-recruit relationship regardless of currency used
Natural mortality	
Maturity	



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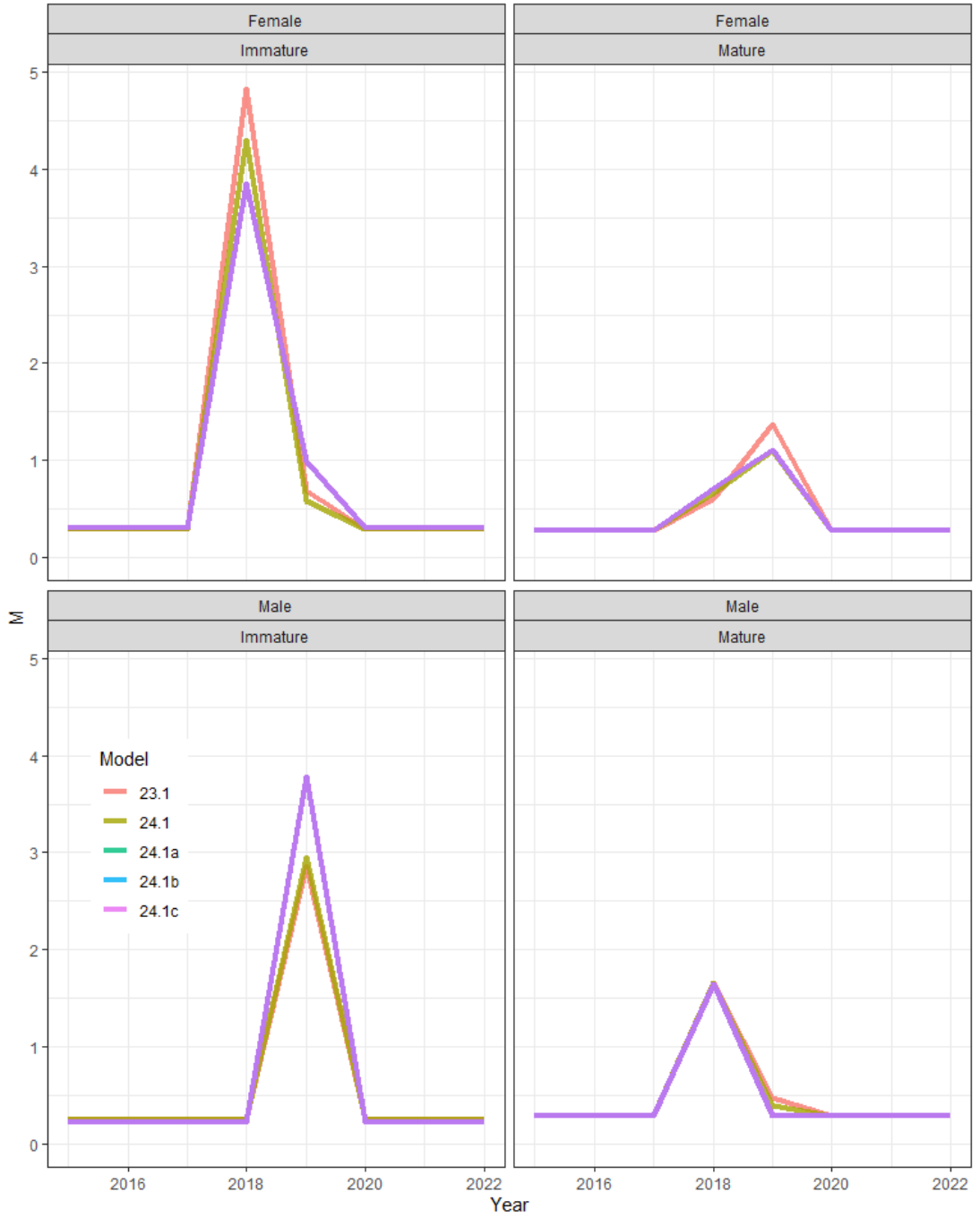
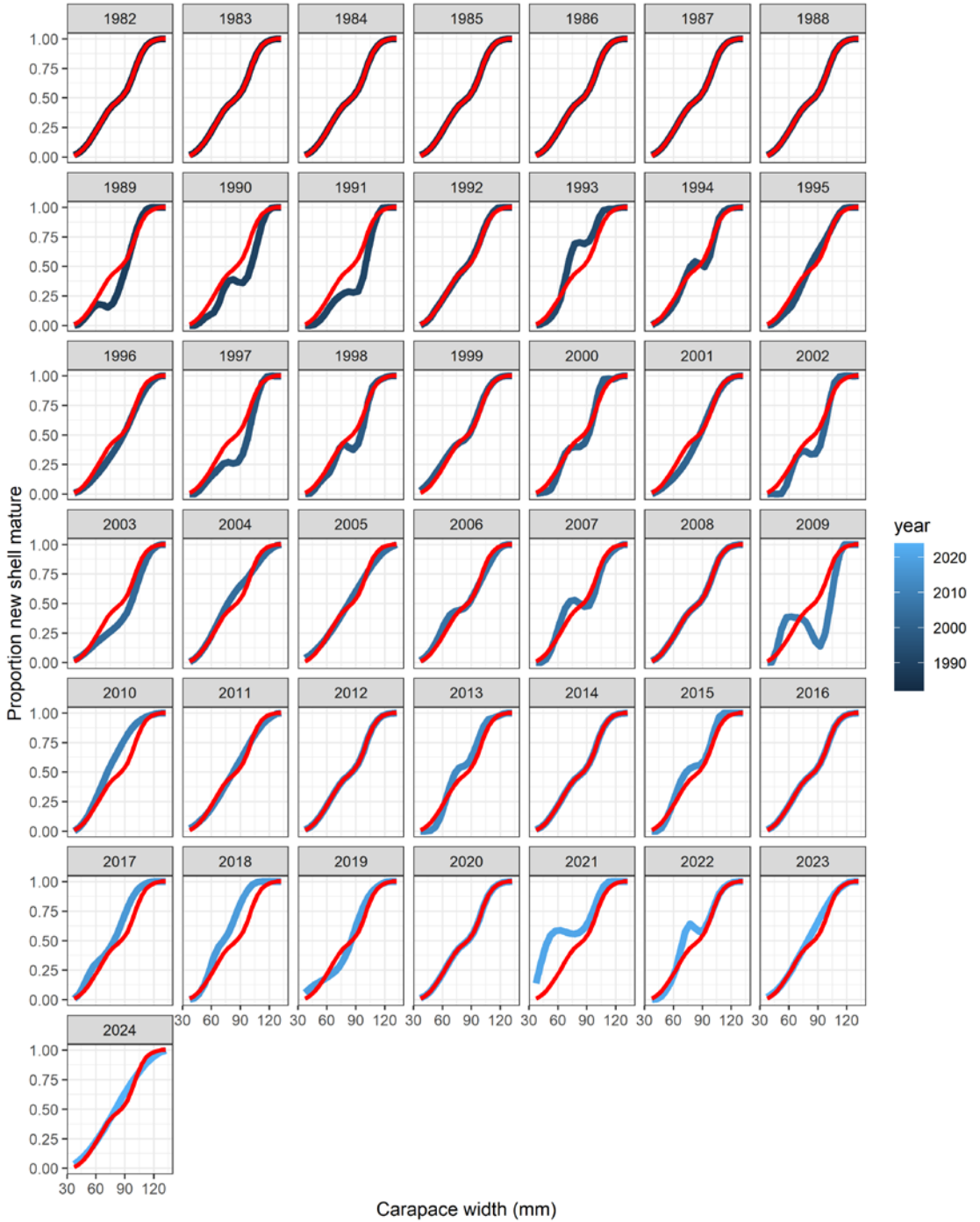
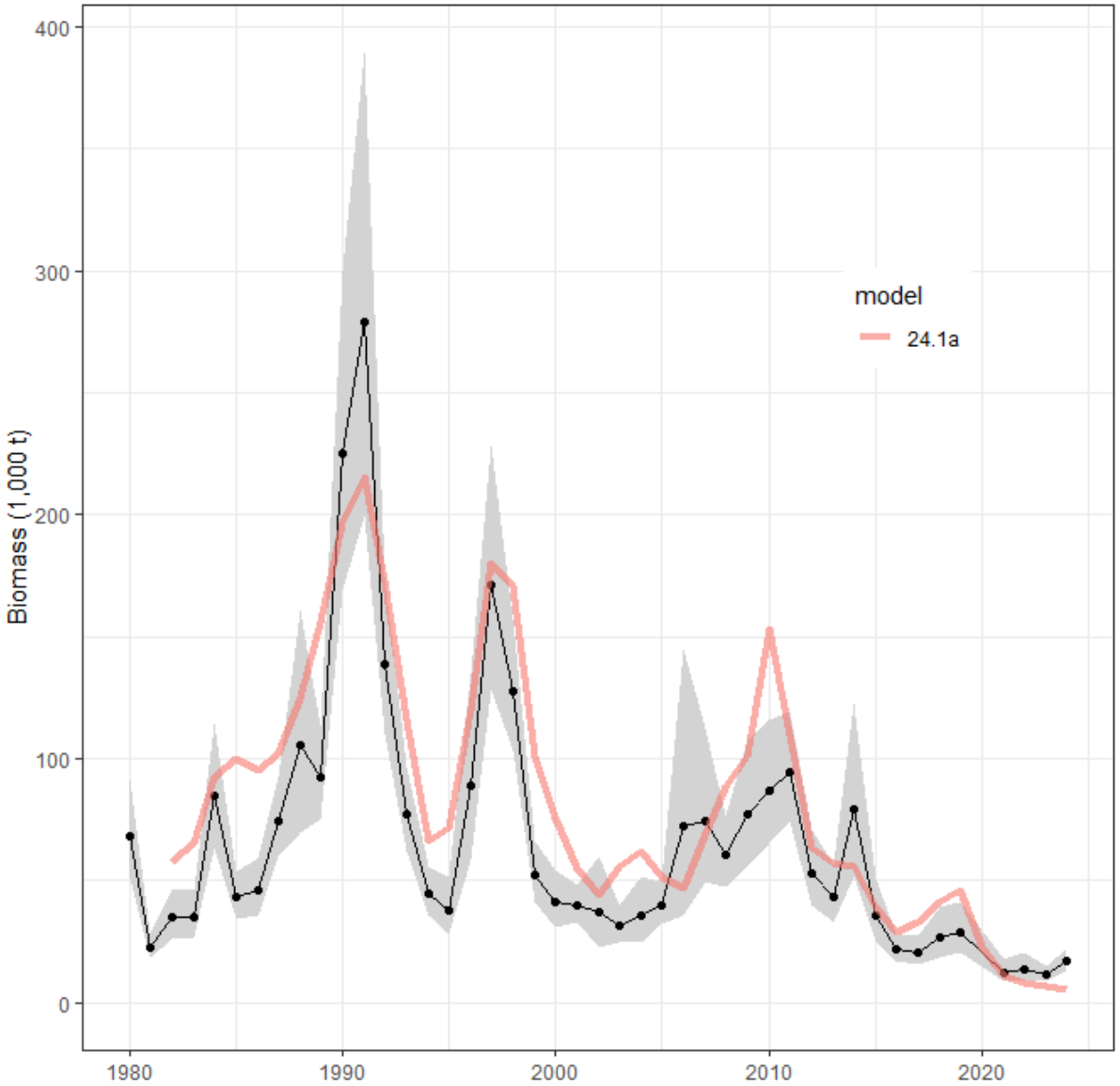
Fishing mortality	High estimated fishing mortality in some years; translate to lower, but still high, exploitation rates
Recruitment	Estimated recruitment different by sex; no clear stock-recruit relationship regardless of currency used
Natural mortality	Strongly constrained by prior except for in 2018-2019, when large estimated mortality occurred for immature animals
Maturity	

