Eastern Bering Sea snow crab

May 16, 2024

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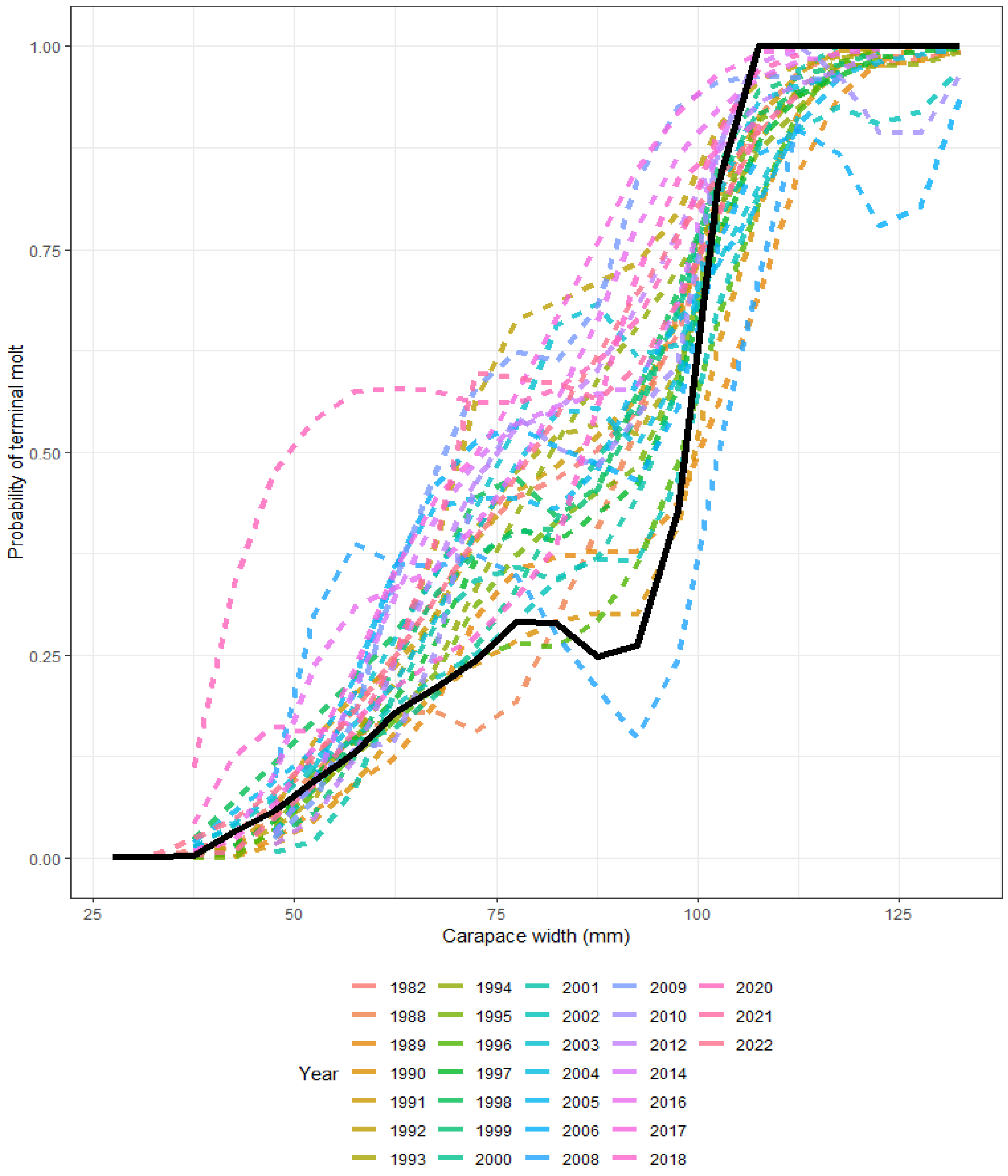
Anchorage, AK

Crab Plan Team

Outline

- No new models; need input on conceptual framework
- Model description and rationale
  - Probability of terminal molt
  - BSFRF data
- Management currency
  - SBPR calculations
  - Maturity definitions
- Climate driven stock projections
  - Rebuilding prospects



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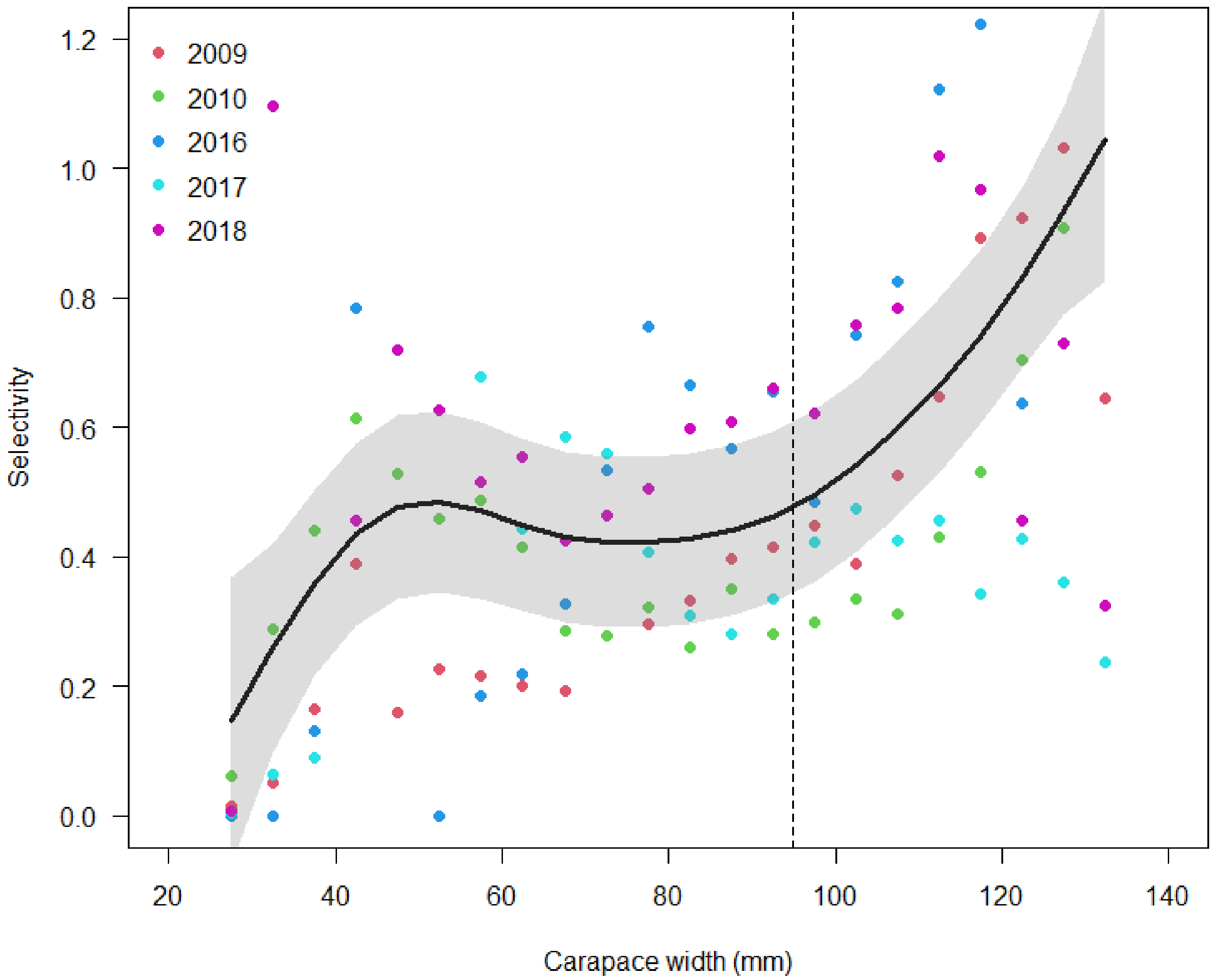

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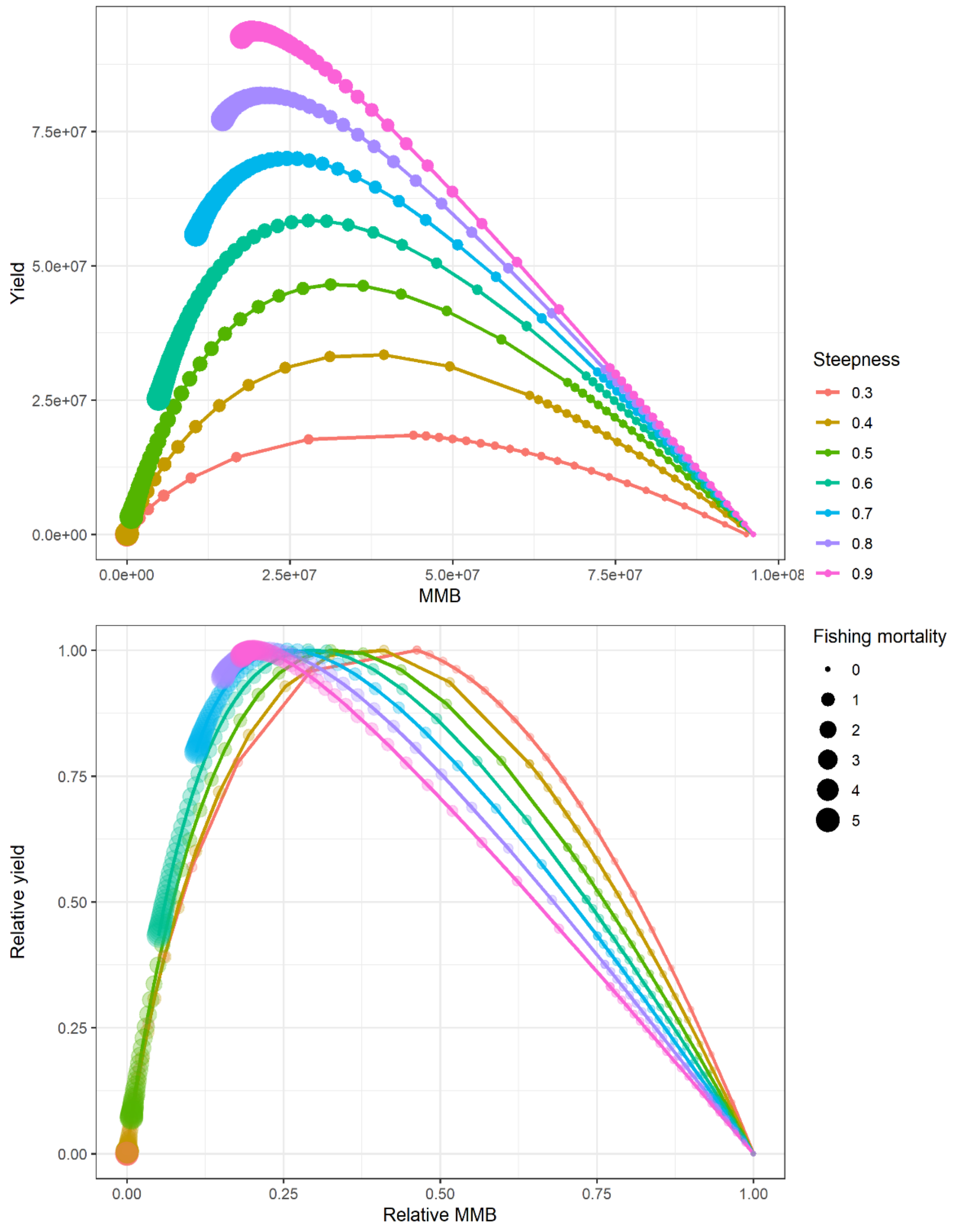

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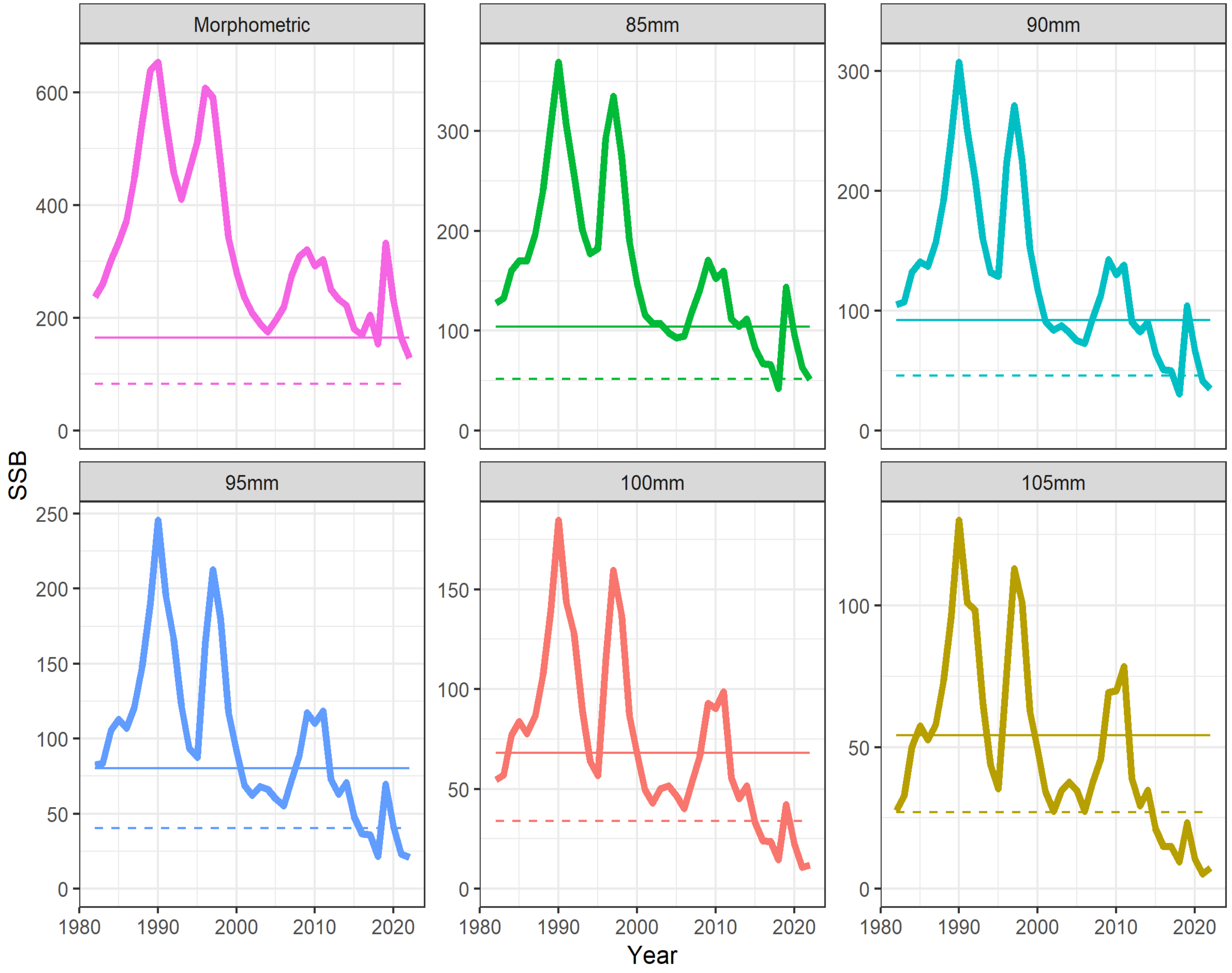

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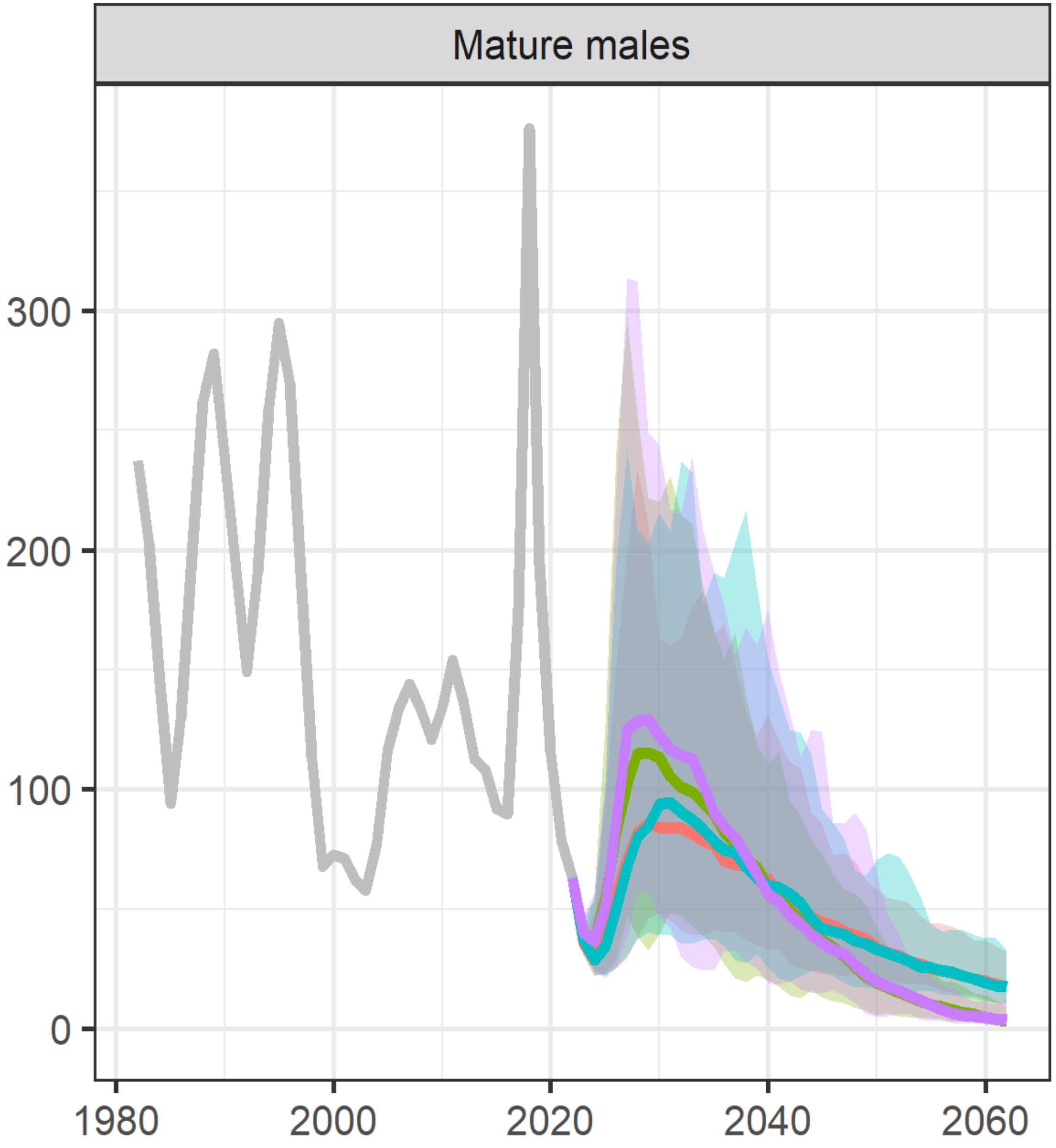


SSC comments and responses

(Public comment) expressed a lack of understanding as well as lack of confidence in the stock assessment modeling. It was suggested that preparing a simple stock assessment narrative that documents recent history on model development for stakeholders could improve comprehension and buy-in. The SSC understands that assessment methods are technical and complex and agrees that more effort is needed
A description of the model, recent changes, and rationale for those changes are included below.

SSC comments and responses

Alternative Snow Crab reference points - A major issue with Model 23.3a is that the value of F35% is extremely high and would effectively remove all the industry-preferred crab from the population. This occurs because snow crab mature at a smaller size than the size at which snow crab are retained by the fishery, so there is a component of mature males that are protected from fishing mortality. This was already an issue in the base model (23.1) but was further exacerbated in 23.3a as the effective maturity was moved to younger males and the length of full selection increased with the addition of the empirical terminal molt probabilities. The analysis that provided the basis for the F35% harvest rate (Clark 19911) assumed that maturity and fishery selection curves were the same, but also considered scenarios where maturation occurred earlier than fishery selection. The extreme mismatch between maturation and selectivity seen for snow crab was not considered in Clark (1991). Furthermore, this mismatch was not found to be an issue when the analyses were done to support adoption of the tier system in the crab FMP. Therefore, potential alternatives to F35% should be considered for snow crab in the future. It is important to note that this flexibility is built into the crab FMP, which indicates that alternative values to the default reference points F35% and B35% can be recommended by the SSC based on best available information. The SSC did not support replacement of M for F35% in the Tier 3 OFL control rule. Due to the delayed fishery selectivity pattern relative to size composition of the exploitable males, natural mortality may be an extremely conservative harvest policy, and it would not be advisable to adopt without further evaluation. The SSC also finds weak support for moving to average MMB for the BMSY proxy as B35% provides a reasonable reference point. The stock has varied above and below B35% primarily due to recruitment variability that does not appear directly associated with harvesting. Indices of female reproduction have remained high, and the proportion of large males in the population has remained stable even while overall abundance has declined.