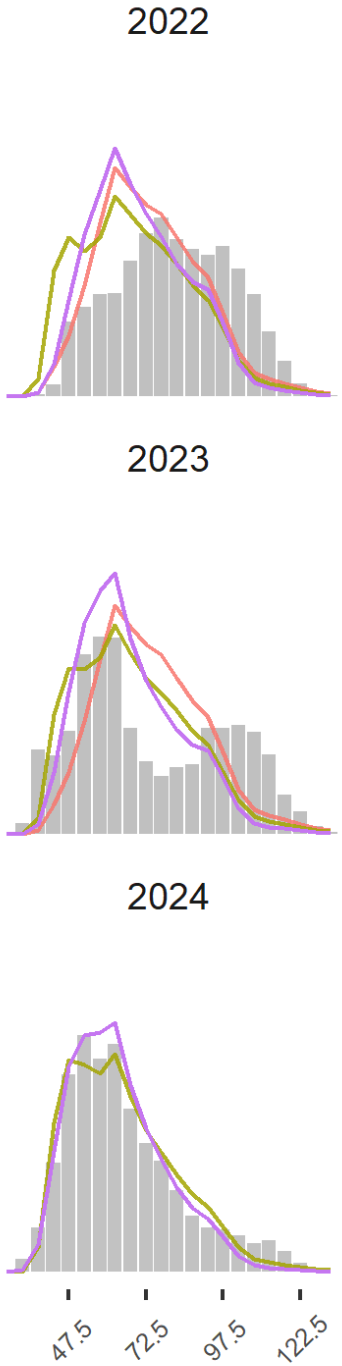


Population process	comments
Selectivity	Total fishery selectivity low for smallest of industry preferred males; big difference between selectivity for males and females
Fishing mortality	High estimated fishing mortality in some years; translate to lower, but still high, exploitation rates
Recruitment	Estimated recruitment different by sex; no clear stock-recruit relationship regardless of currency used
Natural mortality	Strongly constrained by prior except for in 2018-2019, when large estimated mortality occurred for immature animals
Maturity	Possible pattern in probability of terminally molting over time; recent observations average



Why so few large males?





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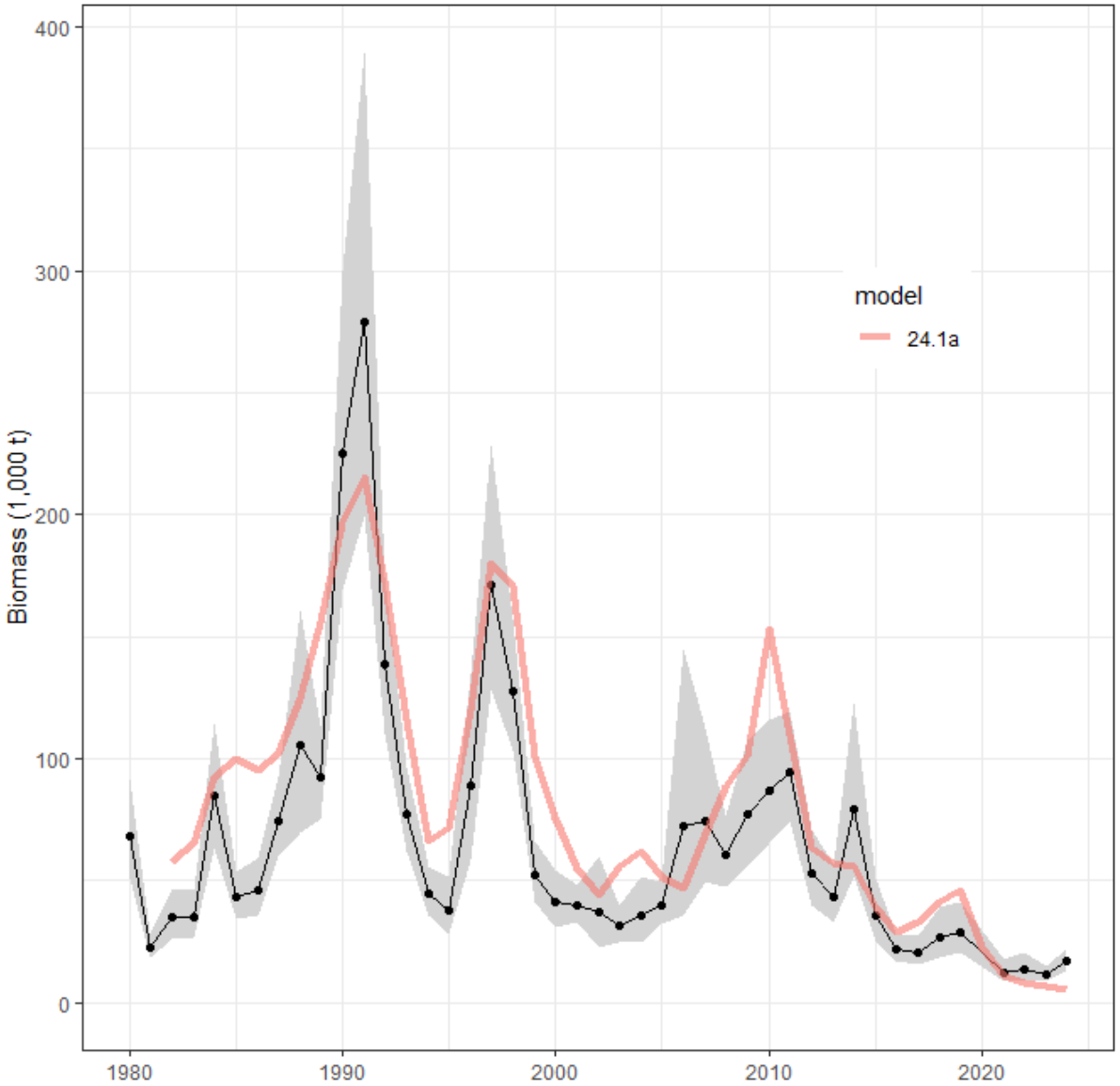
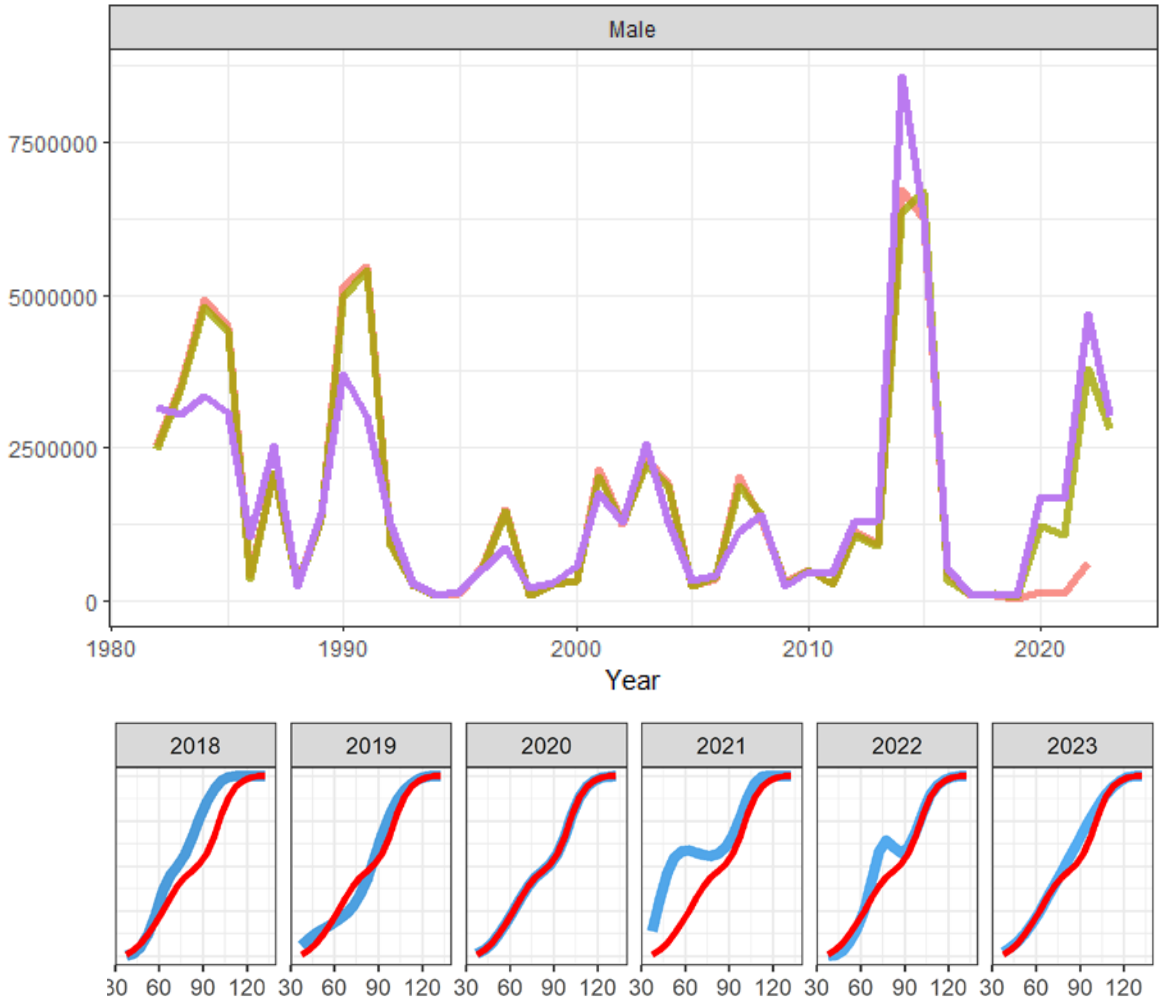