The idea of retaining some percentage of the reproductively important population is conceptually satisfying and relatively intuitive. The reproductively important part of the population (i.e. management currency) and appropriate percentage to be retained (i.e. reference points) need to be identified. SBPR analyses are performed below for different definitions of mature male biomass and at different percentages of unfished biomass as target to explore this question.

SSC comments and responses

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.
Reproductive output appears to be strongly influenced by environmental conditions. Appendix 1 explores the implications of environmentally driven recruitment dynamics and receding ice in the Bering Sea. Short-term projections hold some possibility for rebuilding if conditions align; long-term projections suggest large-scale declines of mature male abundance in the eastern Bering Sea.

SSC comments and responses

The SSC requests a yield analysis be done for snow crab, including the relationship between fishing mortality and catch, MMB, functional maturity, and the proportion of large males in the population. The stock production curve, i.e., yield as a function of MMB, should also be developed.

These were performed for a range of steepnesses and definitions of mature male biomass. Morphometrically mature male biomass could not be depleted to 35% of unfished levels over a wide range of steepnesses. Defining mature male biomass closer to the sizes impacted by the fishery (e.g. 95-100 mm carapace width) resulted in maximin solutions for $SBPR_{XX\%}$ closer to 35% of unfished biomass. See below for further analyses.

SSC comments and responses

consider greater use of the modeling structure to diagnose problems in how the data are being interpreted as opposed to more generally viewing resulting models as potential options for management. Sensitivity and other exploratory approaches using the model should be conducted and presented diagnostically to inform a smaller set of self-consistent models for management considerations.
I think the SSC is asking me to delineate research vs. operational models more carefully and I will do my best.

SSC comments and responses

One idea for statistical exploration regarding the shape of the within-model empirical smoothed estimate of selectivity would be to examine to what extent the spatial distribution of differences in availability of small and large crab (or males and females) would be sufficient to explain the anomalous shape of the survey selectivity curve.

I'm not clear what is 'anomalous' about the shape of the selectivity curve—the shape makes some intuitive sense to me. Very small crab would be poorly selected (they go under and through the gear), a range of medium sized crab would have similar selectivity higher than small crab (harder to go under and through the gear, but still possible) and then selectivity would increase to nearly one for the largest sized crab (the biggest crab do not escape the gear). This seems more reasonable than the historically used logistic curve that had the same selectivity for crab 50-150 mm carapace width. The SSC may also be referring to the small 'hump' at smaller sizes in the BSFRF data. Differences in aggregation behavior by size and maturity state could be related to this phenomenon.

SSC comments and responses

The SSC still requests an analysis of the probability of maturing/terminal molt which treats years as random effects. A hierarchical fit to molt data might be better than annual independent GAMs.
I don't think I have explained this part of the assessment appropriately based on this comment and endeavor to do so more completely below. Reading Richar and Foy (2022; reference below) might also be helpful.

SSC comments and responses

The SSC would like to better understand the sampling design for molt data and is concerned about the weighting of the spatial samples in the analyzing; weighting should be based on abundance if the sampling rate differs by area (which it would, unless abundance were uniform and/or the targets were in direct proportion to abundance). Hierarchical fit to molt data might be better than annual independent GAMs.
Sampling design and methodology for analysis of the chelae data to determine the probability of having undergone terminal molt at size by year is documented in Richar, J and Foy, R (2022) A novel morphometry-based method for assessing maturity in male tanner crab, Chionoecetes bairdi. FACETS. https://doi.org/10.1139/facets-2021-006

SSC comments and responses

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.
This will be explored at a later date.

SSC comments and responses

Providing a clear crab specification narrative would help the SSC and the public navigate the tiers, models, and justifications for both. In addition, it would be helpful to clearly identify models that are being explored for diagnostic purposes as opposed to models that are directly relevant for use in decision making. Public testimony indicated that help and financial support for developing such a narrative might be available.
I will attempt to delineate research vs. operational models more effectively in September.

SSC comments and responses (added from Mike)

A Tier 4 calculation was also provided using survey estimates of industry preferred biomass (>101 carapace width). Since the model was considered suitable for providing management advice, the CPT focused on options that used model estimated reference points, rather than the Tier 4 survey calculation. The SSC had previously requested the Tier 4 approach using survey biomass as a "fallback option" when the model has insurmountable problems and cannot be used for management, as well as a way to provide context for Tier 3 estimates. The authors used the terminal year survey MMB decremented for natural mortality instead of using the REMA model on male survey biomass. The SSC noted that this number was on a different scale than was requested and noted that the MMB used was much smaller than the model estimated MMB. The SSC requests for future years that the authors bring forward the Tier 4 estimate using vulnerable male survey biomass and the REMA model, and do not correct for natural mortality, as, for example, in the 2023 Tanner crab assessment (see also General Crab Comments).

I think this is a bad idea. I've shown in the past using morphometric MMB in a calculation like this could result in OFLs that exceed the number of commercially exploitable crab in the water. The fishery also occurs consistently several months after the survey, so not applying a simple calculation of natural mortality could result in a much larger exploitation rate than assumed. Further, applying REMA to the data might make sense for patchily distributed crab, but snow crab are observed at hundreds of stations. Presumably the reason for not using the assessment is that the model output is not believable. In this case, 'believe the survey' is a reasonable standby. The 2019 survey is a good example where we should have 'believed the survey' and REMA would have prevented us from doing that.

Stock assessment

Goal: Model how the population changes

Biomass(t+1) = Biomass(t) + Additions(t) – Removals(t)

Additions:

- Births
- Immigration
- Somatic growth

Removals:

- Natural deaths
- Fishing deaths
- Emmigration

$$S_{l,dir} = \left(1 + \exp\left(-\frac{\log(19)\left(\bar{L}_l - L_{50,dir}\right)}{L_{95,dir} - L_{50,dir}}\right)\right)^{-1} \quad (A.6)$$

$$S_{l,disc} = \left(1 + \exp\left(-\frac{\log(19)\left(\bar{L}_l - L_{50,disc}\right)}{L_{95,disc} - L_{50,disc}}\right)\right)^{-1} \quad (A.7)$$

$$S_{l,surv} = q * \left(1 + \exp\left(-\frac{\log(19)\left(\bar{L}_l - L_{50,surv}\right)}{L_{95,surv} - L_{50,surv}}\right)\right)^{-1} \quad (A.8)$$

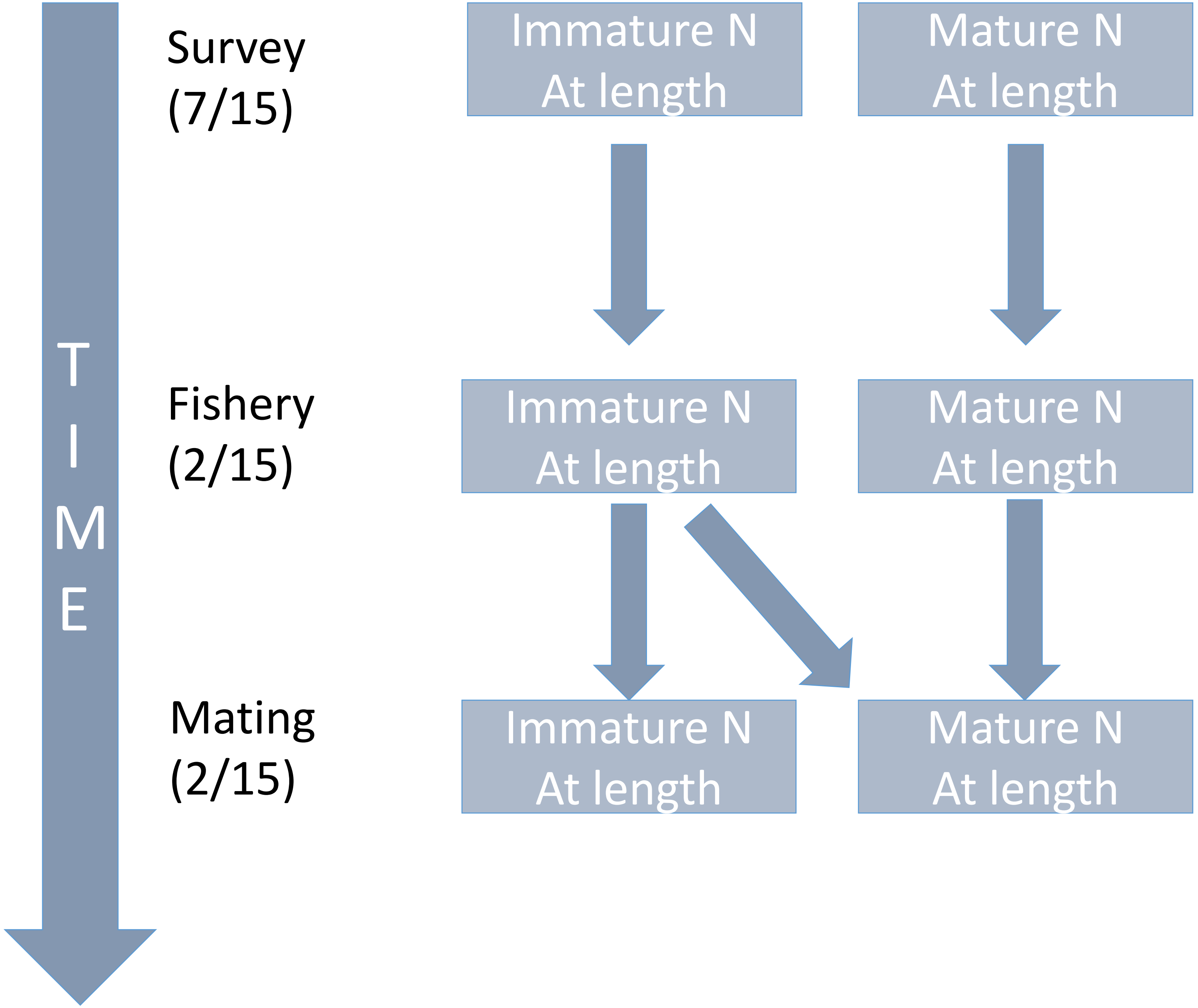
$$I_{a,t,m,l} = \sum_{x} N_{a_x,t,m,l}\, move_{l,s}\, Prop_{a_x,t} \quad (A.9)$$

$$P_2 = \gamma_w \sum_{l} \sum_{a} \left(\ln(\eta_{l,a}) - \ln(\eta_{l-1,a})\right)^2 \quad (A.28)$$

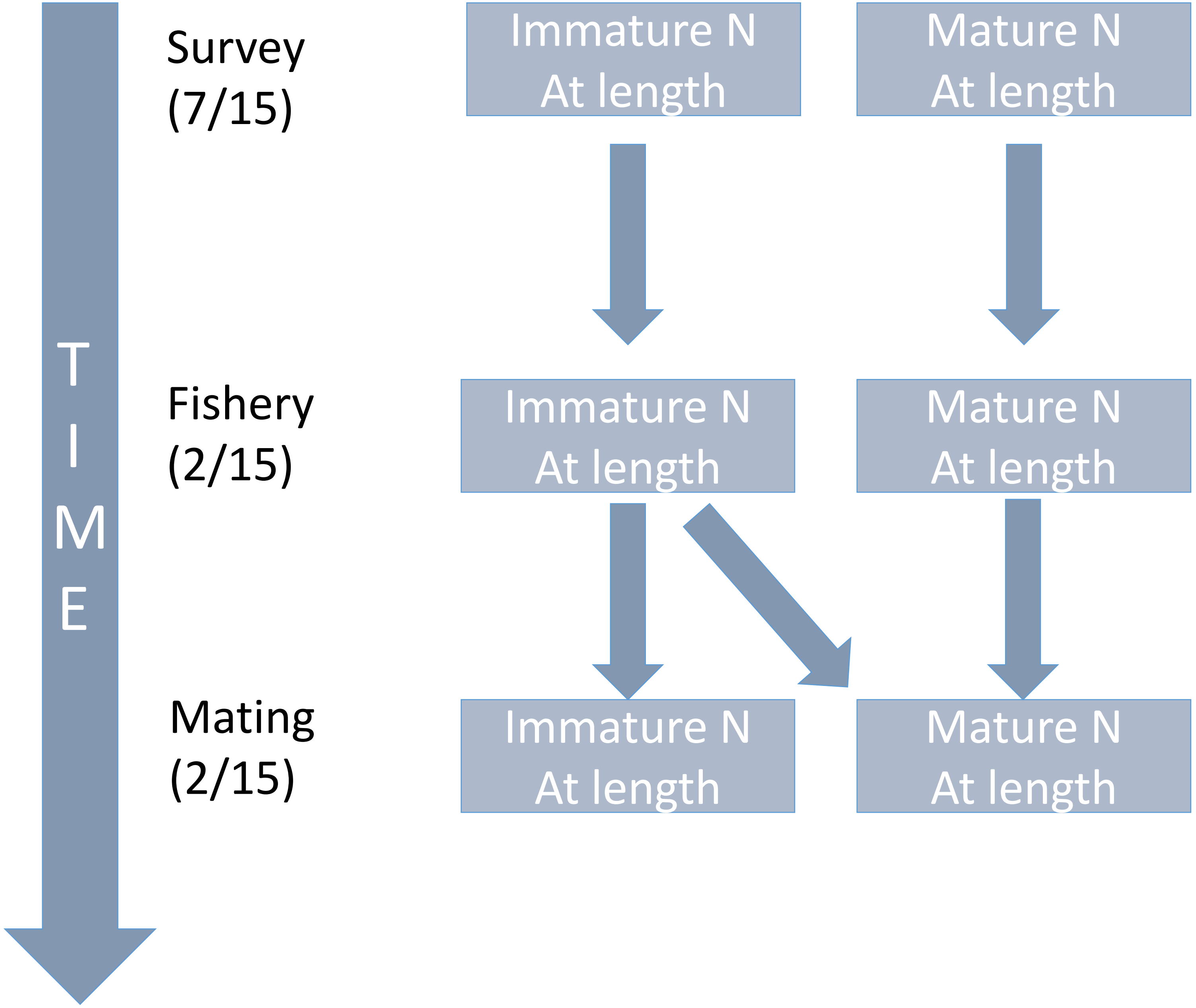
$$\hat{C}^{tot}_{y,a,l} = \sum_{m} S_{l,dir}\, N_{a,m,y,l} e^{-midpt_y * M} (1 - e^{-F_{a,t,l}}) \quad (A.10)$$

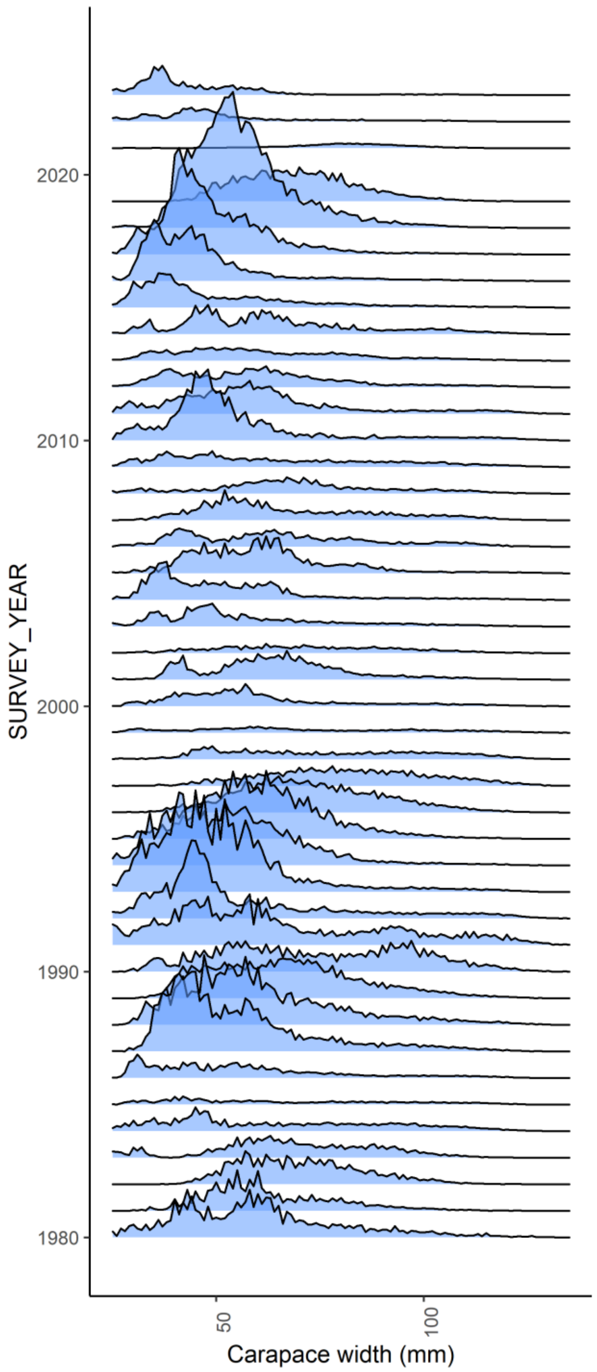
$$\hat{C}^{ret}_{y,a,l} = \hat{C}^{tot}_{y,a,l} S_{l,disc} \quad (A.11)$$

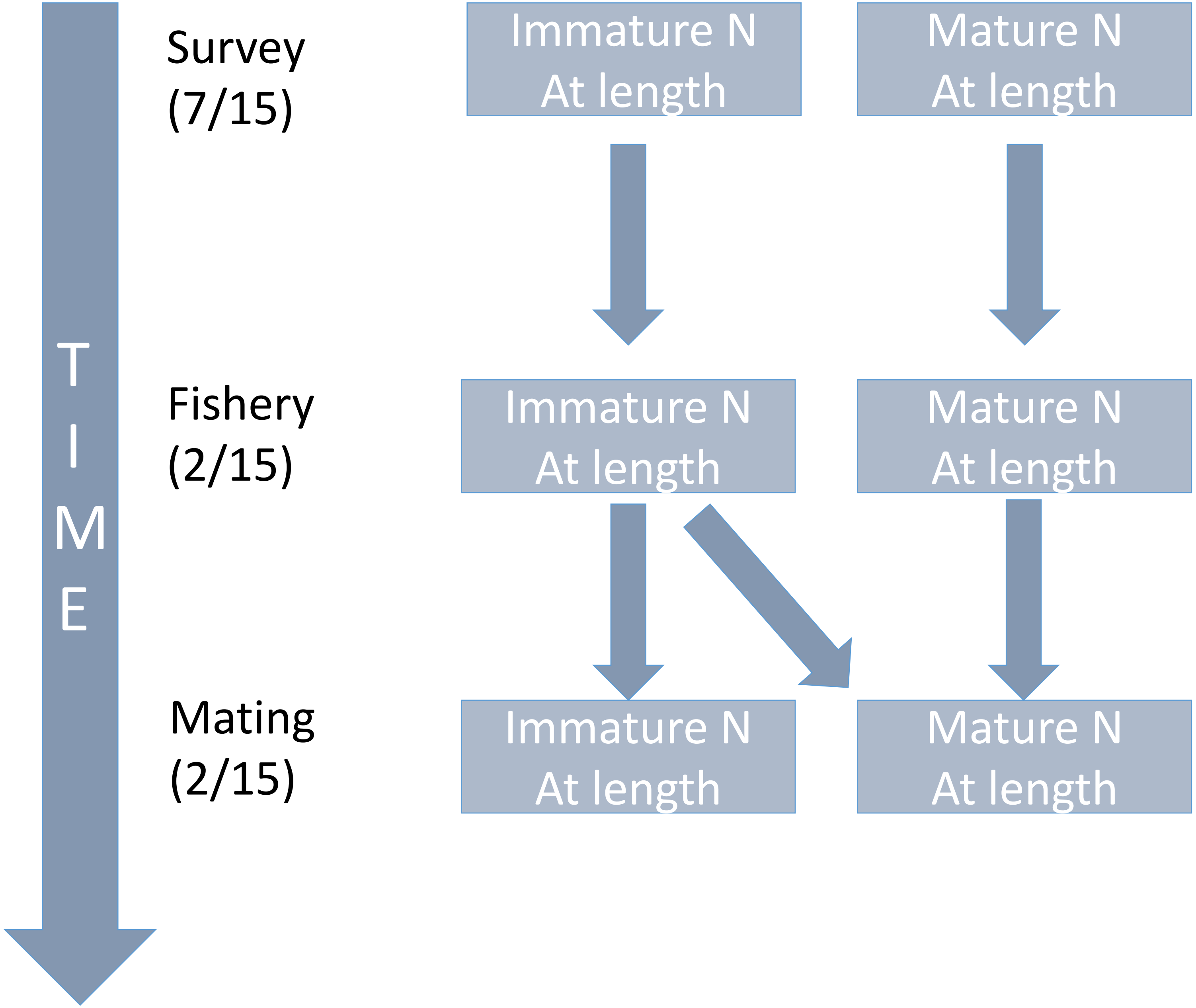
$$P_l = \frac{1}{\left(1 + \exp\left(\frac{\log(19)\left(L_{50,moult} - \bar{L}_l\right)}{L_{95,moult} - L_{50,moult}}\right)\right)} \quad (A.12)$$



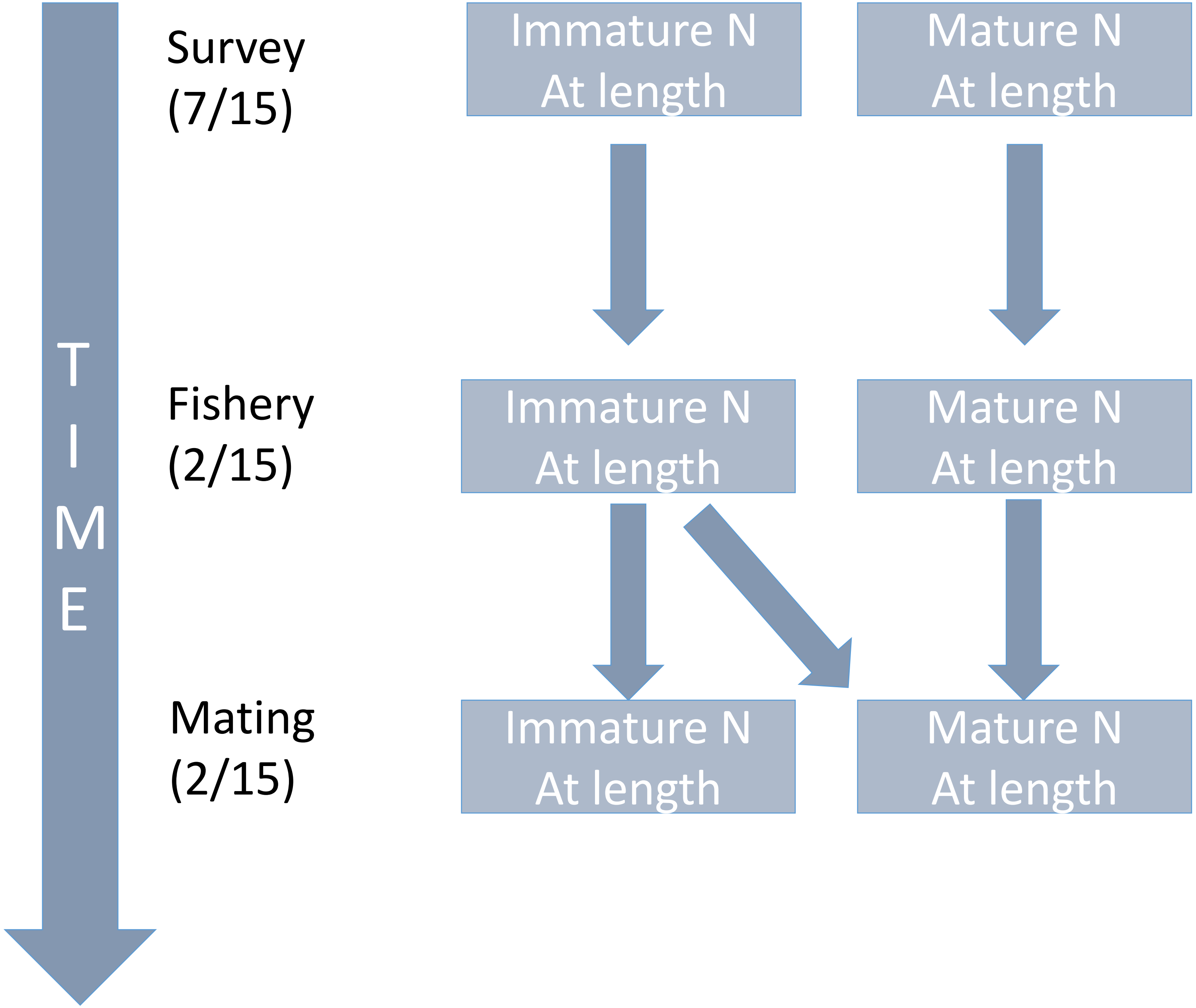
	27.5	**32.5**	**37.5**	**42.5**	**47.5**	**52.5**	**57.5**	**62.5**	**....**
1982									
1983									
1984									
1985									
1986									
1987									
....									


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

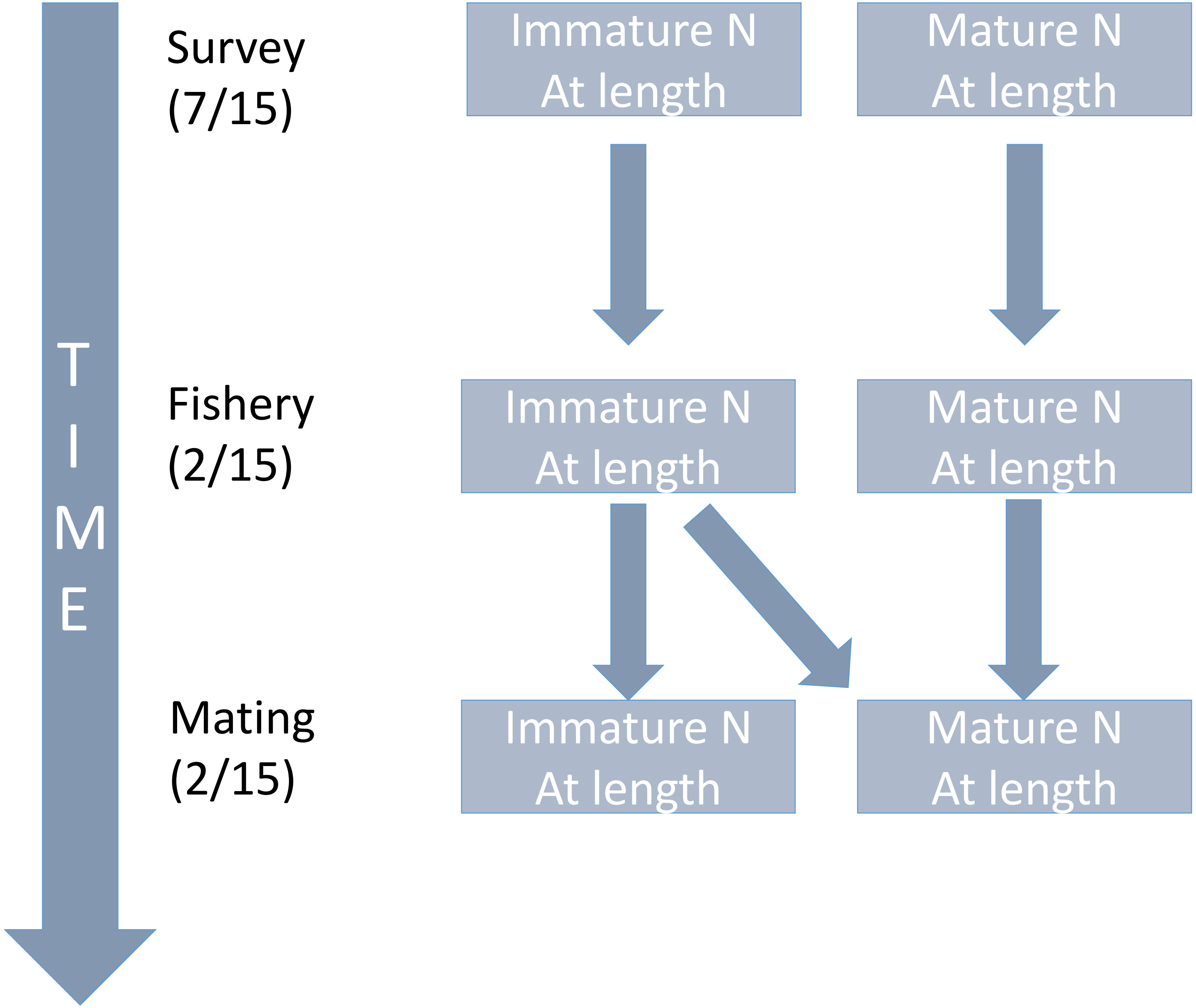

SURVEY_YEAR
2020
2010
2000
1990
1980
50
100
Carapace width (mm)



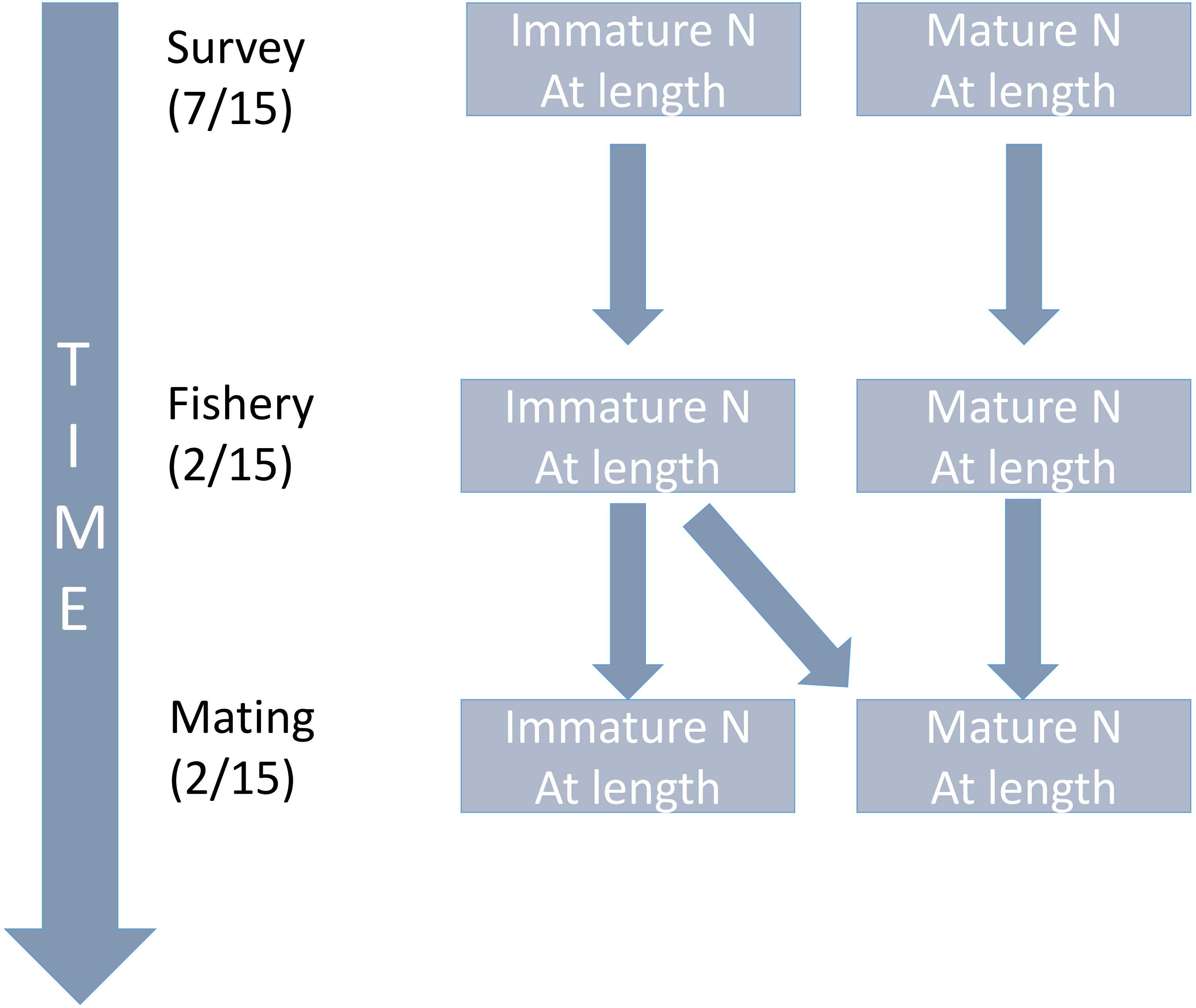
Survey data collected with an estimated selectivity



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

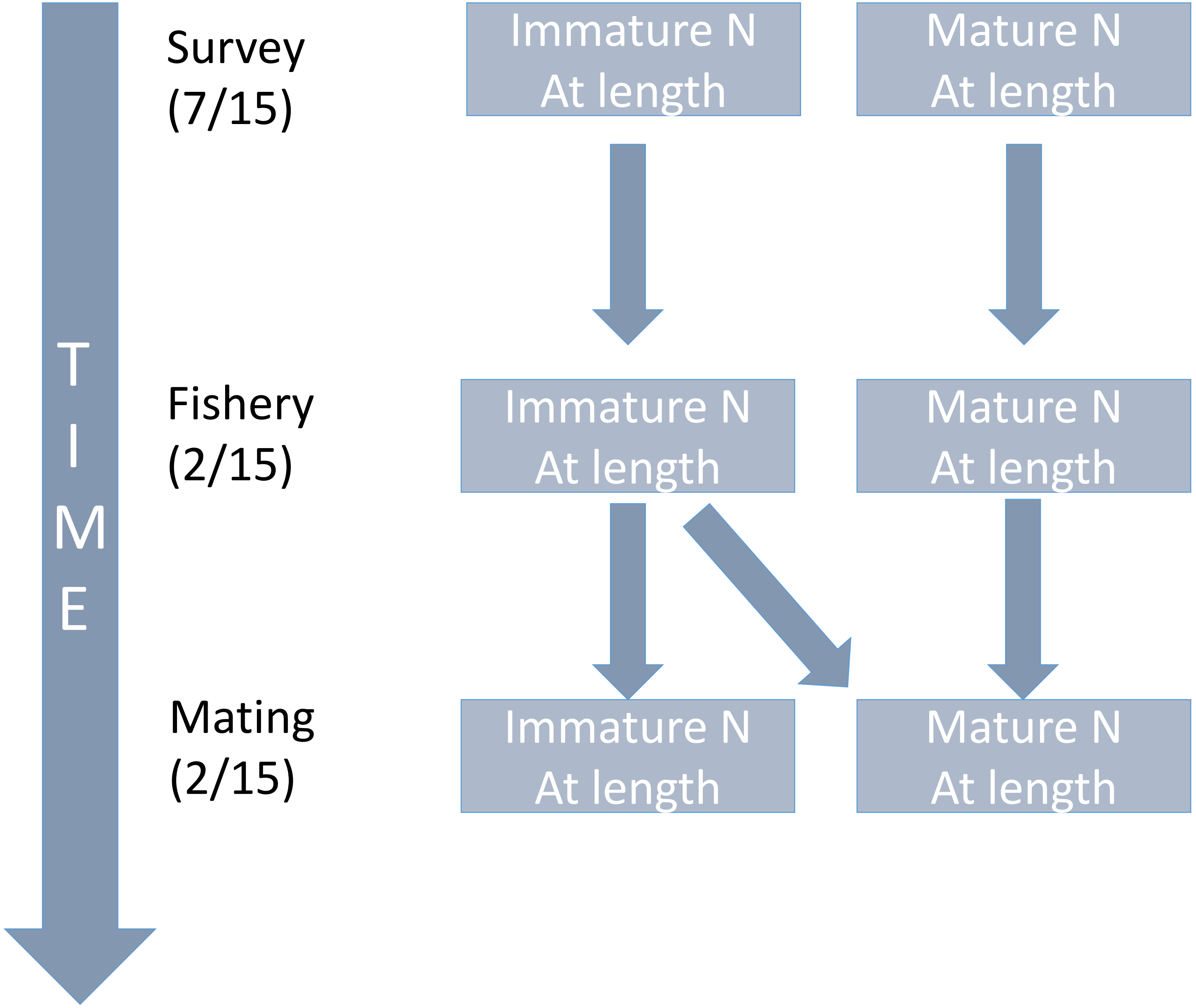


Directed and non-directed fishery occur with sex and fishery specific selectivity.

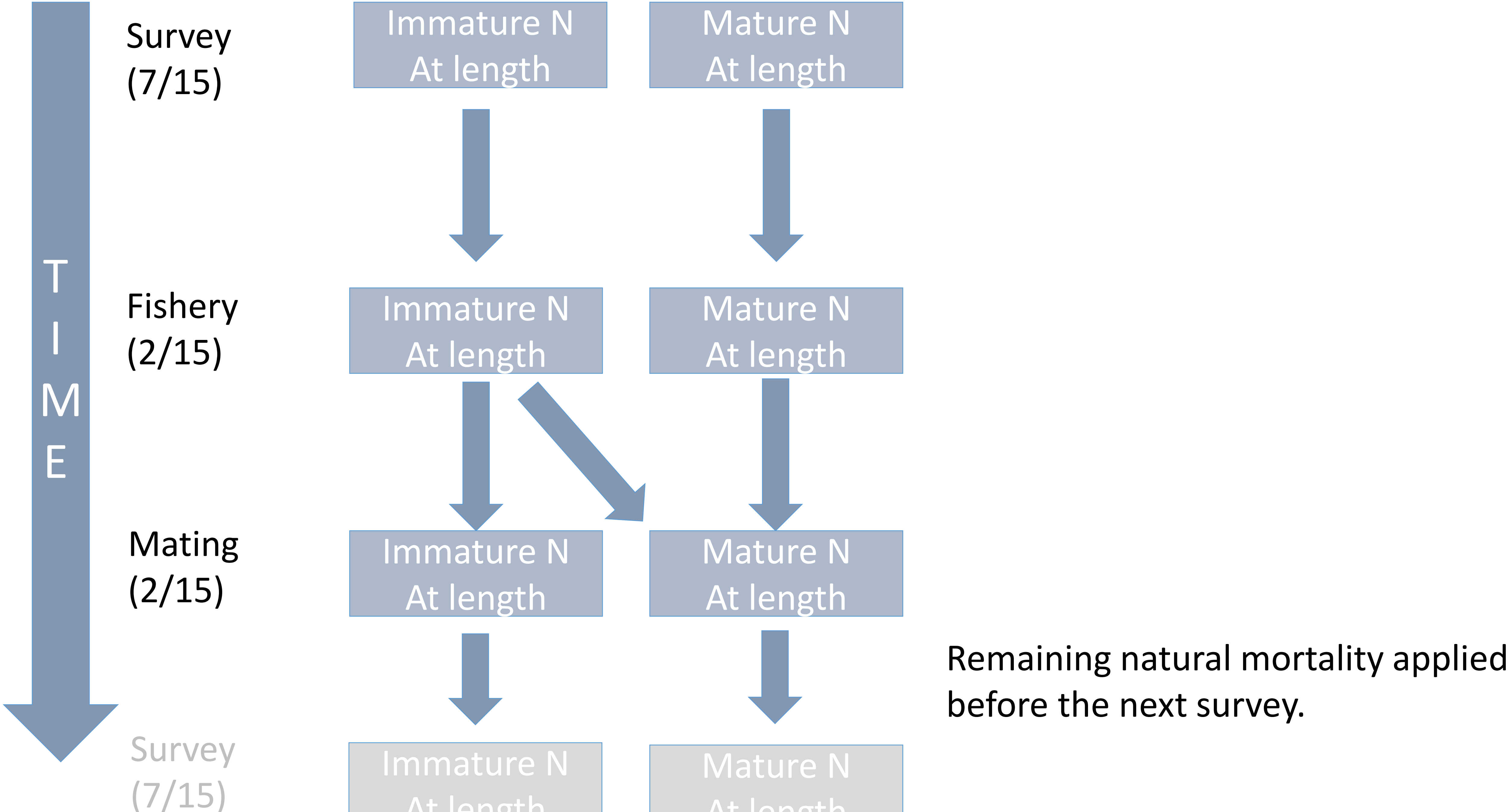


Growth occurs

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.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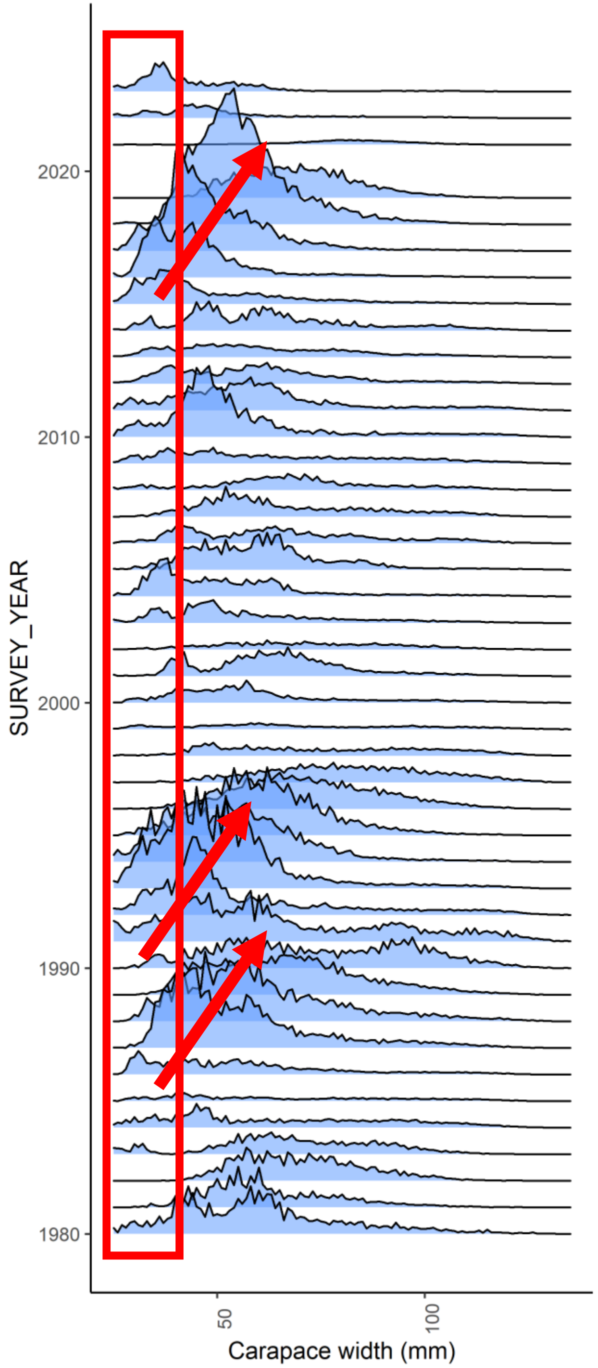
Survey
(7/15)
Immature N
At length
Mature N
At length
Fishery
(2/15)
Immature N
At length
Mature N
At length
Mating
(2/15)
Immature N
At length
Mature N
At length
Remaining natural mortality applied before the next survey.
Survey
(7/15)
Immature N
Mature N