- Low recruitment
- High probability of terminal molt

Model Summary

- Things I like
  - Data sources are modeled in ways that represent the biology well
  - (the move to non-parametric survey selectivity + realistic probability of terminal molt was what was needed)

- Things that could use work
  - Survey selectivity estimates smoothness
  - Poor fits to large males recently

- Things I hope to explore
  - Modifications to GMACS to accept an input F for tier 4 rules
  - Sensitivities to explore estimates of fishery selectivity
  - Estimating probability of terminally molting with priors
  - Why is the jitter jittery
  - density dependence in probability of terminal molt and the implications for management

Harvest control rules

GMACS biomass + tier 3

24.1a: Morphometric mature biomass; B35%

24.1b: >95mm mature biomass; B35%

24.1c: >95mm mature biomass; B45%

Model	MMB	B35	F35	FOFL	OFL	M	avg_rec	Status
23.1	128.11	164.05	61.78	24.21	23.40	0.29	154.55	0.78
24.1	115.46	181.01	59.72	26.12	20.15	0.29	167.37	0.64
24.1a	106.52	191.81	49.63	25.07	19.60	0.28	164.98	0.56
24.1b	13.40	94.82	0.81	0.00	0.05	0.28	164.98	0.14
24.1c	13.40	121.91	0.53	0.00	0.05	0.28	164.98	0.11

FEDERAL CLOSURE

GMACS biomass + tier 4

24.1a: Morphometric mature biomass; M + avg biomass

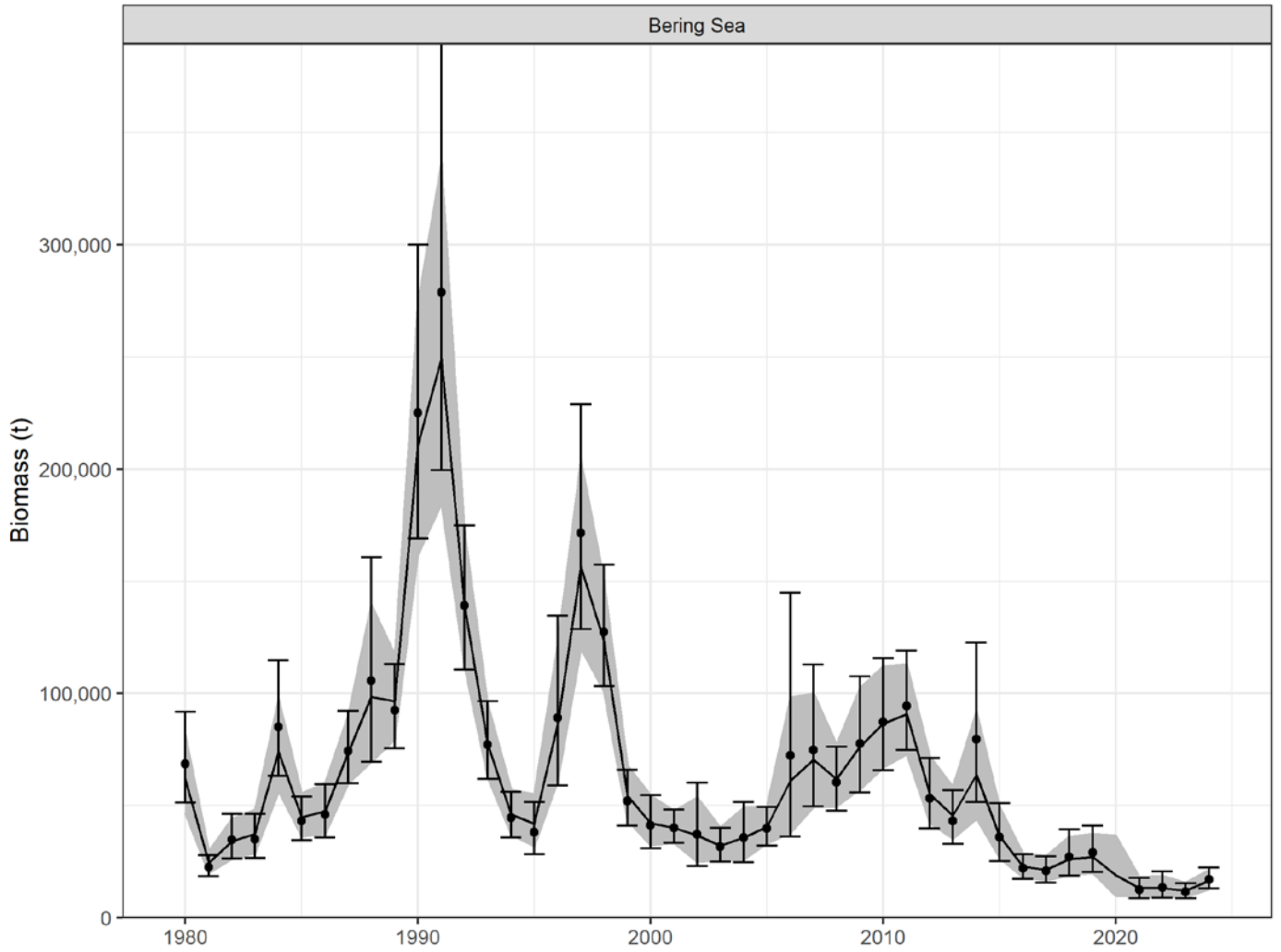
24.1b: >95mm mature biomass; M + avg biomass

Model	MMB	B35	F35	FOFL	OFL	M	avg_rec	Status
23.1	128.11	164.05	61.78	24.21	23.40	0.29	154.55	0.78
24.1	115.46	181.01	59.72	26.12	20.15	0.29	167.37	0.64
24.1a	106.52	275.80	0.28	0.11	0.45	0.28	164.98	0.39
24.1b	13.40	64.77	0.28	0.00	0.05	0.28	164.98	0.21

FEDERAL CLOSURE

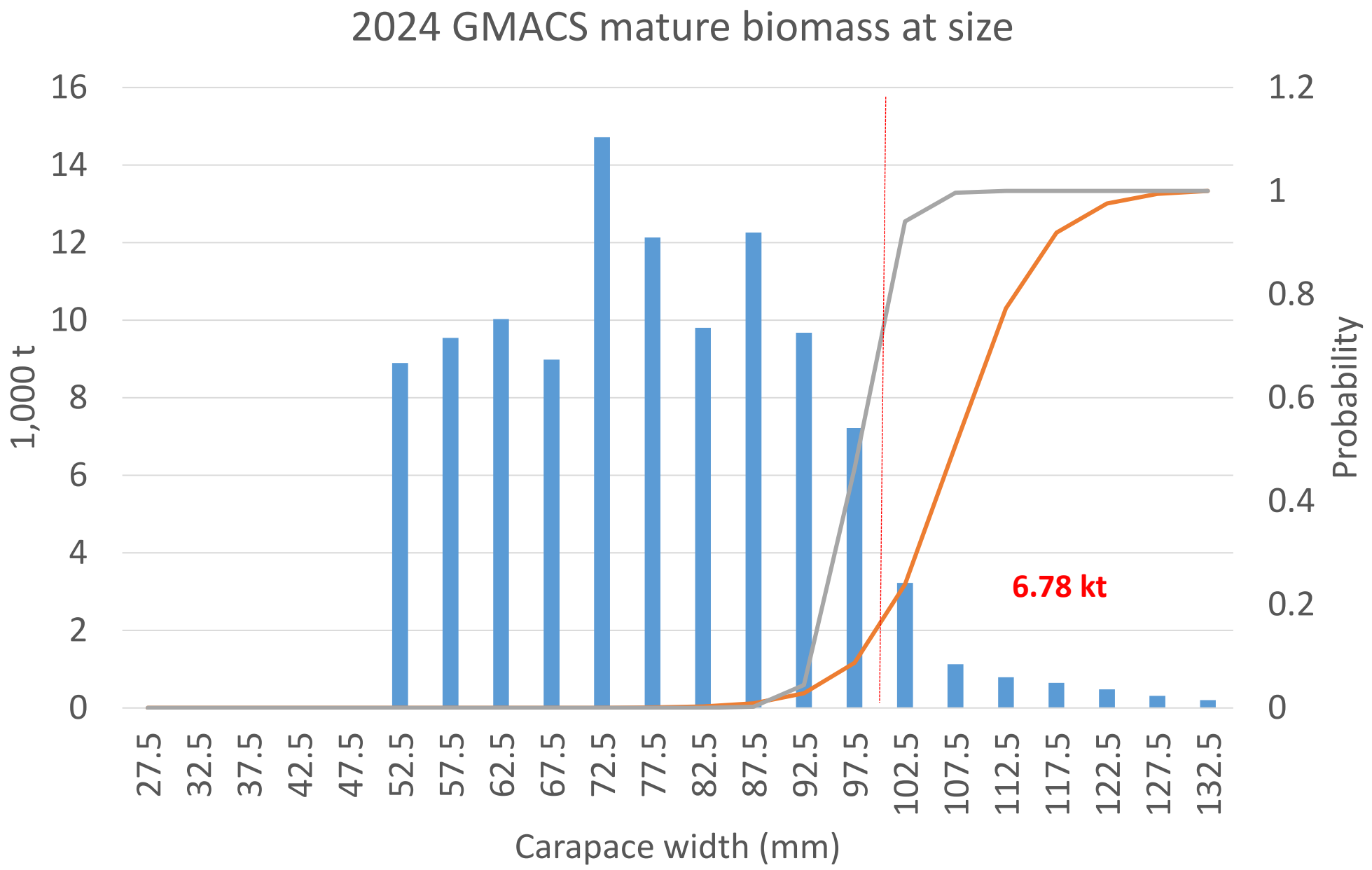
Survey biomass + tier 4

- 4_author:
  - >101 mm mature males;
  - sloped HCR; FMSY = M;
  - BMSY = avg biomass 1982-2022;
  - decrement survey biomass by M to fishery
- 4_ssc:
  - >101 mm mature males;
  - FMSY = M



Year	Tier	BMSY	Males_com	Status	FOFL	OFL	Years	M
2023/2024	4_author	57.27	14.58	0.25	0.05	0.66	1982-2022	0.27
2023/2024	4_SSC	NA	16.56	NA	0.27	3.92	NA	0.27

Biomass	FMSY	BMSY	Currency	OFL	comments
GMACS 24.1a	F35%	B35%	Morphometric	19.60	
GMACS 24.1b	F35%	B35%	>95mm	0.05	
GMACS 24.1c	F45%	B45%	>95mm	0.05	
GMACS (not shown)	M	Avg biomass	Morphometric	0.45	
GMACS (not shown)	M	Avg biomass	>95mm	0.05	
Survey 4_author	M	Avg biomass	>101mm	0.66	
Survey 4_SSC	M	NA	>101mm	3.92	


2024 GMACS mature biomass at size
1,000 t
Probability
Carapace width (mm)
6.78 kt
16
14
12
10
8
6
4
2
0
1.2
1
0.8
0.6
0.4
0.2
0
27.5
32.5
37.5
42.5
47.5
52.5
57.5
62.5
67.5
72.5
77.5
82.5
87.5
92.5
97.5
102.5
107.5
112.5
117.5
122.5
127.5
132.5

Biomass	FMSY	BMSY	Currency	OFL	comments
GMACS 24.1a	F35%	B35%	Morphometric	19.60	Only 6.28 kt of the OFL is industry-preferred, 7.9 kt is retained; the rest of the OFL is discard. Even a 65% buffer allows for the removal of all the large males.
GMACS 24.1b	F35%	B35%	>95mm	0.05	
GMACS 24.1c	F45%	B45%	>95mm	0.05	
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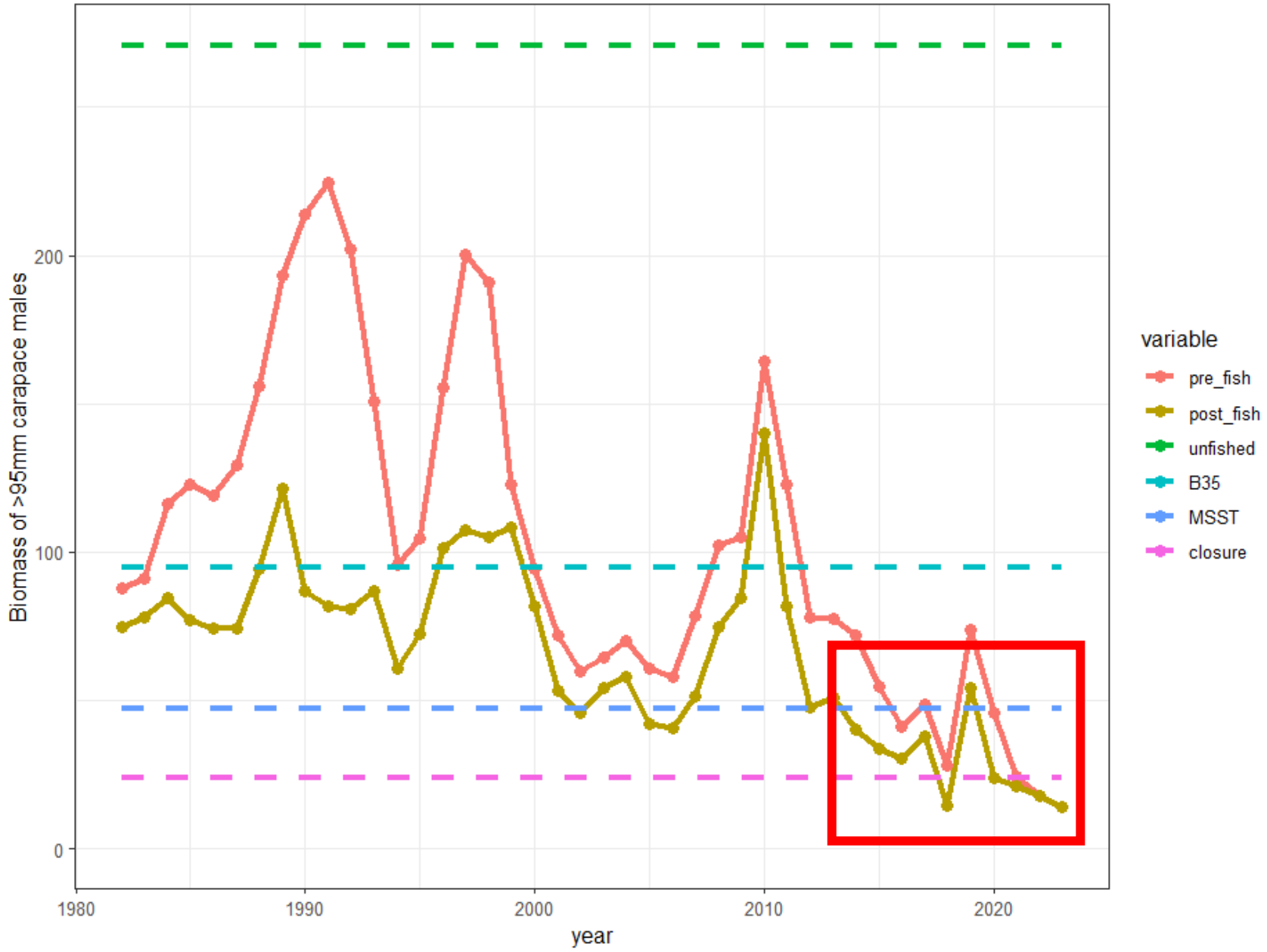

Retrospectively, this harvest control rule would have been declared overfished in 2014, and closed in 2018.