Process	Data
Recruitment	Survey abundance + size composition
Natural mortality	Longevity + survey data
Growth	Growth increment
Maturity	Chelae height
Fishing mortality	Observer data
Fishery selectivity	Observer data
Survey selectivity	BSFRF



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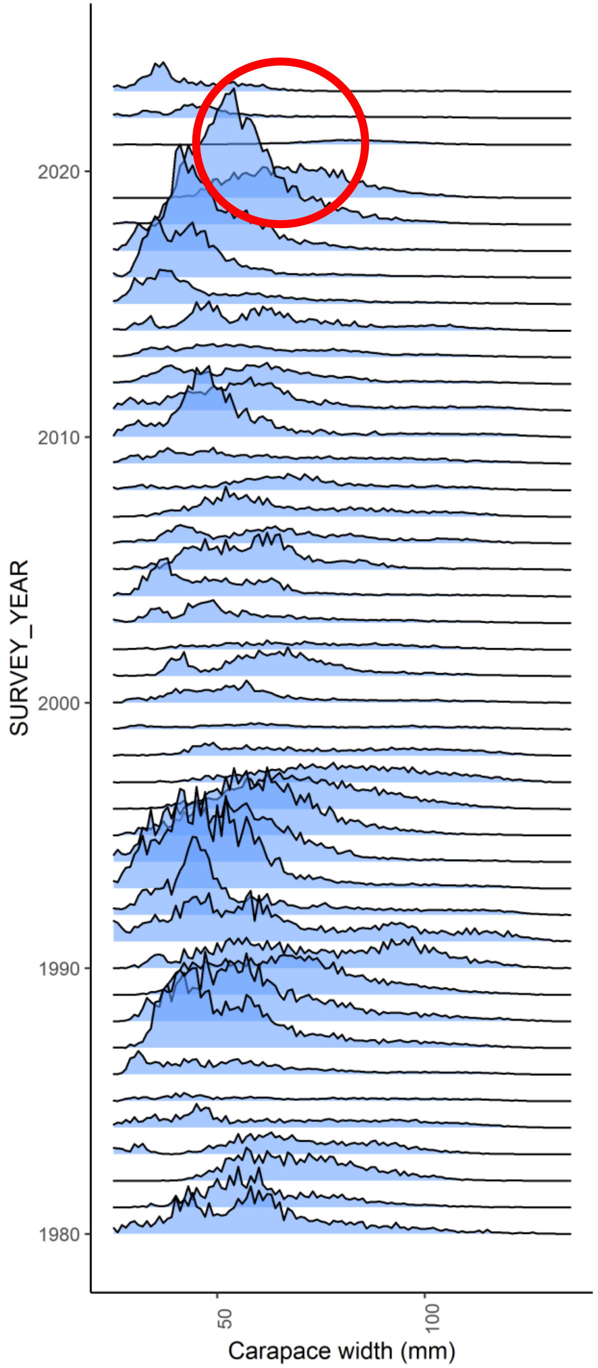

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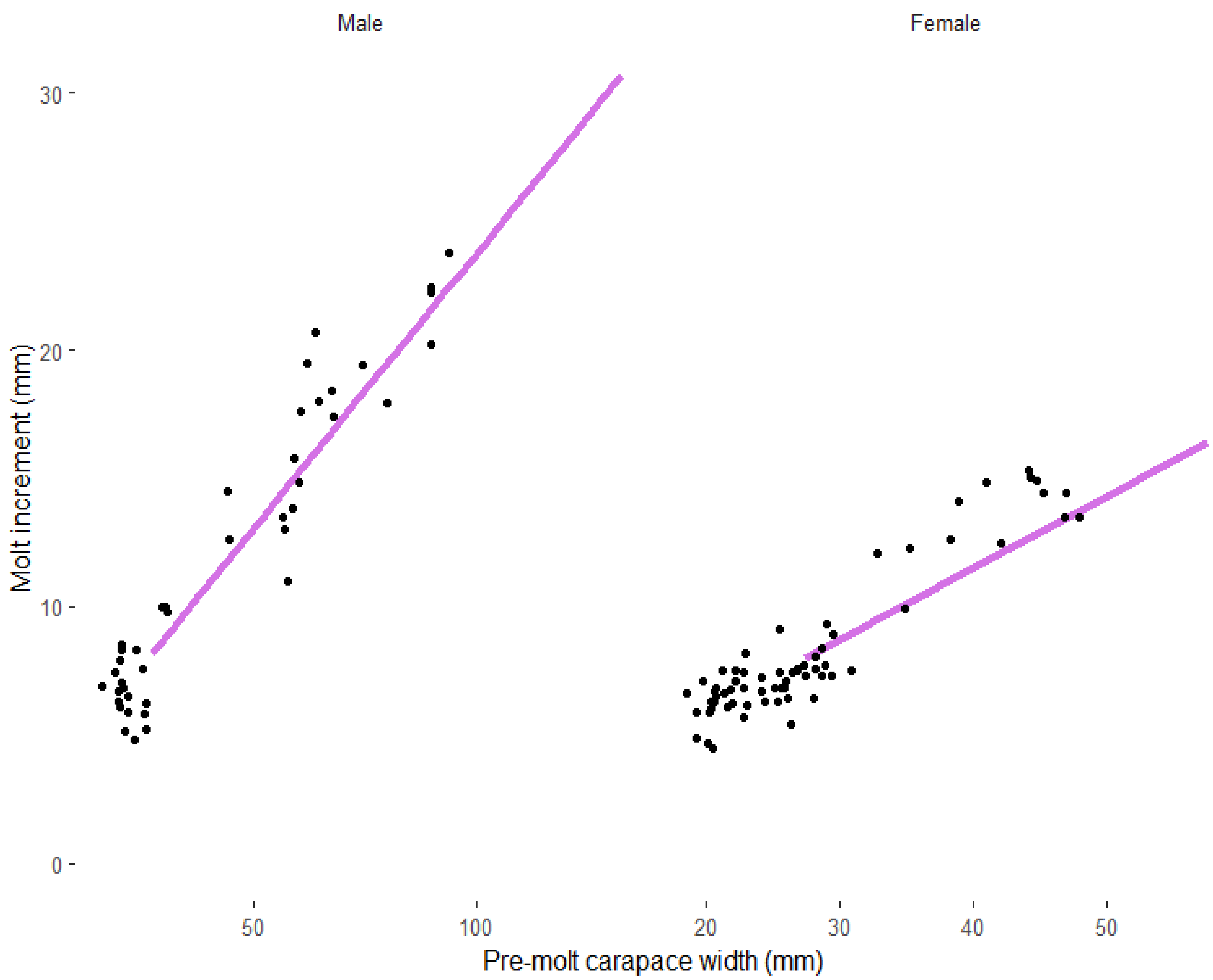

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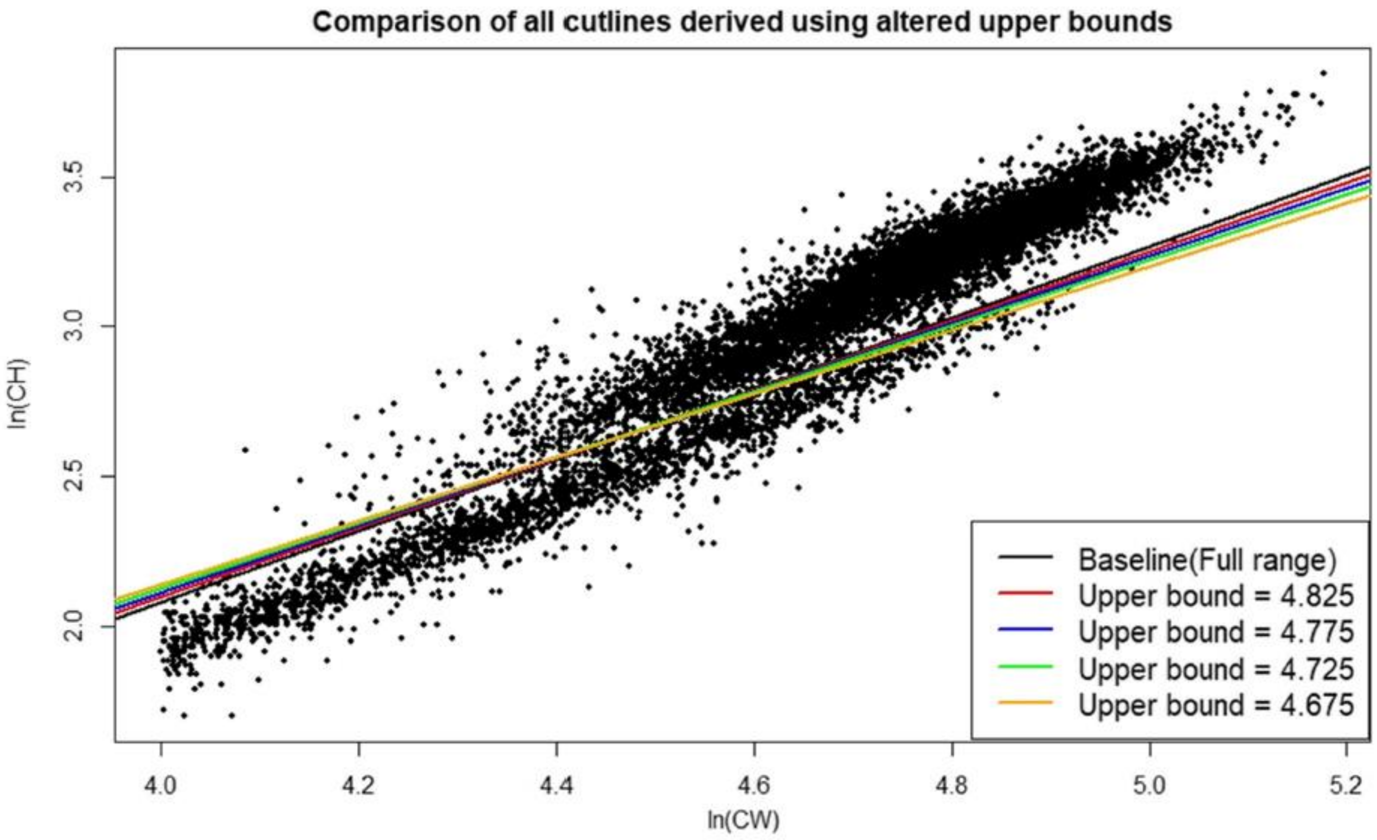

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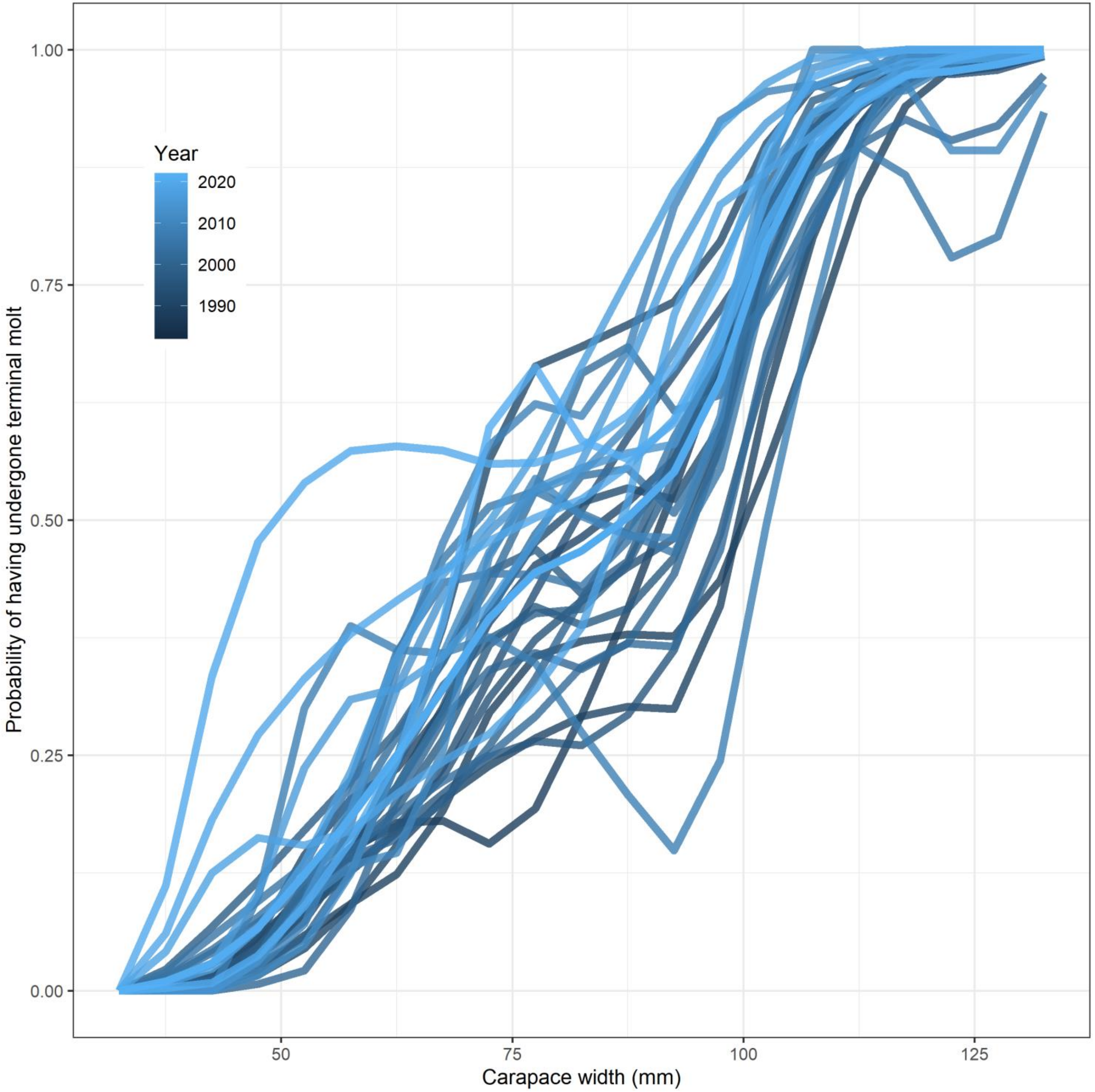

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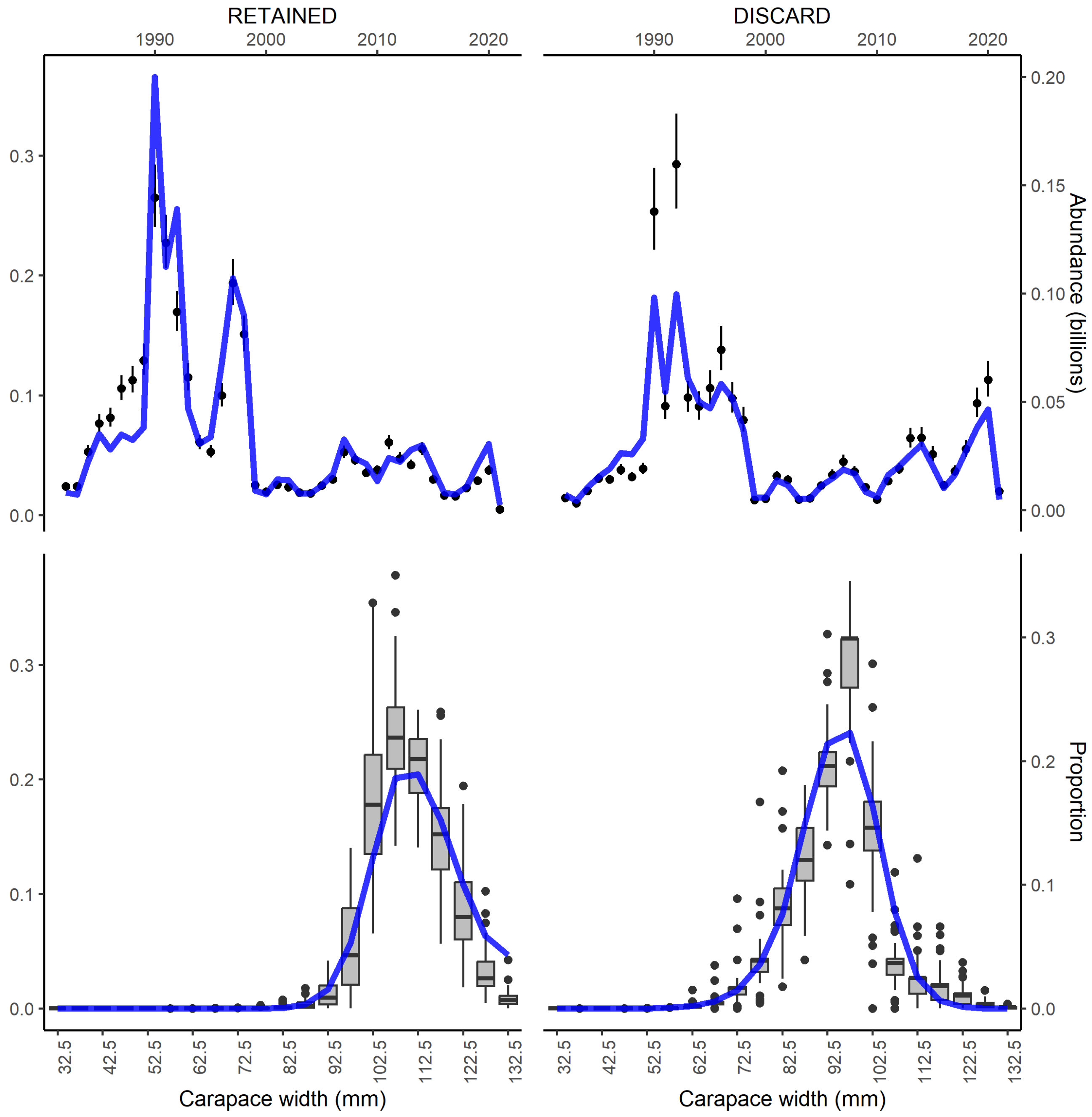