Biomass	FMSY	BMSY	Currency	OFL	comments
GMACS 24.1a	F35%	B35%	Morphometric	19.60	Only 6.28 kt of the OFL is industry-preferred, 7.9 kt is retained; the rest of the OFL is discard. Even a 65% buffer allows for the removal of all the large males.
GMACS 24.1b	F35%	B35%	>95mm	0.05	Overfished fishery in 2014-now; closures 2018, 2020-present
GMACS 24.1c	F45%	B45%	>95mm	0.05	Overfished fishery in 2014-now; closures 2018, 2020-present with worse status
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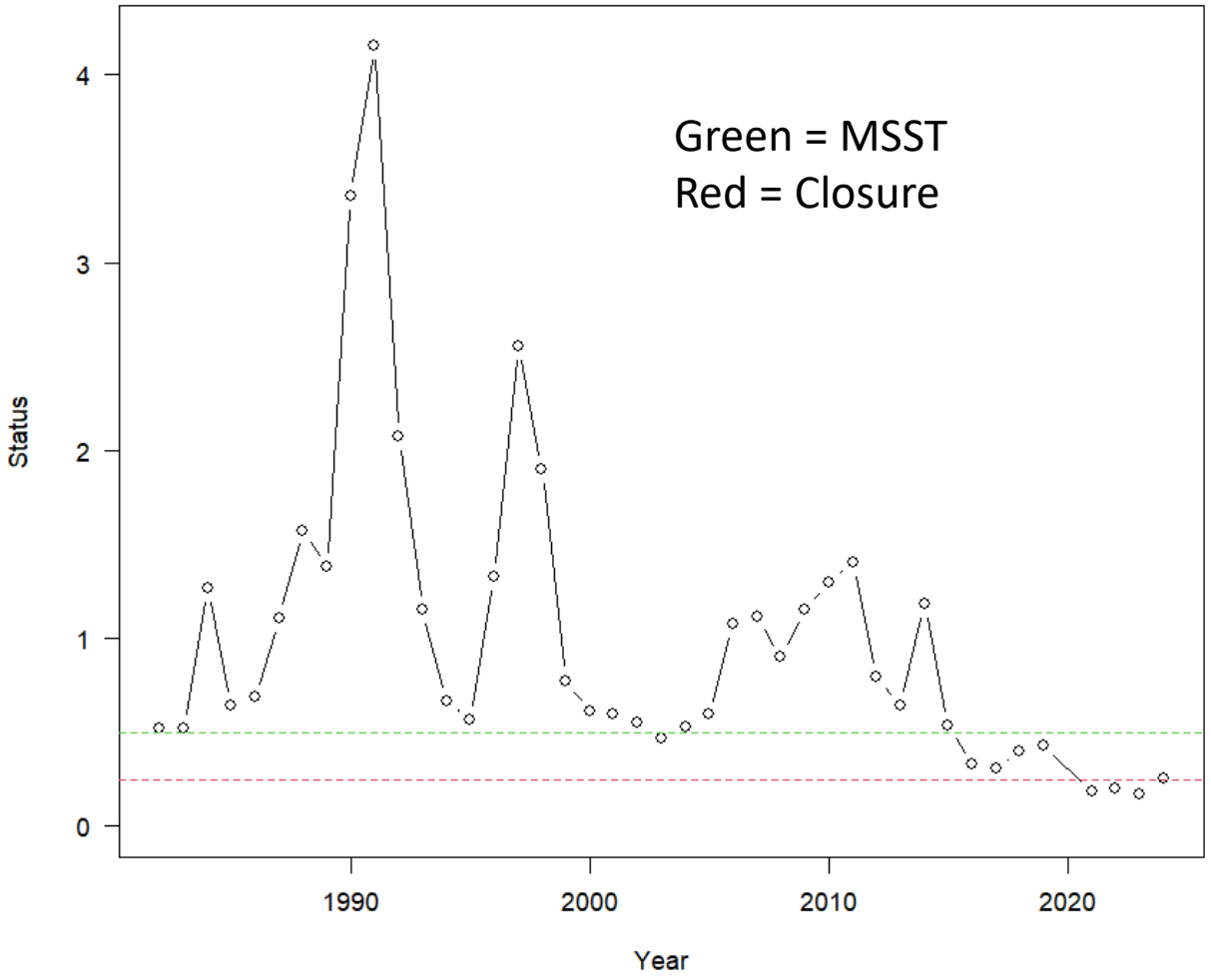
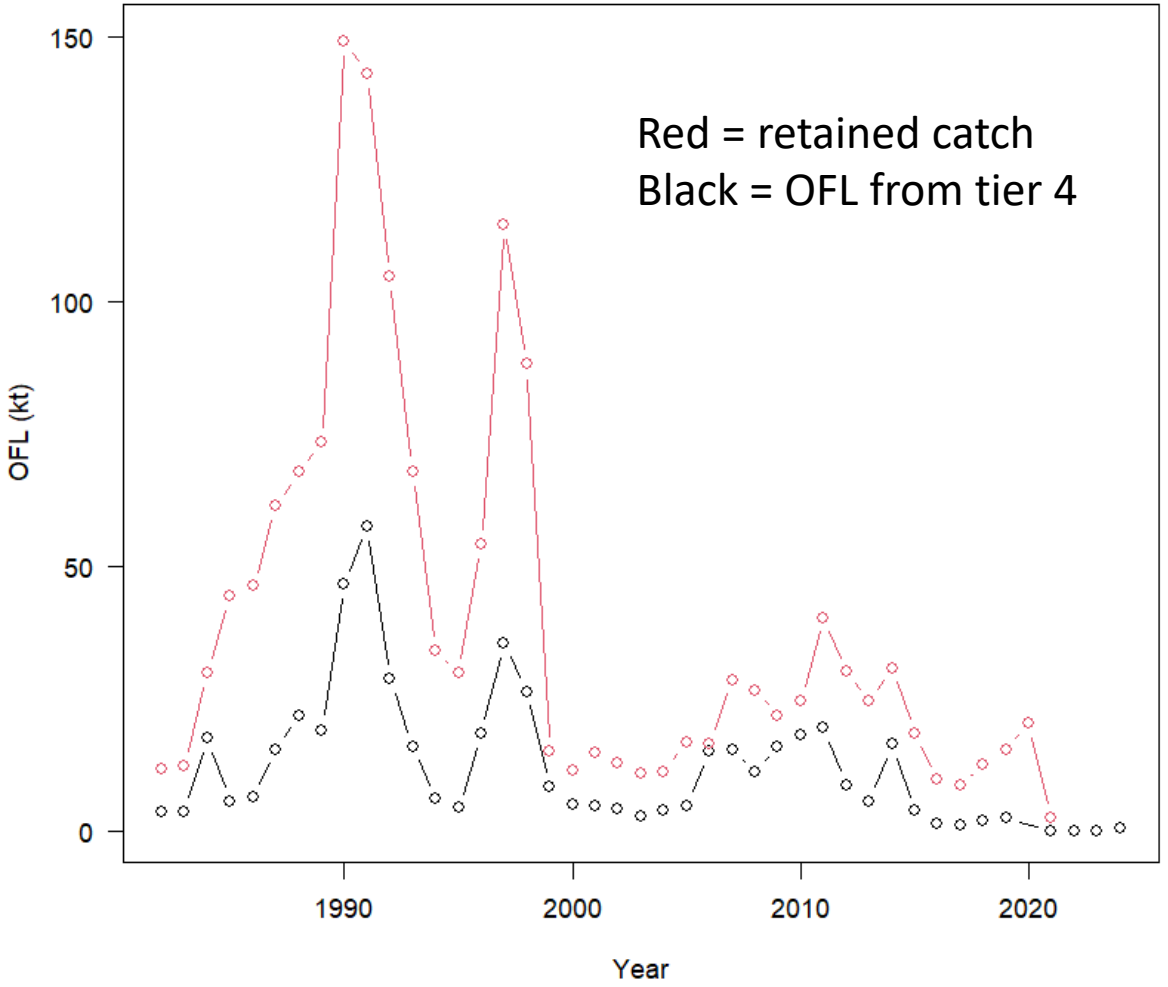
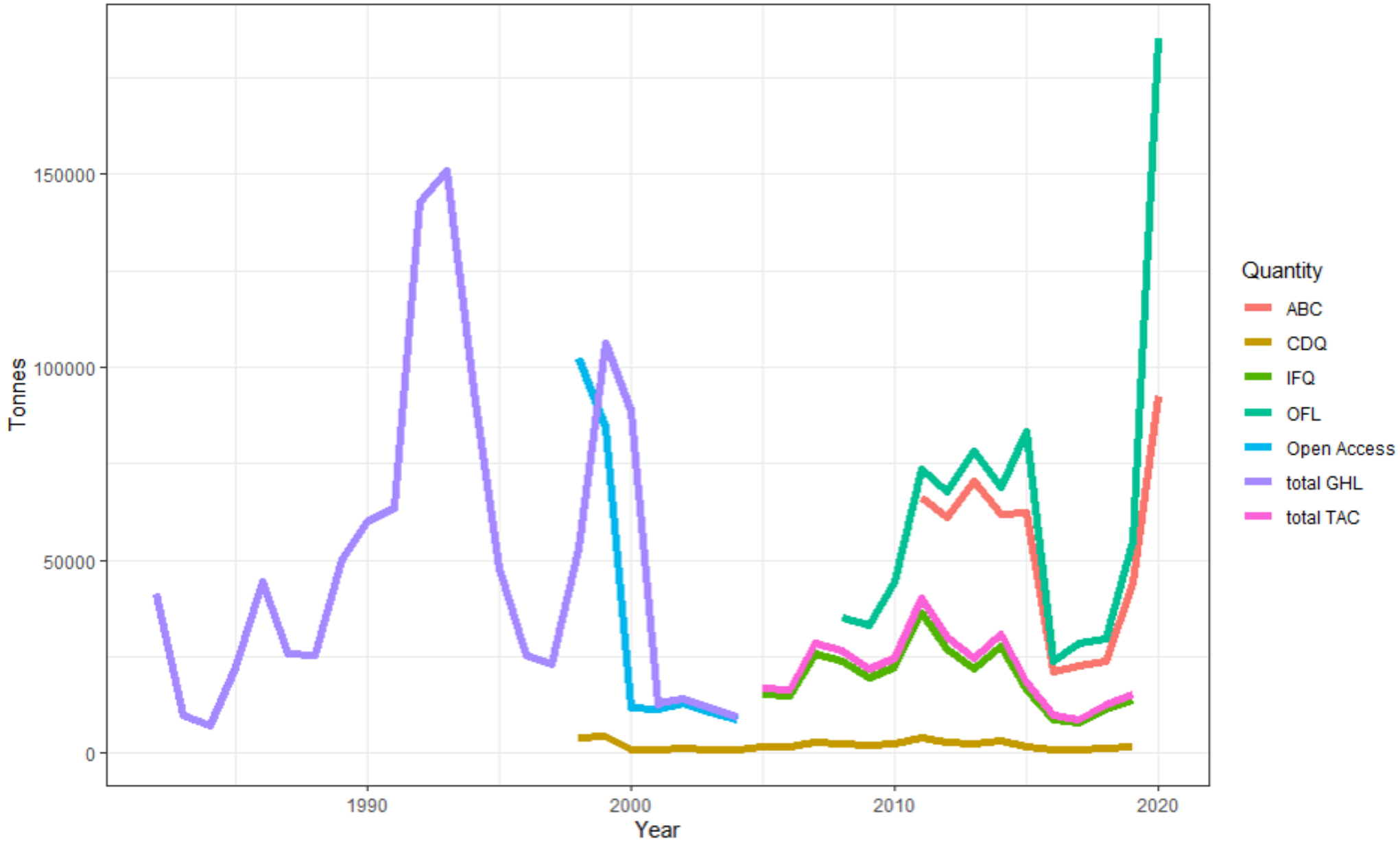
Tier 4 retrospective (>101mm)





(Tier 4 w/in GMACS might bring these closer together)

Federal vs. State HCRS



Biomass	FMSY	BMSY	Currency	OFL	comments
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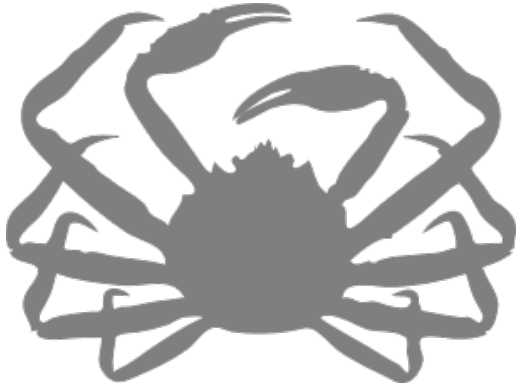
GMACS (not shown)	M	Avg biomass	>95mm	0.05	Fishery mortality + natural mortality != FMSY exploitation rate
Survey 4_author	M	Avg biomass	>101mm	0.66	Only close the fishery the last 3 years, but retrospective catches more conservative than TAC
Survey 4_SSC	M	NA	>101mm	3.92	No slope/status in HCR == no mechanism for closure; No decrement between survey and fishery

BUFFER

- CPT recommended 20% in 2023
- SSC recommended 50% in 2023
- I recommend 20% in 2024, contingent upon model/tier selection

Are small mature males equivalent to large mature males in reproduction?