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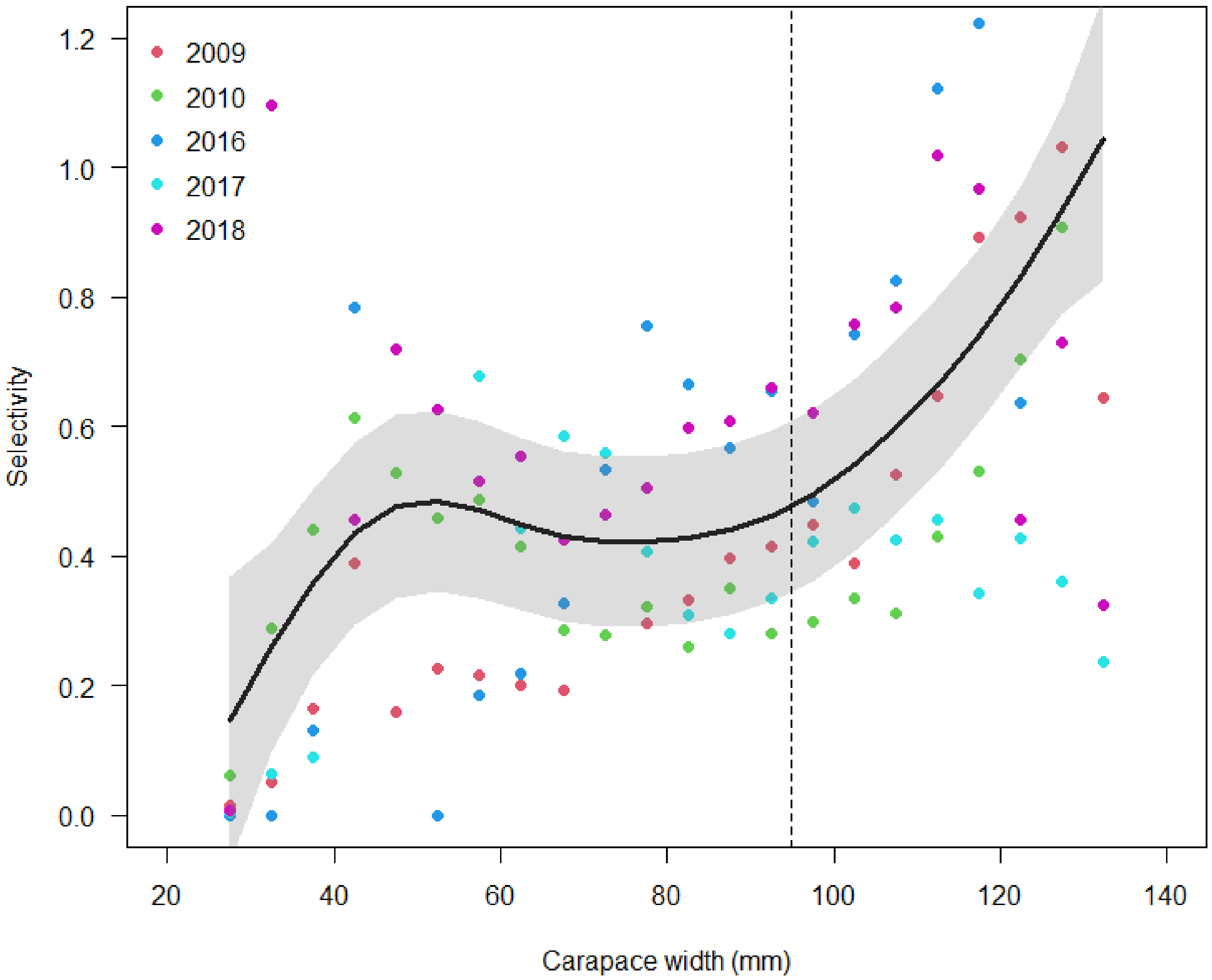

Process	Historical assumptions	Updated assumptions
Recruits	Equal sex ratio	Unequal sex ratios
Natural mortality	Constant with strong priors	Strong priors and time-block in 2018-2019
Growth	Piece-wise	Linear
Maturity	Single estimated ogive	Input yearly observations
Fishing mortality	Freely estimated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

Rationale

Retrospective patterns

Lack of survey fit

Model instability

Reproducibility

Reproducibility

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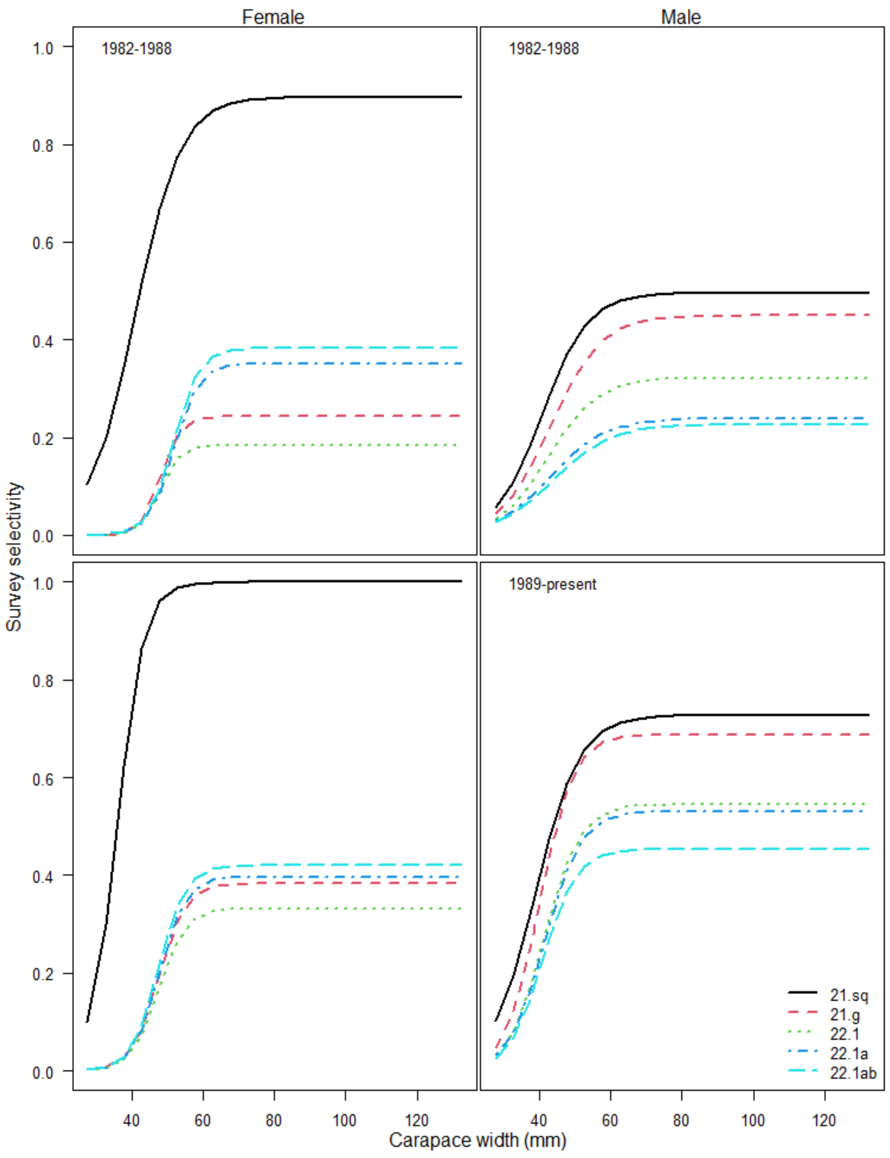
Data interpretation

Reproducibility

Reproducibility

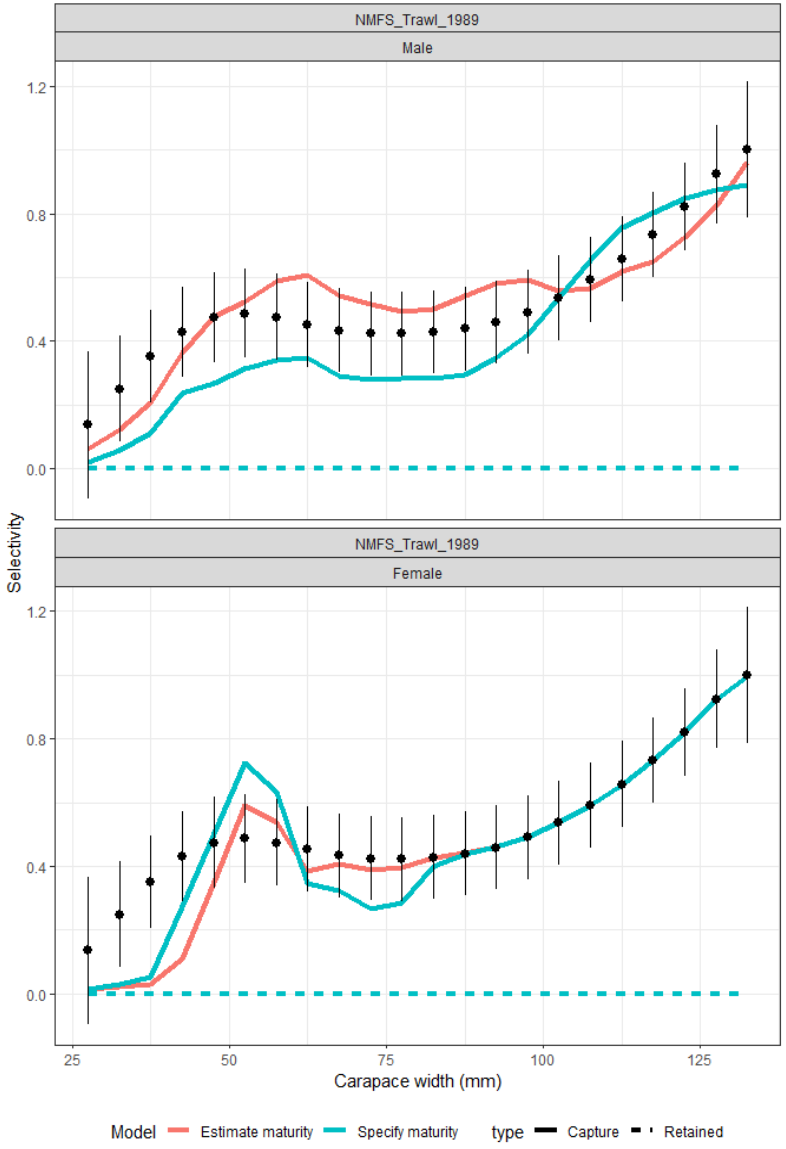
Data interpretation

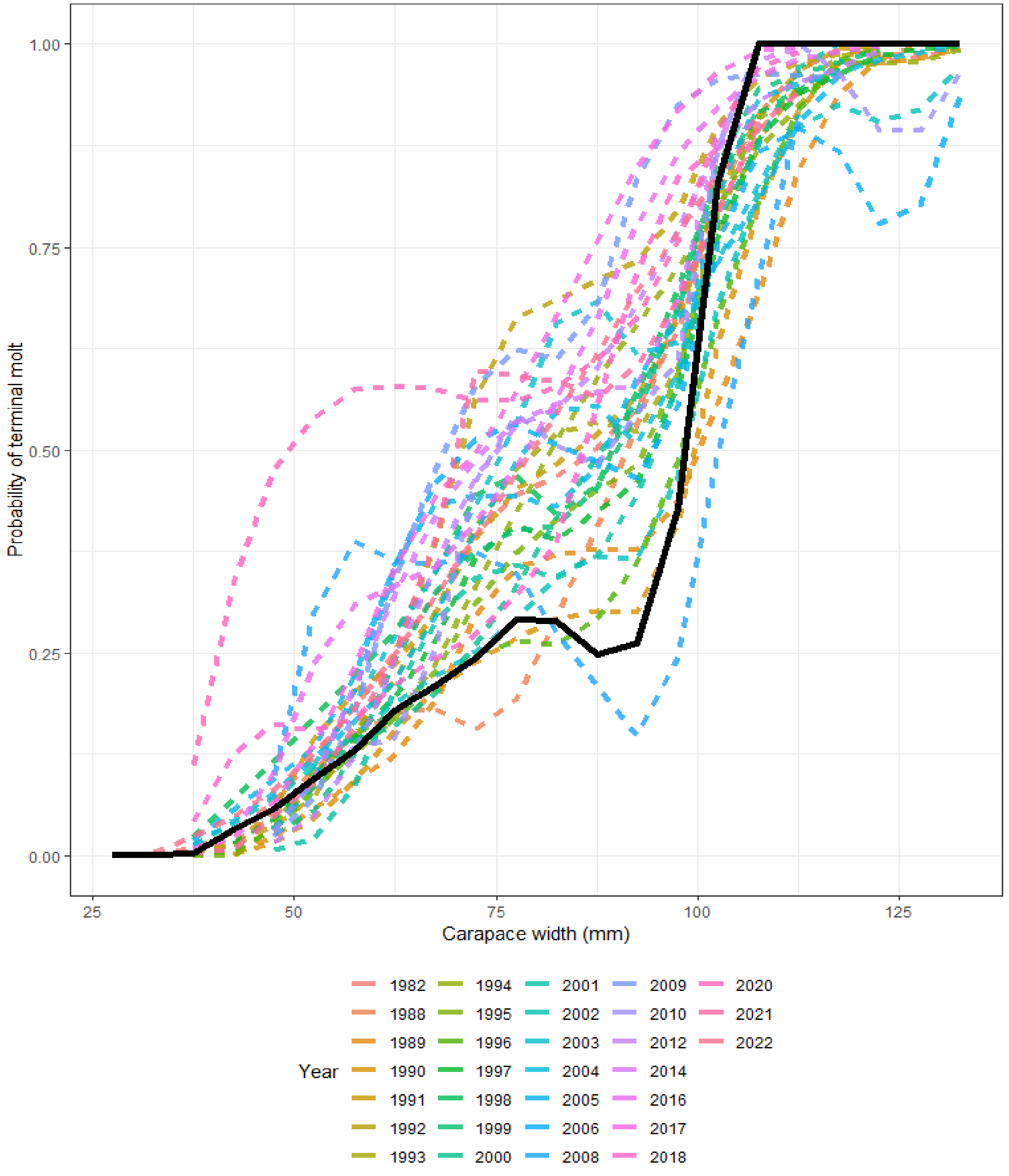
2022 Survey selectivity



- 2022
  - Logistic survey selectivity
- 2023
  - Non-parametric survey selectivity (priors shared between sexes)

2023 Survey selectivity

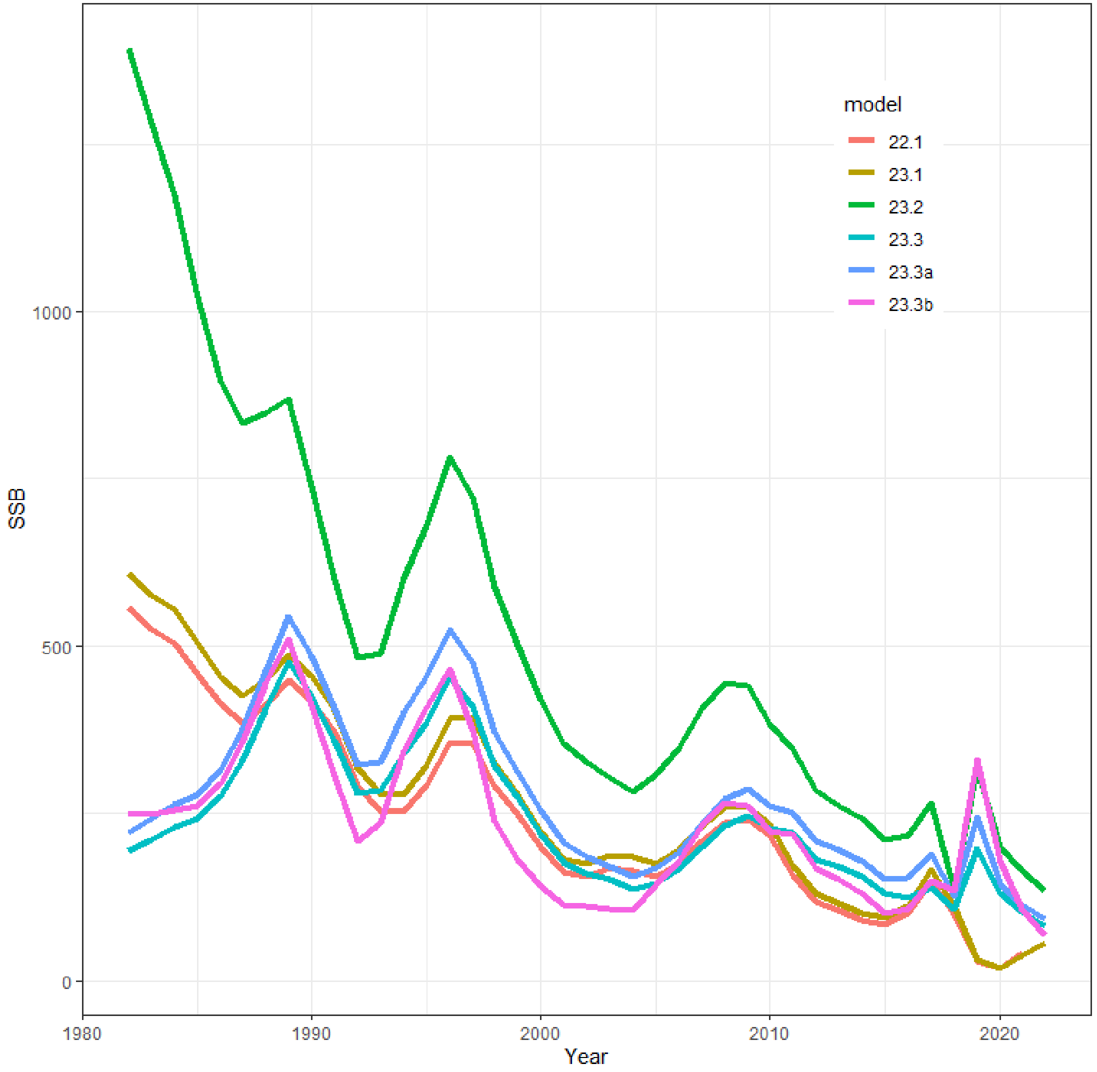




Maturity

- Colored lines are the yearly probability of having undergone terminal molt
- Black line is the estimated probability of having undergone terminal molt

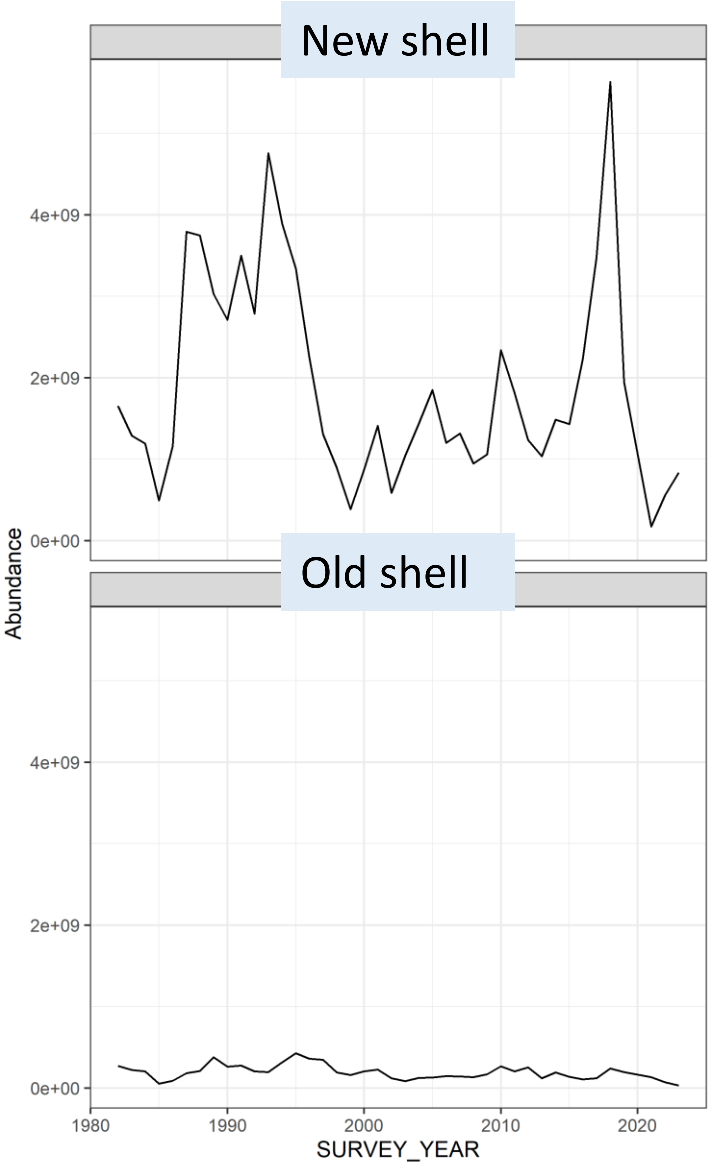
2023 Assessment

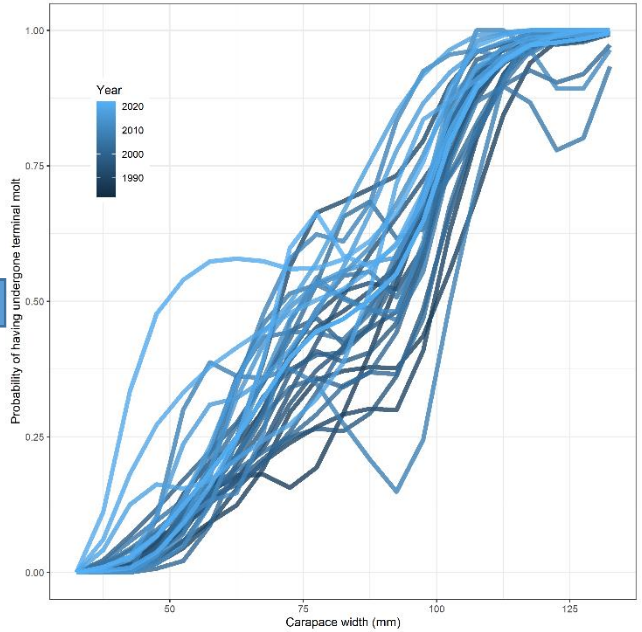


- Gold line (23.1):
  - Estimate probability of having undergone terminal molt + logistic survey selectivity
- Green line (23.2):
  - Specify probability of maturing, retain logistic survey selectivity
- Blue line (23.3a):
  - Specify probability of maturing, non-parametric survey selectivity