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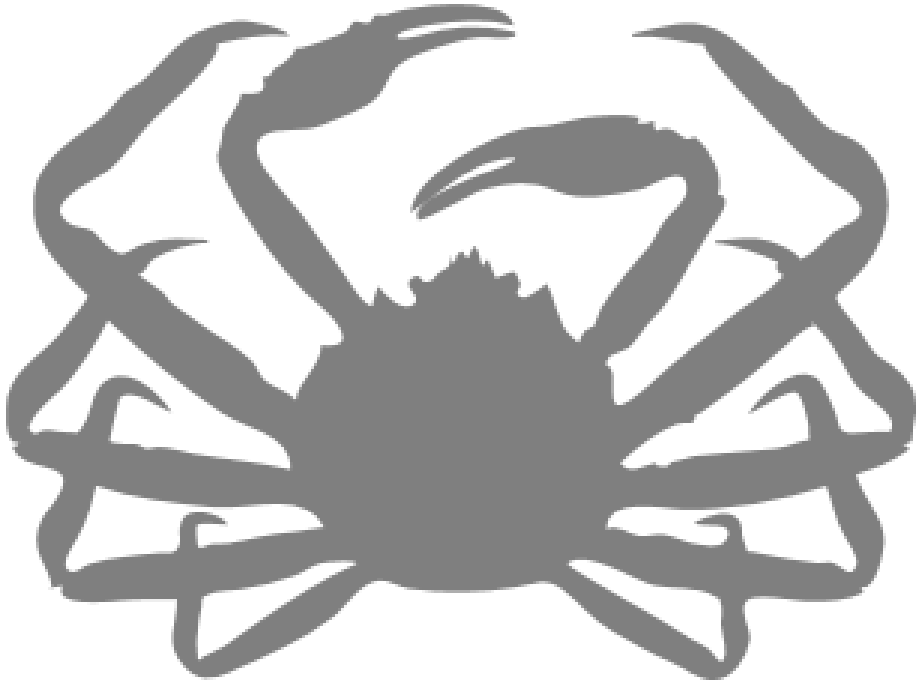
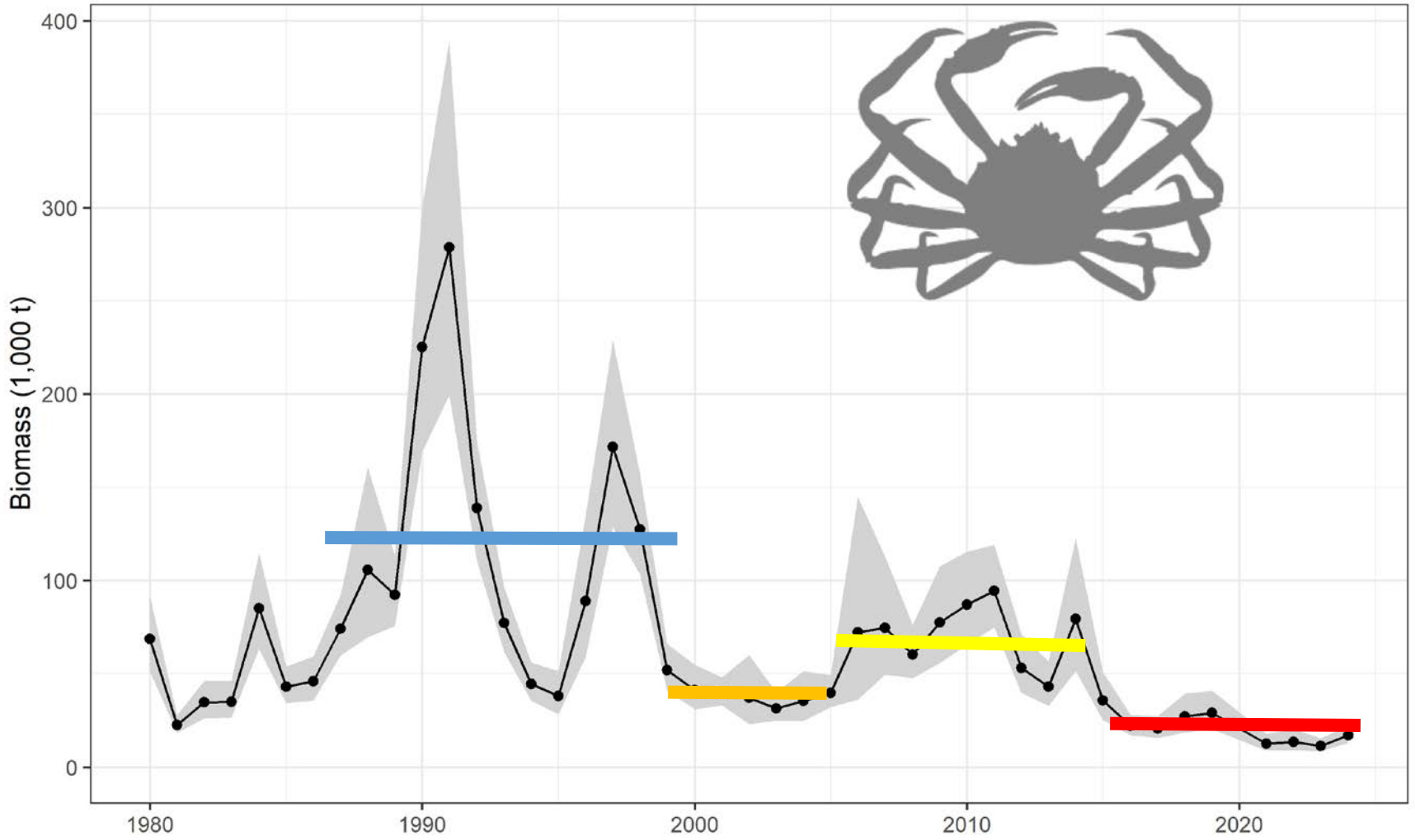


- We are going to spin our wheels until we have resolution on whether or not the small males are important in reproduction
- Trying to identify a ‘risk neutral’ compromise resulted in what seems to be very conservative management
- Are there differences between population sustaining reproduction and fishery sustaining reproduction?
- Can we talk about status of the fishery differently than the status of the population?