Model	MMB	B35	F35	FOFL	OFL	M	avg_rec	Status
23.1	56.41	189.24	1.60	0.30	8.58	0.29	169.90	0.30
23.2	135.43	132.46	71.89	30.14	37.10	0.29	222.75	1.02
23.3a	92.39	155.91	53.25	14.96	15.44	0.29	141.66	0.59

Preparing assessment data (MMB)



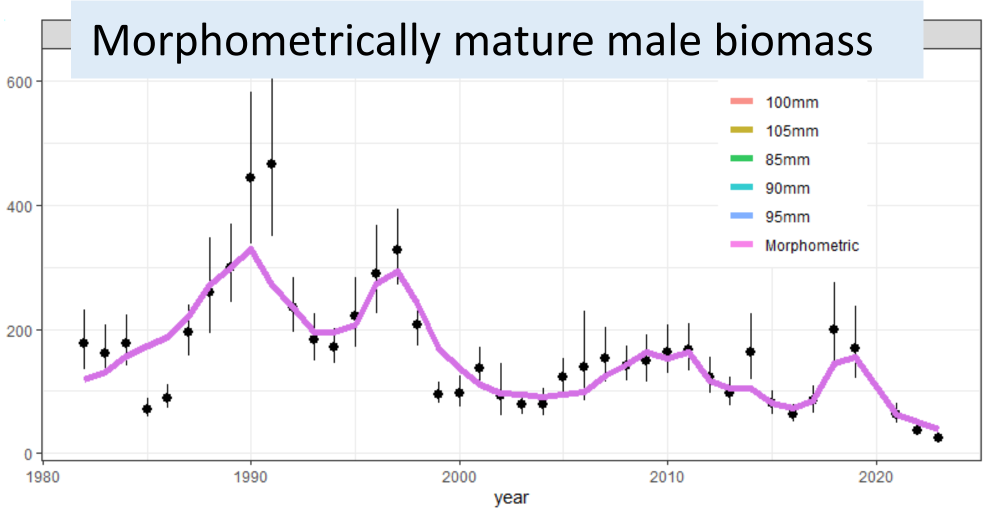


Index of immature animals not fit

Immature size composition data are fit

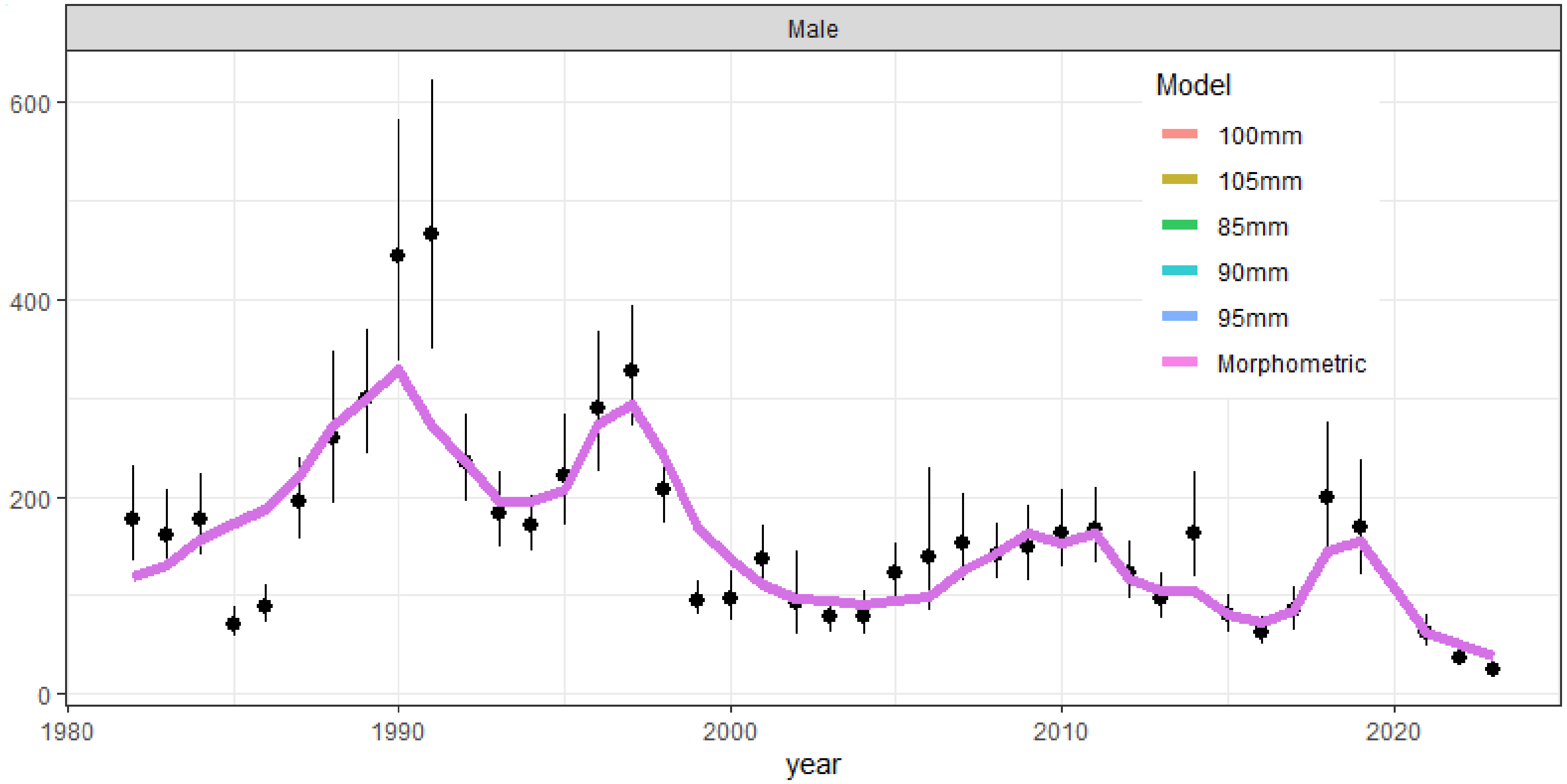
Weight at size

Weight at size



- MMB time series to which the models are fit are the same

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



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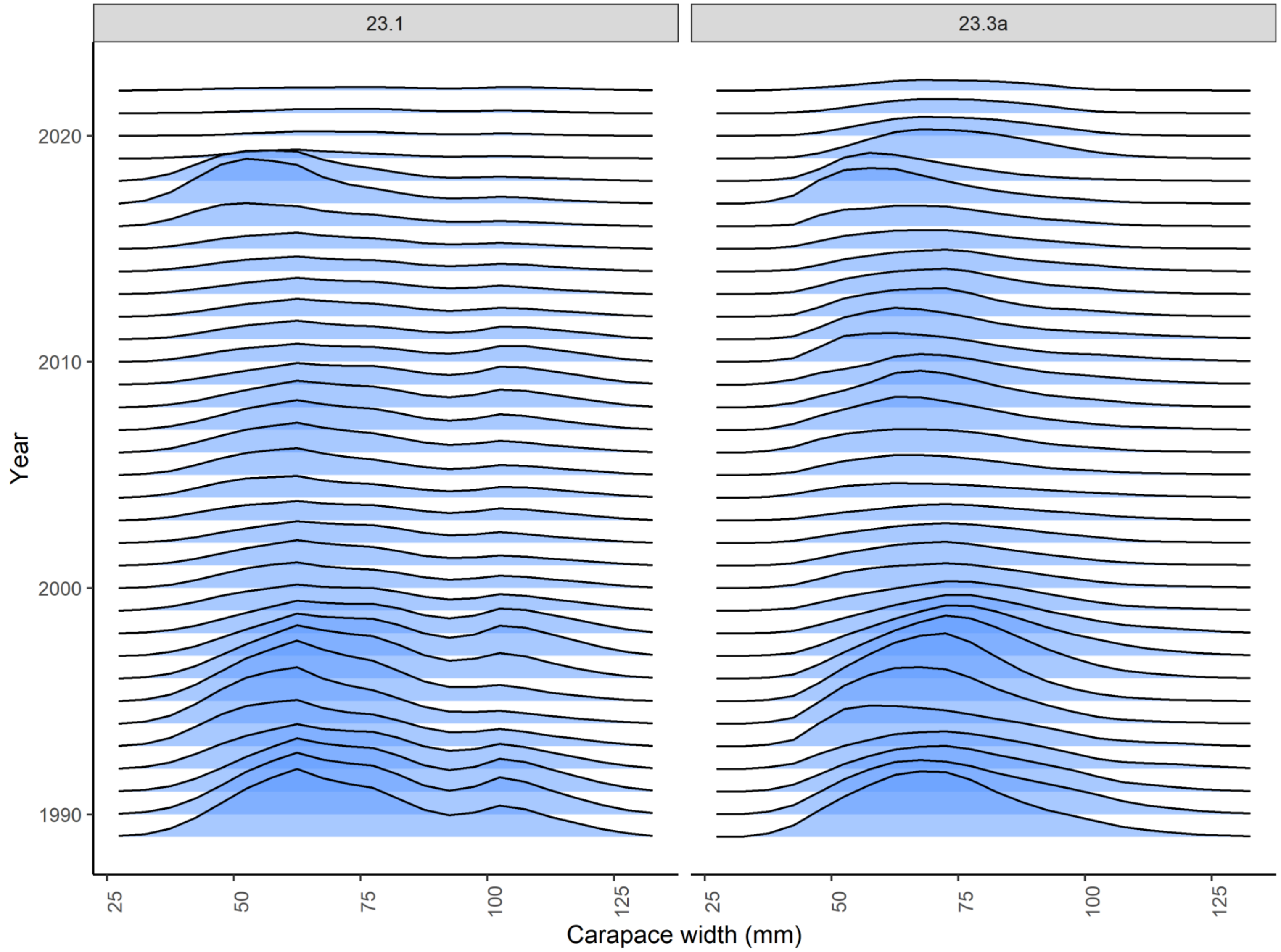
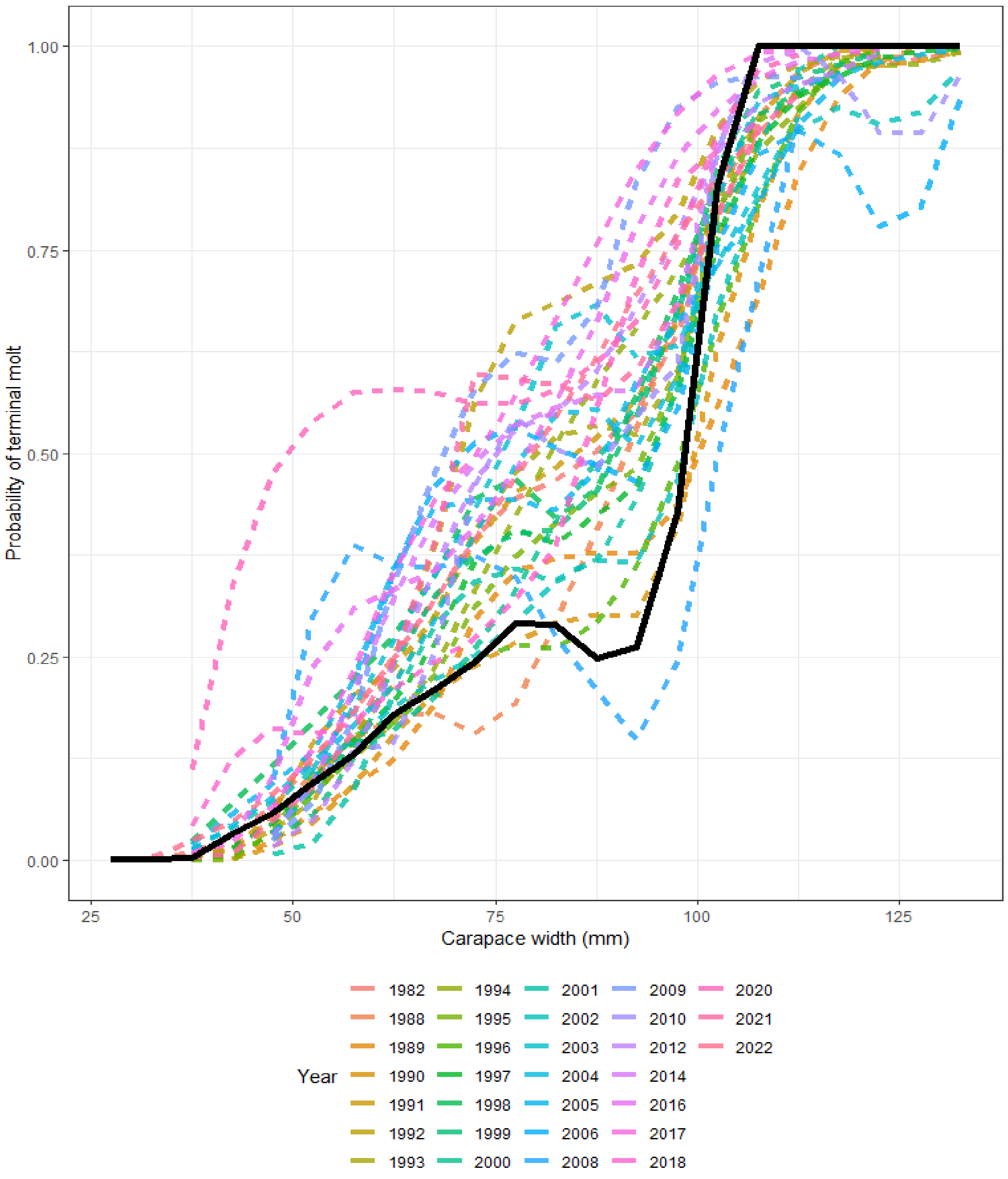


- Inability of the model to estimate maturation well suggests there is an issue elsewhere in the model.
- Inability to estimate this process inspite of these data being ‘baked in’ to the data prep process is a problem.
- We have encountered this before, but the large F35% resulting kept us from pursuing this.
- The SSC supported the idea ‘build from biology first’.



If we use this model, what do we do for reference points?

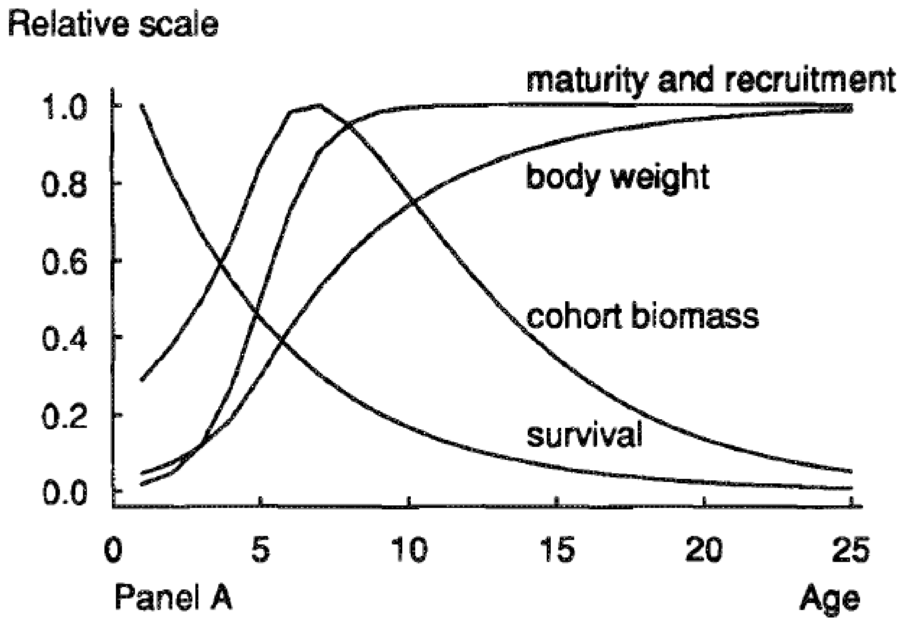
Groundfish Exploitation Rates Based on Life History Parameters

William G. Clark

International Pacific Halibut Commission, Seattle, WA 98145-2009, USA

Clark, W. G. 1991. Groundfish exploitation rates based on life history parameters. Can. J. Fish. Aquat. Sci. 48: 734–750.

- Spawning biomass per recruit proxies used for crab came from Clark, 1991.
- These were based on a groundfish life history in which maturity was equal to fishery selectivity.



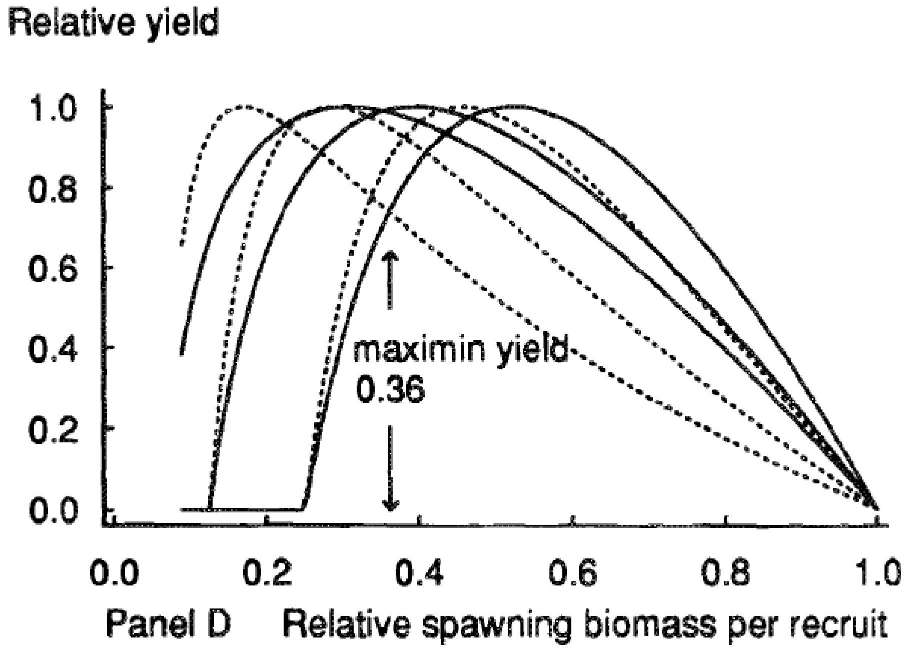
Groundfish Exploitation Rates Based on Life History Parameters

William G. Clark

International Pacific Halibut Commission, Seattle, WA 98145-2009, USA

Clark, W. G. 1991. Groundfish exploitation rates based on life history parameters. Can. J. Fish. Aquat. Sci. 48: 734–750.

- Spawning biomass per recruit proxies used for crab came from Clark, 1991.
- These were based on a groundfish life history in which maturity was equal to fishery selectivity.
- Equilibrium yield at relative biomass was calculated for a range of recruitment dynamics.
- Maximin yield was identified as the relative SBPR that maximized the minimum yield.



Reproduce Clark 1991 with crab model

ELSEVIER

Fisheries Research
Volume 157, September 2014, Pages 28-40

An evaluation of stock–recruitment proxies and environmental change points for implementing the US Sustainable Fisheries Act

André E. Punt [a], Cody S. Szuwalski [a], William Stockhausen [b]

Show more

"the assumption $F_{MSY} = F_{35\%}$ is generally reasonable, but that the stock and recruitment data do not generally support the current B_{MSY} values"

- Are reference points based on targets of 35% unfished yield appropriate with new models?

  RESEARCH MODEL

- What would the impact on status and OFLs be of using different definitions of maturity?

  GMACS

- What would the impact on status and OFLs be of using different SBPR percentages be for morphometric maturity as currency?

  GMACS

Research model description

Used for ease of manipulation

Key differences include:

- only considers male crab
- excludes the bycatch fishery
- specifies the size transition matrix
- fits to an index of immature abundance
- Weightings somewhat different (e.g. lower for size composition data)

Data component in GMACS	Years	Fit in RM?	Inform RM?
Retained male crab pot fishery size frequency by shell condition	1982 - 2022	X	X
Discarded Males and female crab pot fishery size frequency	1992 - 2022	X	X
Trawl fishery bycatch size frequencies by sex	1991 - 2022		
Survey size frequencies by, maturity, sex and shell condition	1982 – 2019 2021 - 2023	X	X
Retained catch estimates	1982 - 2022	X	X
Discard catch estimates from crab pot fishery	1992 - 2022	X	X
Trawl bycatch estimates	1993 - 2022		
Total survey abundance estimates and coefficients of variation	1982 - 2019, 2021 - 2023	X	X
2009 study area biomass estimates, CVs, and size frequency for BSFRF and NMFS tows	2009		X
2010 study area biomass estimates, CVs, and size frequency for BSFRF and NMFS tows	2010		X
Growth increment data	2003, 2016-18		X

Research model description

- Male only
- 30-135 mm CW
- Growth and maturity input
- Fit to:
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- Similar to Szuwalski et al., 2023, but incorporates the fishery and a larger range of sizes

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Population dynamics model

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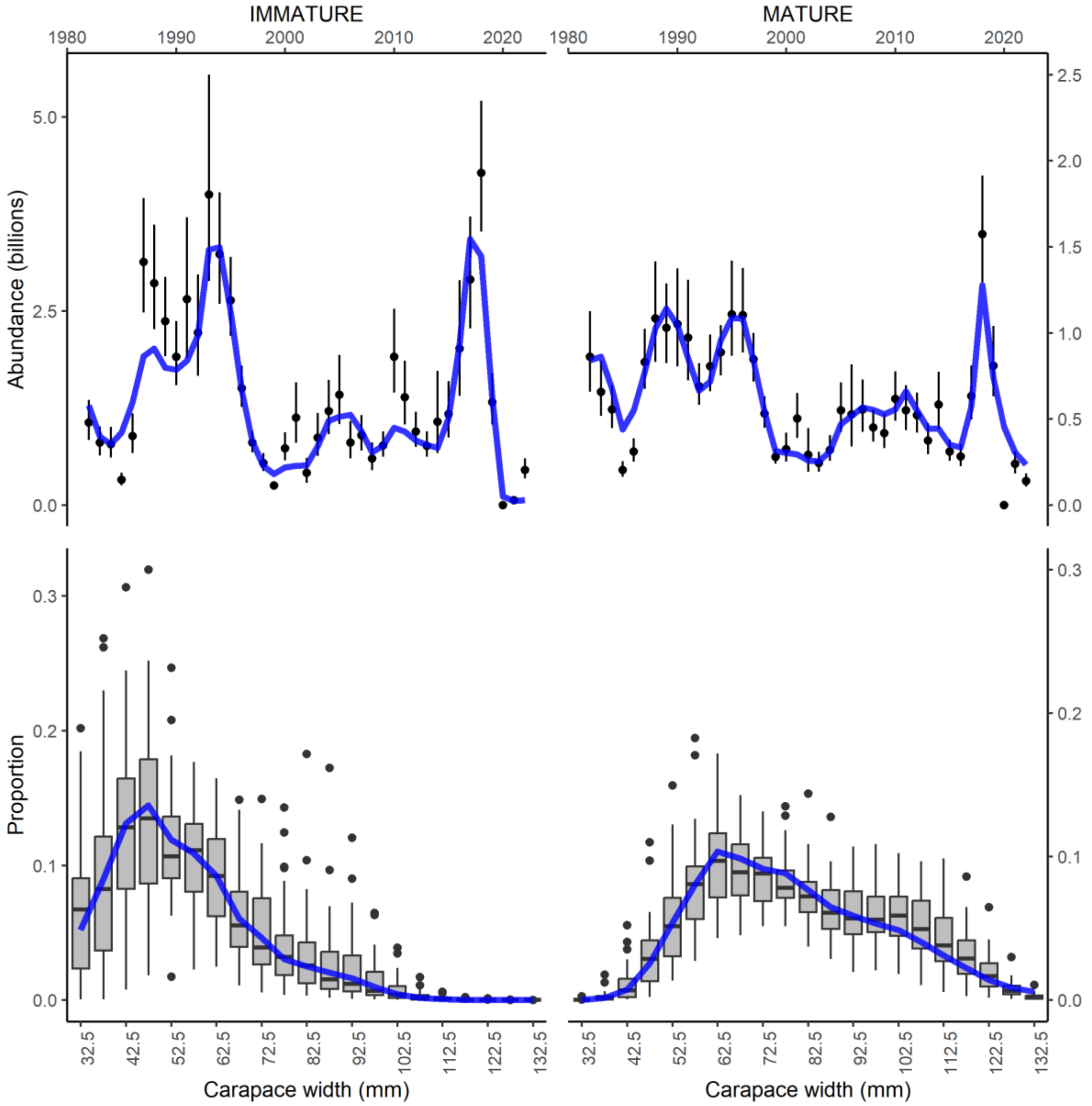

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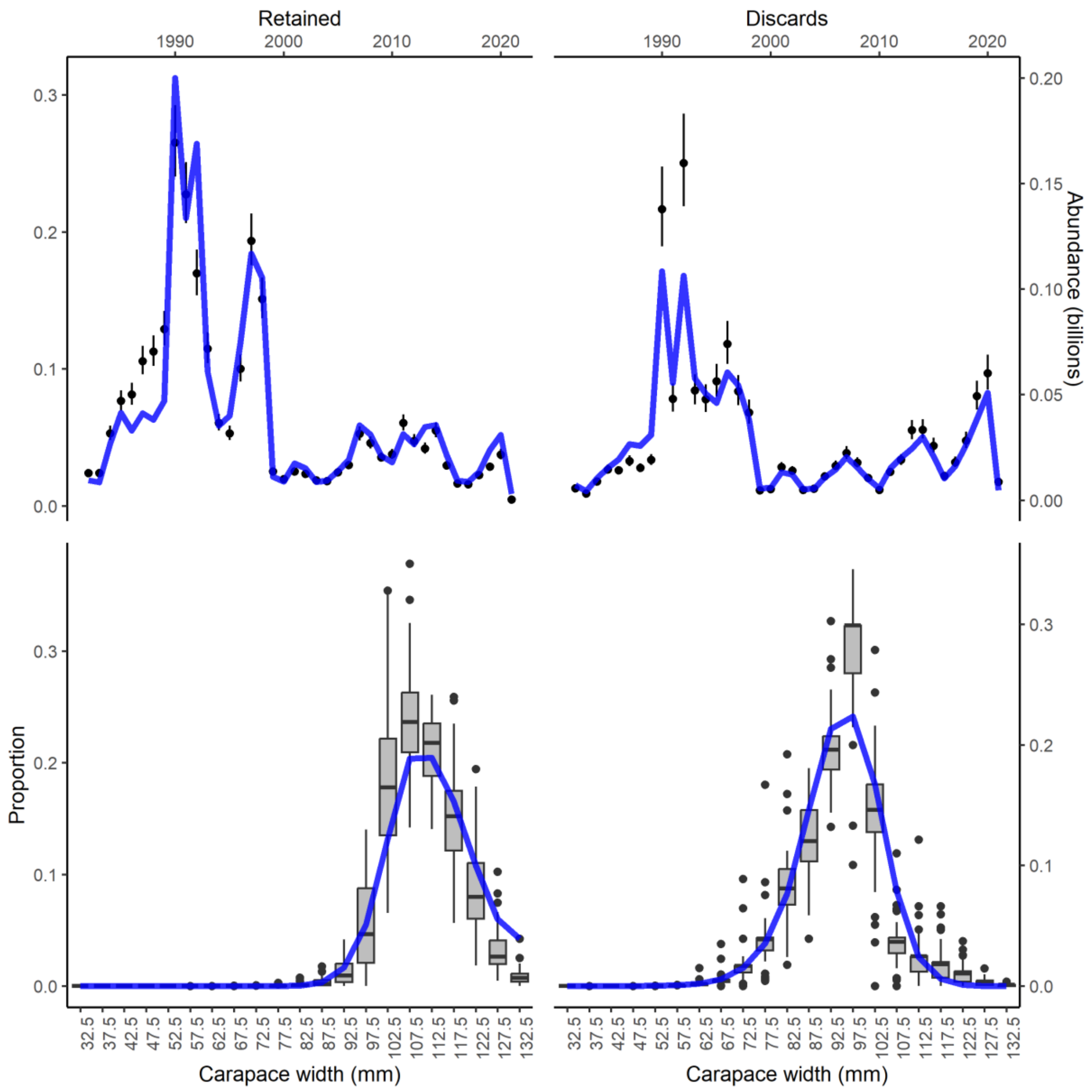
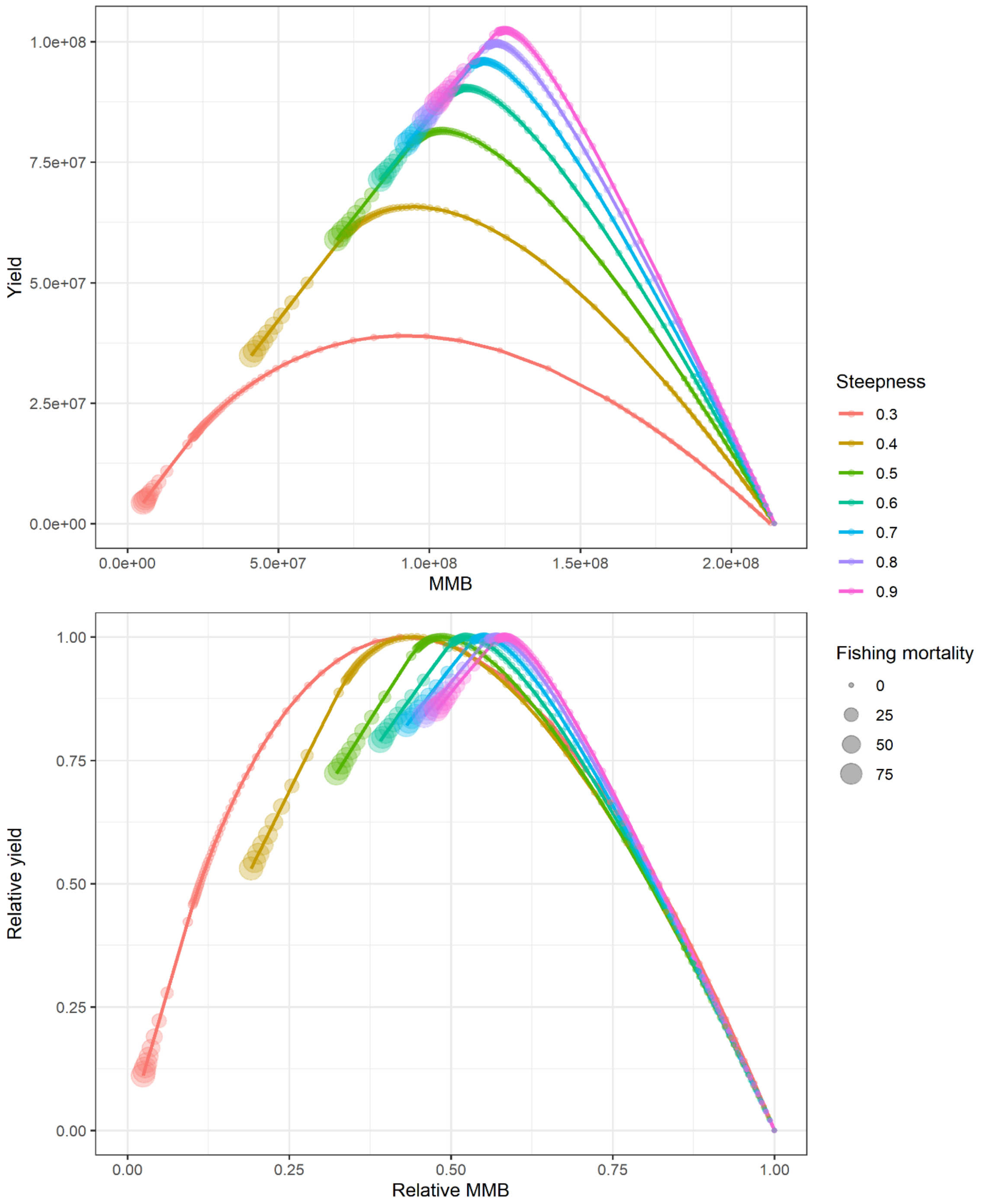


SBPR yield curves

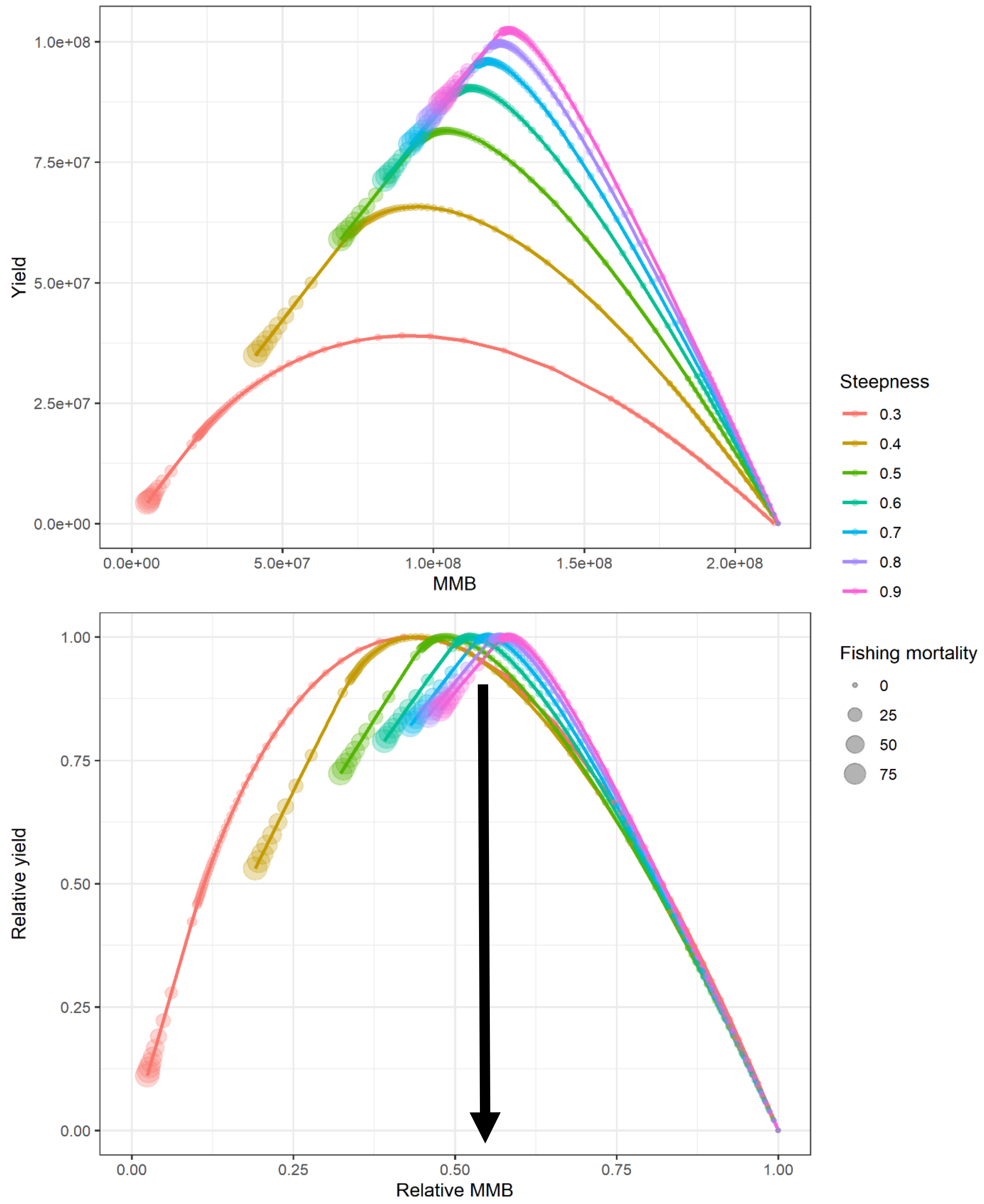
- SR relationship defined in terms of steepness
- Specify a fishing mortality
- Project to equilibrium
- Record biomass and yield
- Normalize curves



SBPR yield curves

Morphometrically mature

- Maximin yield ~ SBPR55%
- Large range of steepnesses that cannot be depleted to B35%



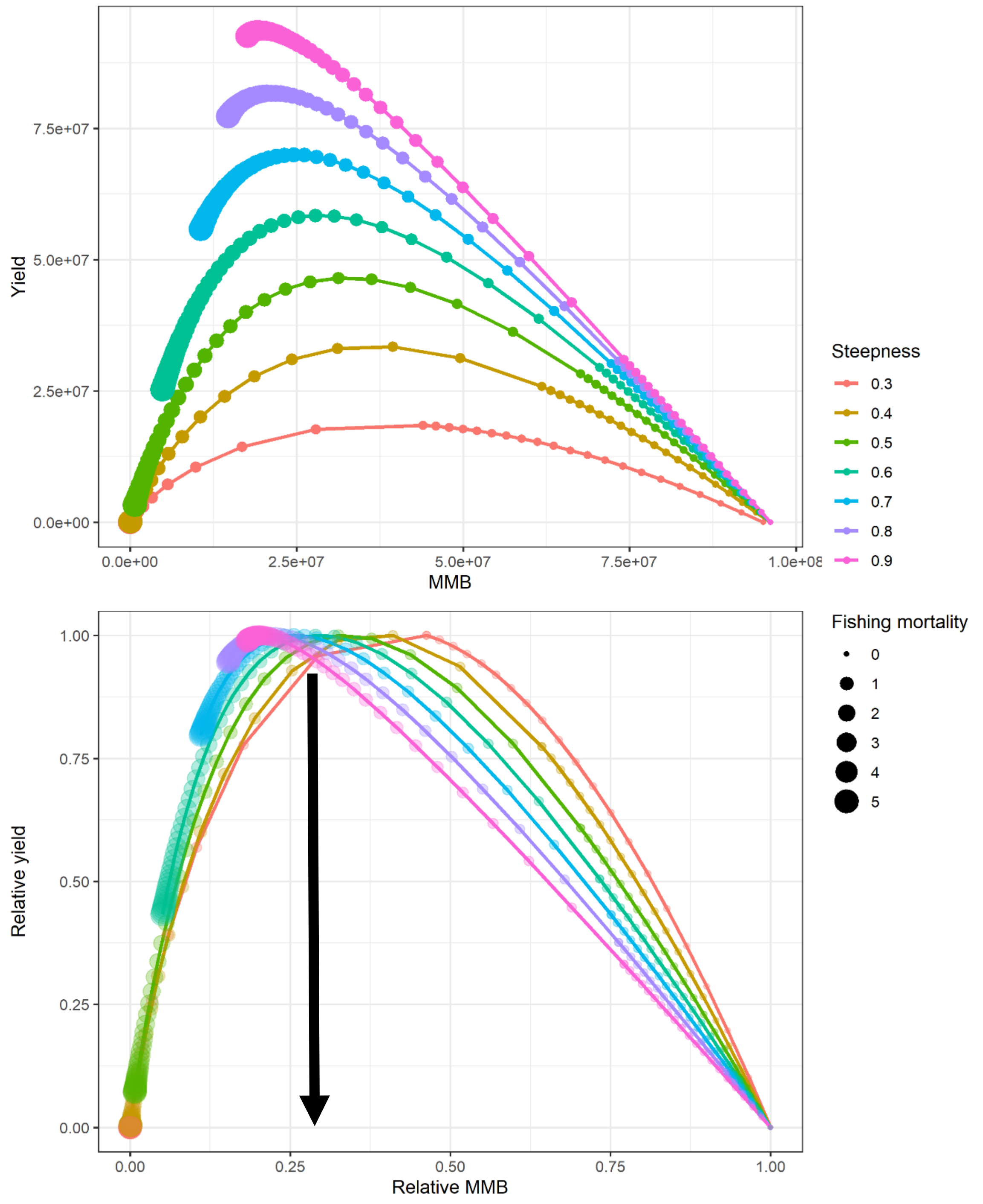
SBPR yield curves

Morphometrically mature

- Maximin yield ~ SBPR55%
- Large range of steepnesses that cannot be depleted to B35%

95 mm carapace width

- Maximin yield ~ SBPR28%



SBPR yield curves

Morphometrically mature

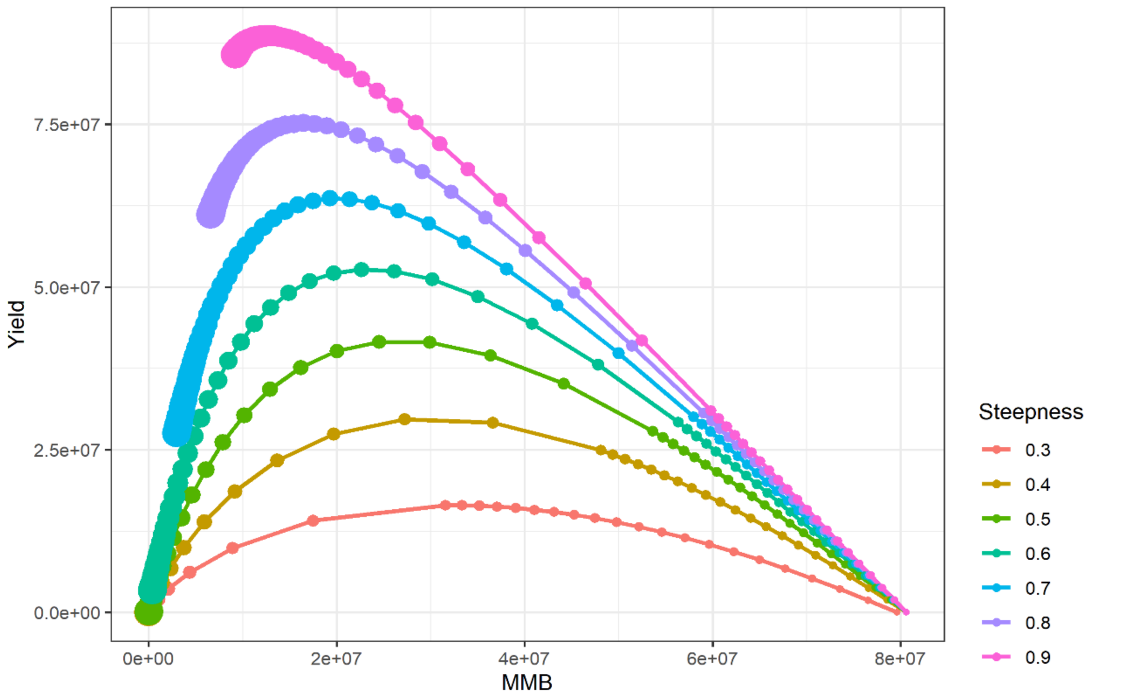
- Maximin yield ~ SBPR55%
- Large range of steepnesses that cannot be depleted to B35%