OPTIMISM

CAUTION

Long slow decline for lg males

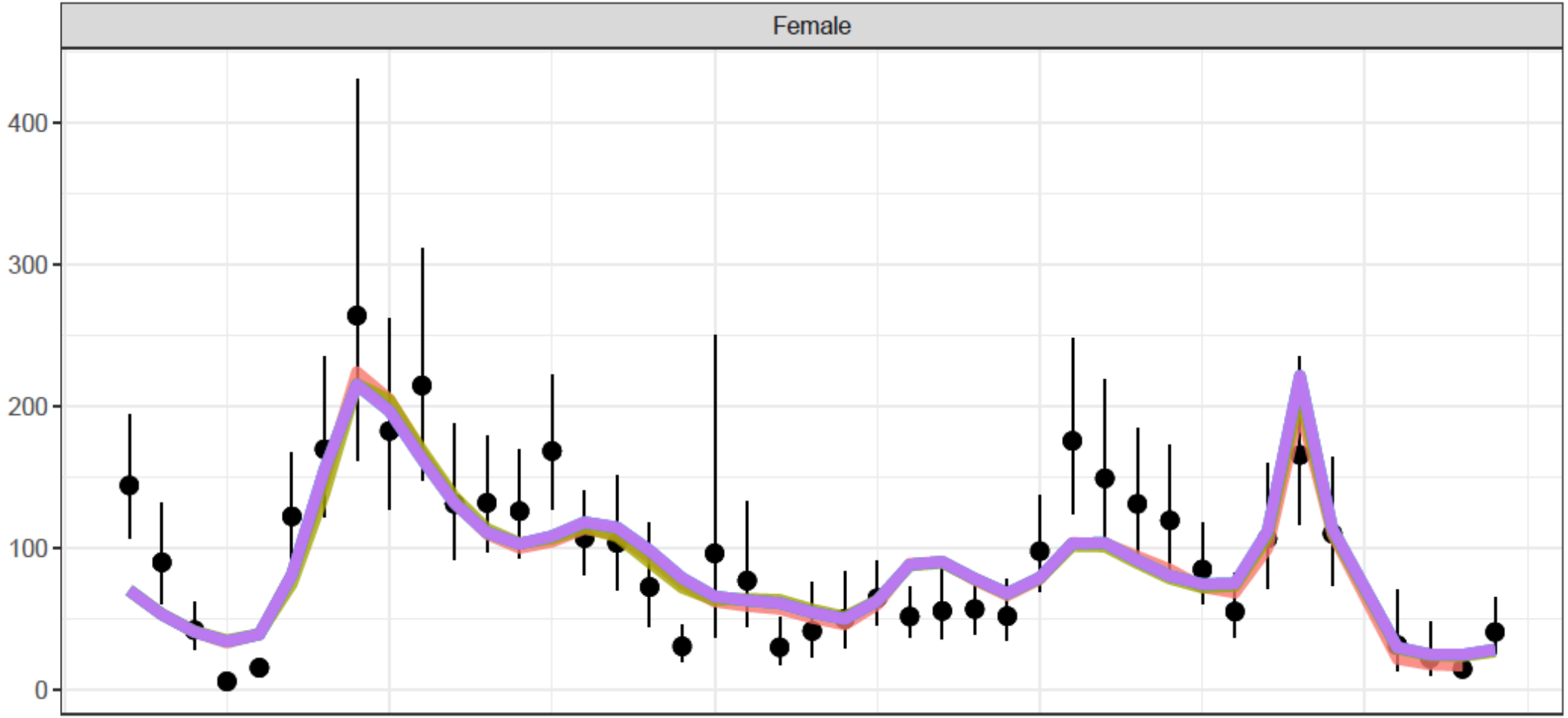


OPTIMISM

Females were doing fine

CAUTION

Long slow decline for lg males



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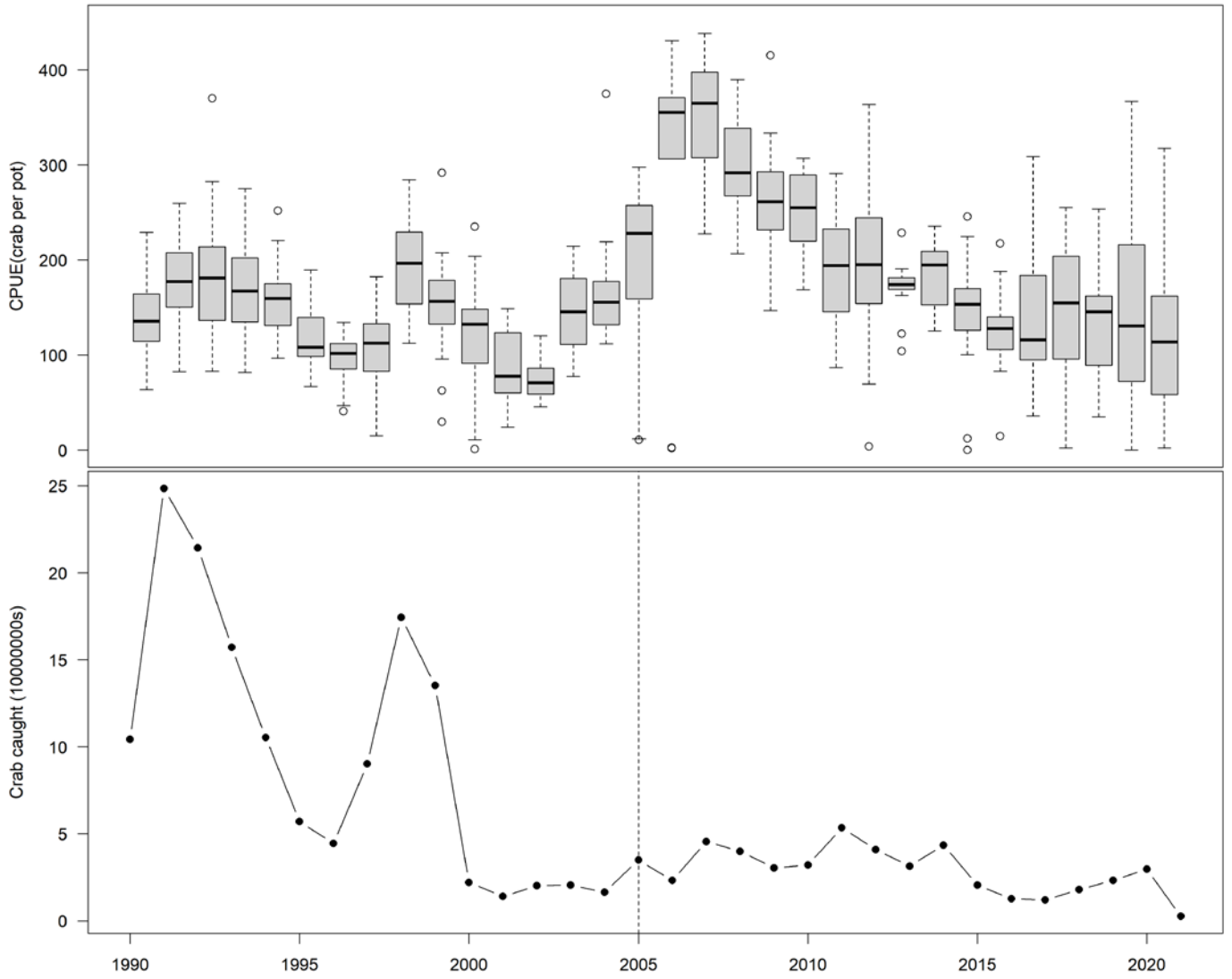
Females were doing fine

CAUTION

Long slow decline for lg males

Steady decline in fishery CPUE since rationalization



OPTIMISM

Females were doing fine

More immature females in the survey than ever in 2024

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Long slow decline for lg males

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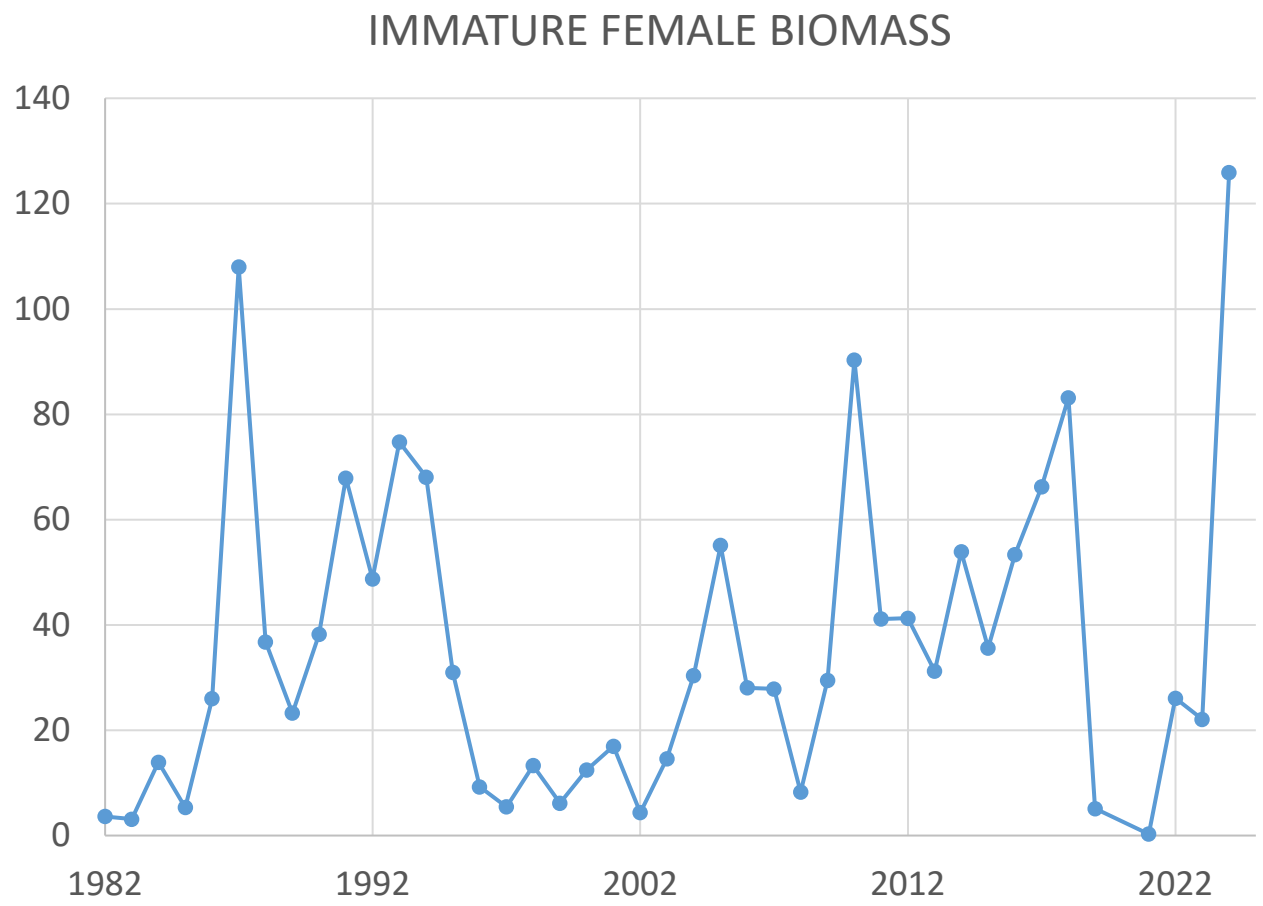

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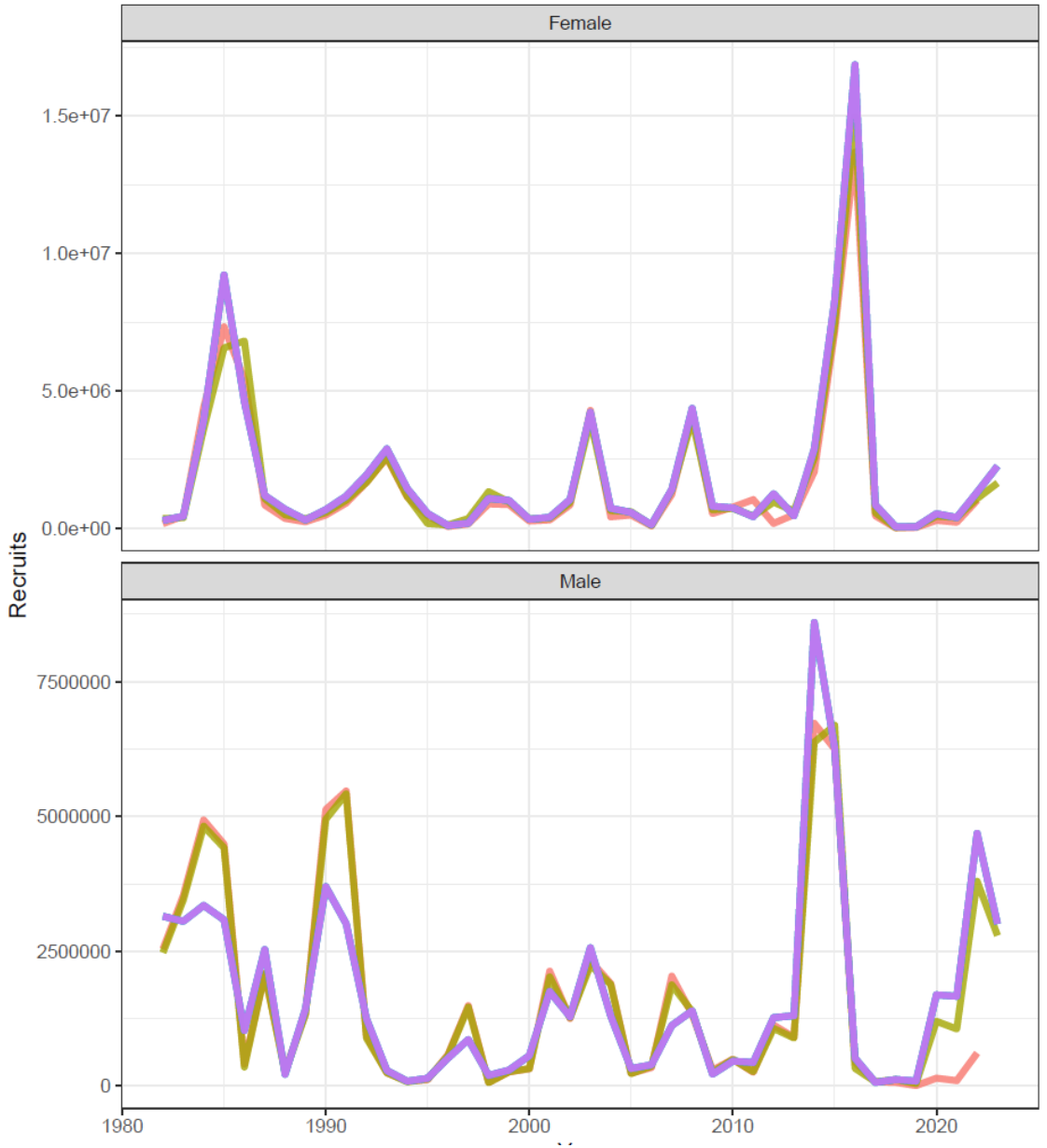
Recent record recruitments



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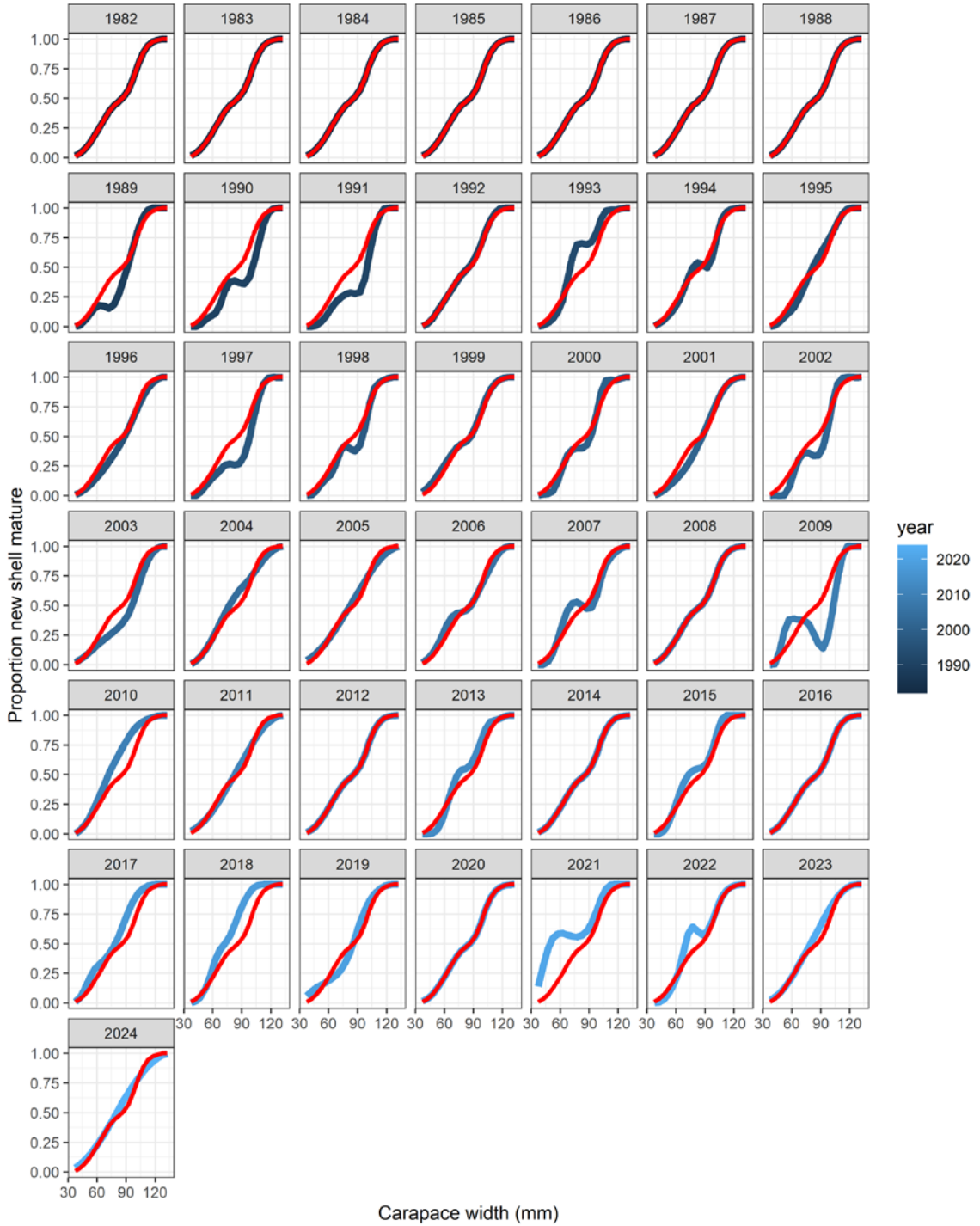

CAUTION

Long slow decline for lg males

Steady decline in fishery CPUE since rationalization

Density dependence in maturity?

OPTIMISM

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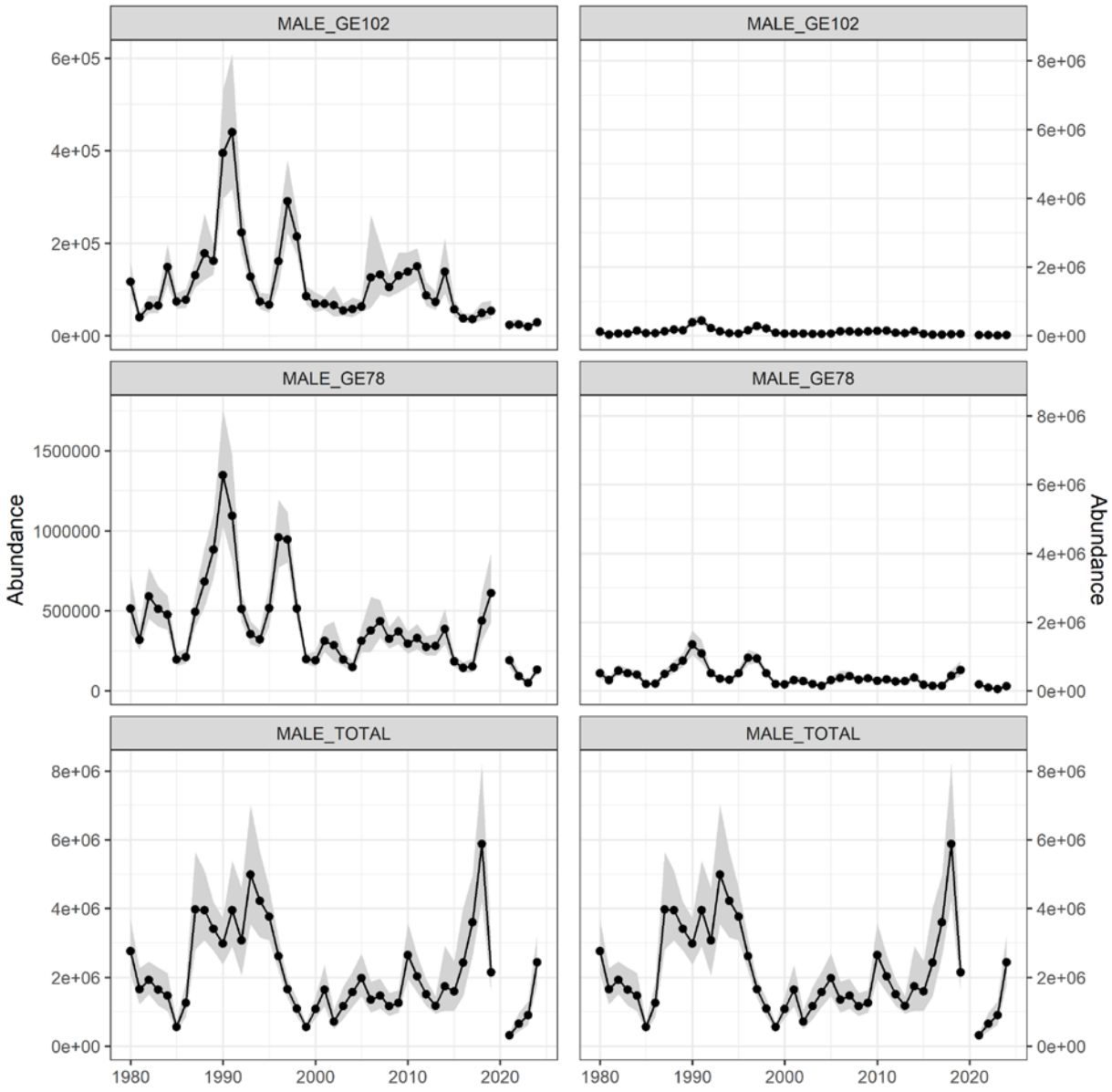
More immature females in the survey than ever in 2024

Recent record recruitments

Divergent trends for total and large males



CAUTION

Long slow decline for lg males

Steady decline in fishery CPUE since rationalization

Density dependence in maturity?

Final thoughts

- Stock is in bad shape with potential reasons for optimism
- Assessment model represents the biology better than ever
- Models are the only tools we have to:
  - try to understand the drivers of the stocks (e.g. why did the stock collapse?),
  - ask hypotheticals (e.g. what if we change selectivity?),
  - incorporate multiple data sources (e.g. BSFRF data)
- Management options were not designed with snow crab biology in mind
- Uncertainties around biology compound problems selecting reference points
- Harmonizing state and federal rules would be useful

Risk table

TOPIC	COMMENT	SCORE
Assessment	Biology good Reference points bad Fits to large males bad Jittering bad	Increased concern (2)
Population dynamics	Large males downward trajectory Recent population collapse Potential for density dependence in terminal molt	Extreme concern (3)
Environmental/ecosystem	ESP indicators mostly neutral	Normal (1)
Fishery performance	CPUE on a long-term downward trend since rationalization Fishery closure	Extreme concern (3)

Recommendations

- Reference points
  - Status quo tier 3 reference points allow for total removal of large males
  - Modified tier 3 reference points would have closed the fishery from 2014-present
  - **Tier 4 recommended**
- GMACS vs. survey
  - No immediate way to actually apply the exploitation rate associated with M given the estimated fishery selectivity
  - GMACS underestimates the large males considerably
  - Jittering issues also present with GMACS
  - **Use the survey estimates of males >101mm**

Year	Tier	BMSY	Males_com	Status	FOFL	OFL	Years	M
2023/2024	4_author	57.27	14.58	0.25	0.05	0.66	1982-2022	0.27
2023/2024	4_SSC	NA	16.56	NA	0.27	3.92	NA	0.27