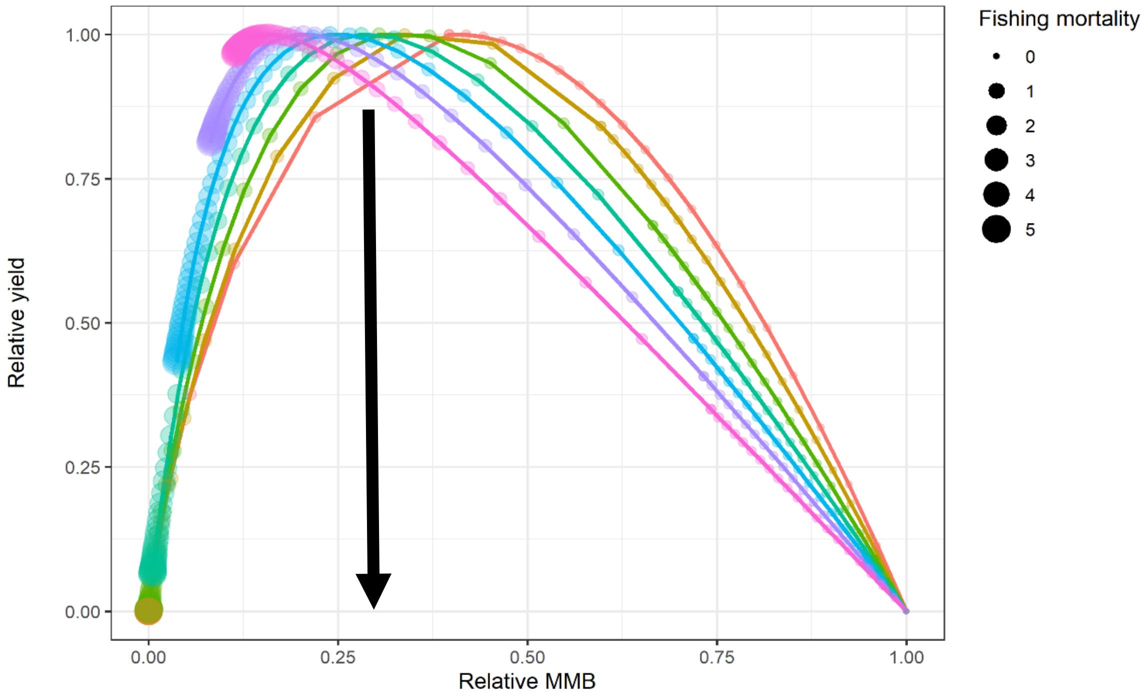
95 mm carapace width

- Maximin yield ~ SBPR28%

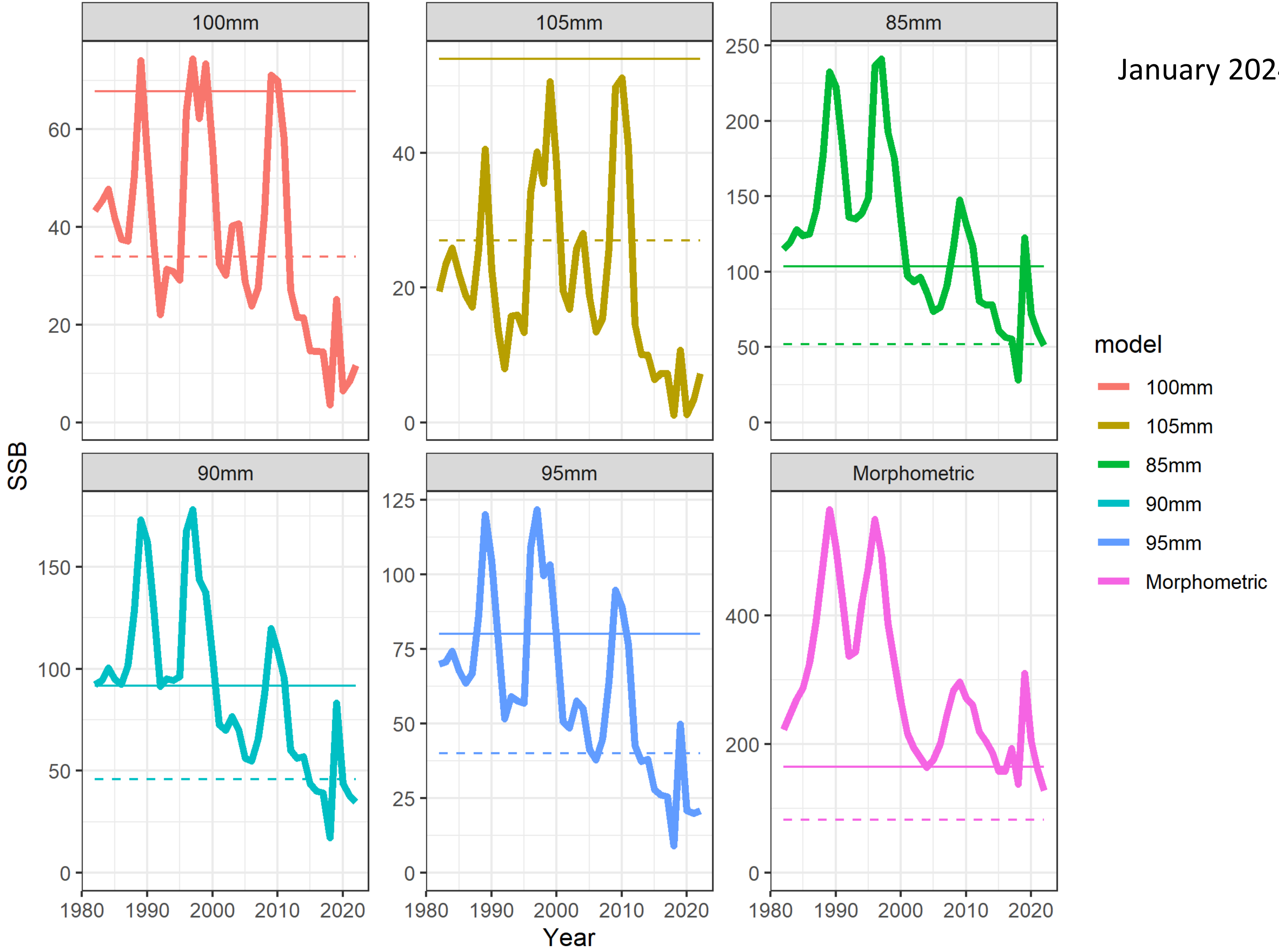
100 mm carapace width

- Maximin yield ~ SBPR29%

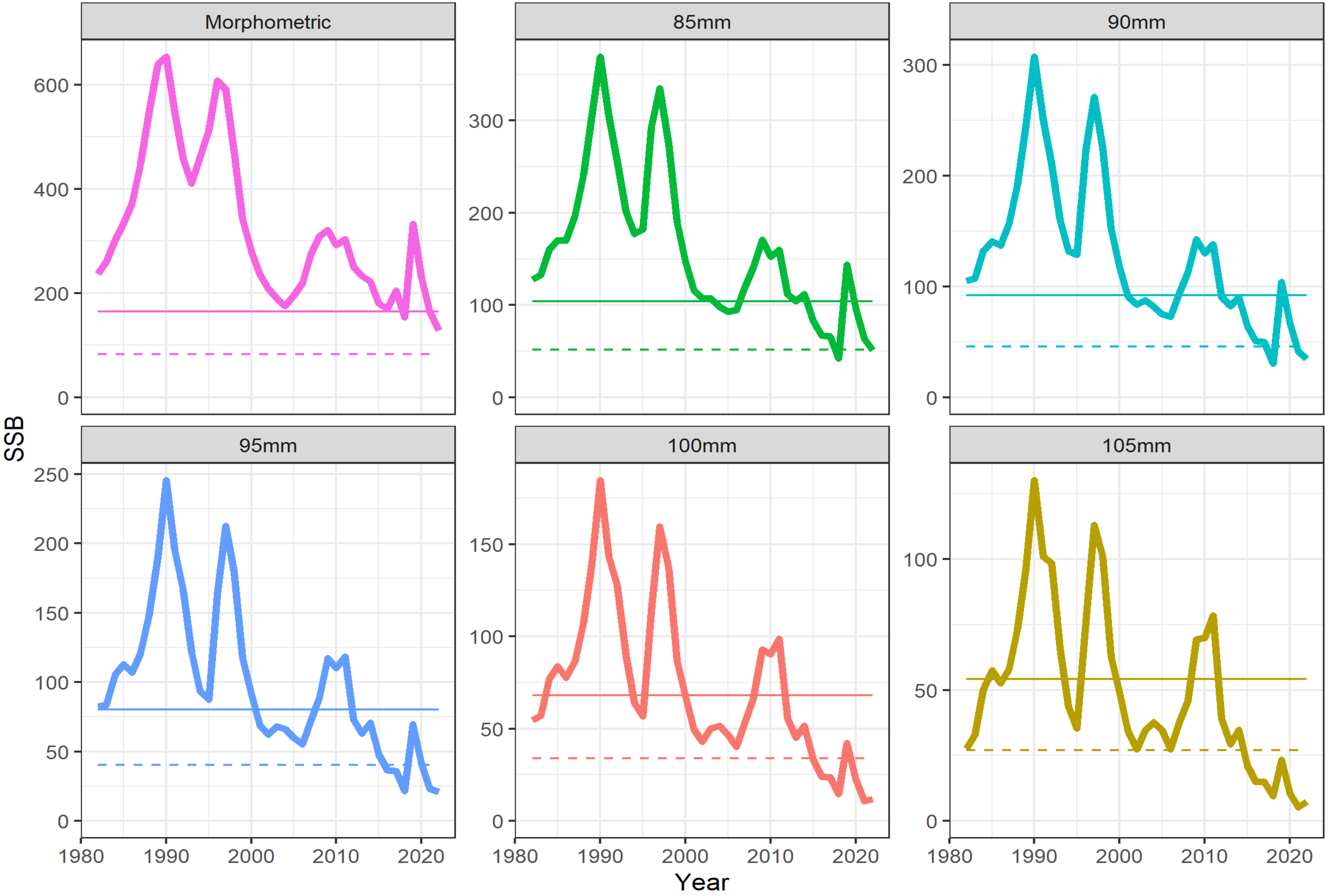




How would different definitions of maturity impact status and OFLs?



January 2024



Morphometric
85mm
90mm
95mm
100mm
105mm
SSB
Year
0
200
400
600
100
300
50
150
250
1980
1990
2000
2010
2020

Maturity	MMB	B35	F35	FOFL	OFL	M	avg_rec	Status
Morphometric	128.51	165.03	305.86	167.34	41.78	0.29	155.67	0.78
85mm	51.27	103.91	8.29	2.57	8.90	0.29	155.67	0.49
90mm	34.83	92.12	4.31	0.93	4.59	0.29	155.67	0.38
95mm	20.96	80.44	2.48	0.00	0.06	0.29	155.67	0.26
100mm	11.76	67.97	1.59	0.00	0.06	0.29	155.67	0.17
105mm	7.32	54.14	1.12	0.00	0.06	0.29	155.67	0.14

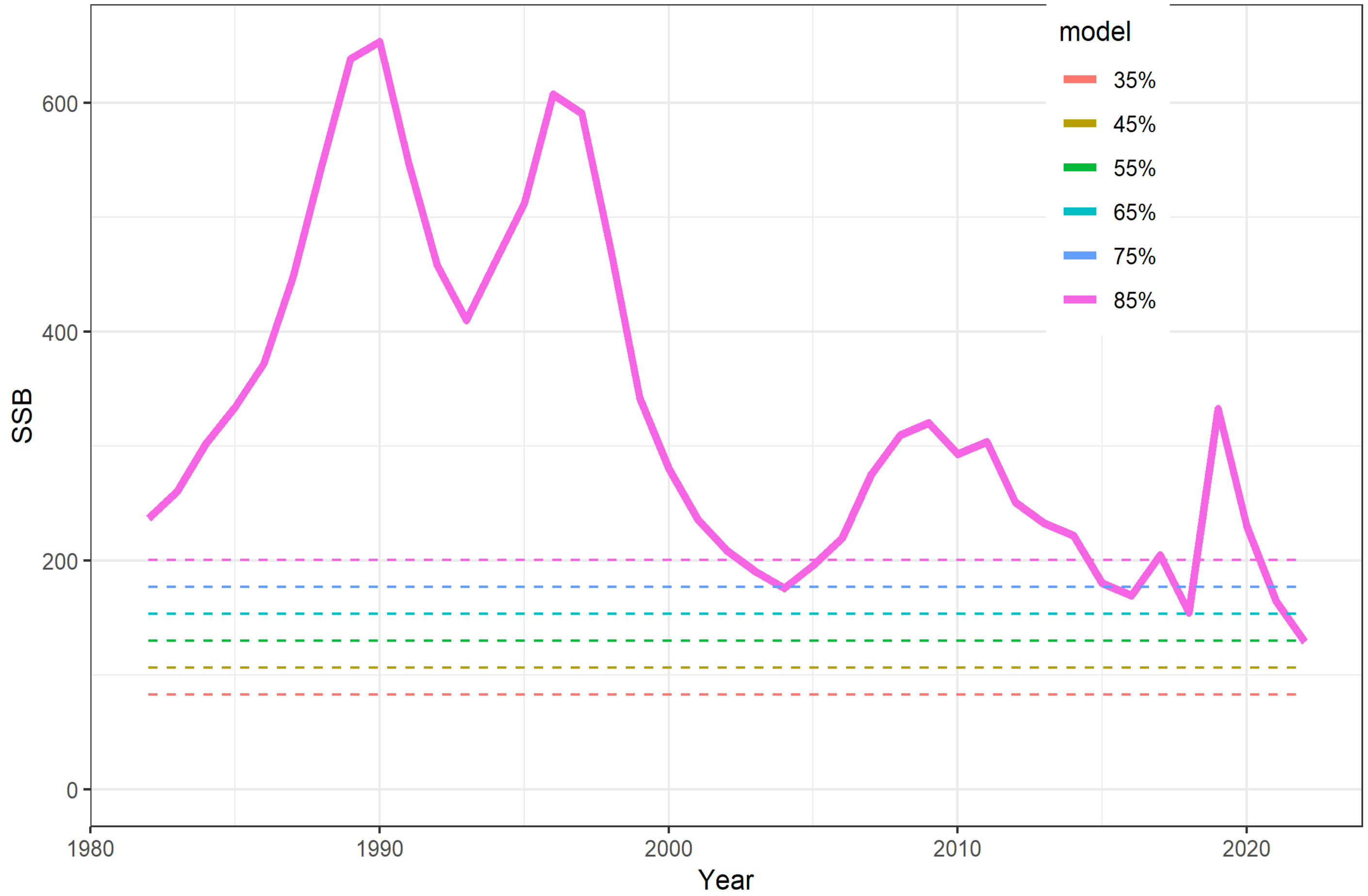
- Increasing the size at maturity decreases F35% and status
- Once the size is >=95mm carapace width, the fishery would have been closed in 2023 at the federal level

How would using different SBPR percentages impact status and OFLs while using morphometric maturity as currency?

SBPR% modification

- Target F and status decrease as the percentage of unfished biomass as target increases

- The fishery would have been closed in 2023 at >=85%.



SBPR%	MMB	B_target	F_target	FOFL	OFL	M	avg_rec	Status
35%	128.51	165.03	305.86	167.34	41.78	0.29	155.67	0.78
45%	128.51	212.18	67.12	26.90	24.06	0.29	155.67	0.61
55%	128.51	259.34	14.32	4.41	11.63	0.29	155.67	0.50
65%	128.51	306.49	3.12	0.76	3.94	0.29	155.67	0.42
75%	128.51	353.64	0.92	0.18	1.14	0.29	155.67	0.36
85%	128.51	400.79	0.30	0.00	0.06	0.29	155.67	0.32

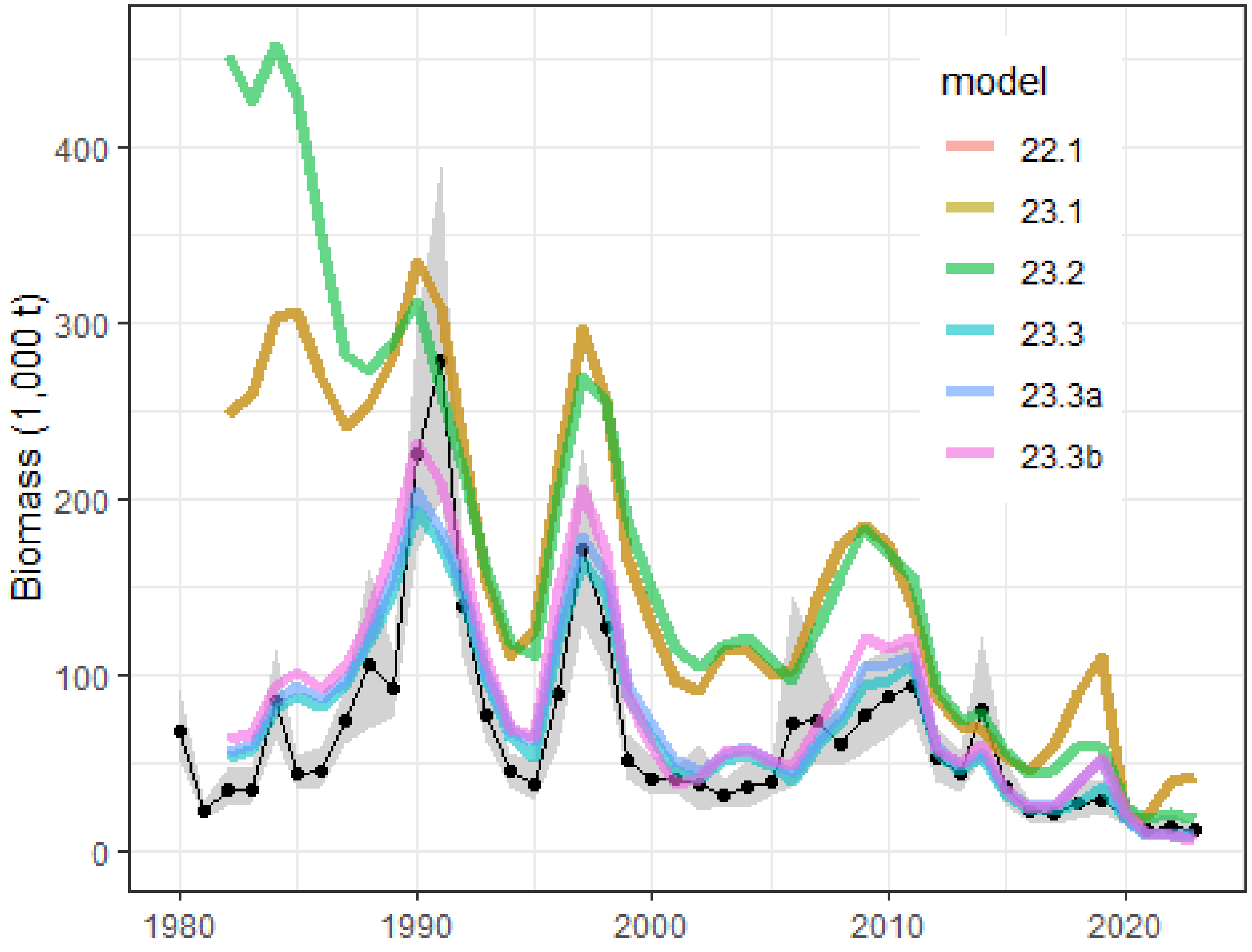
What I would do?

Complex model

- Model: 23.3a
  - Specify probability of terminally molting
  - BSFRF as priors
- Currency of management: 95 or 100mm
- SBPR reference points based on the model and currency chosen (rerun this with GMACS)

Simple model

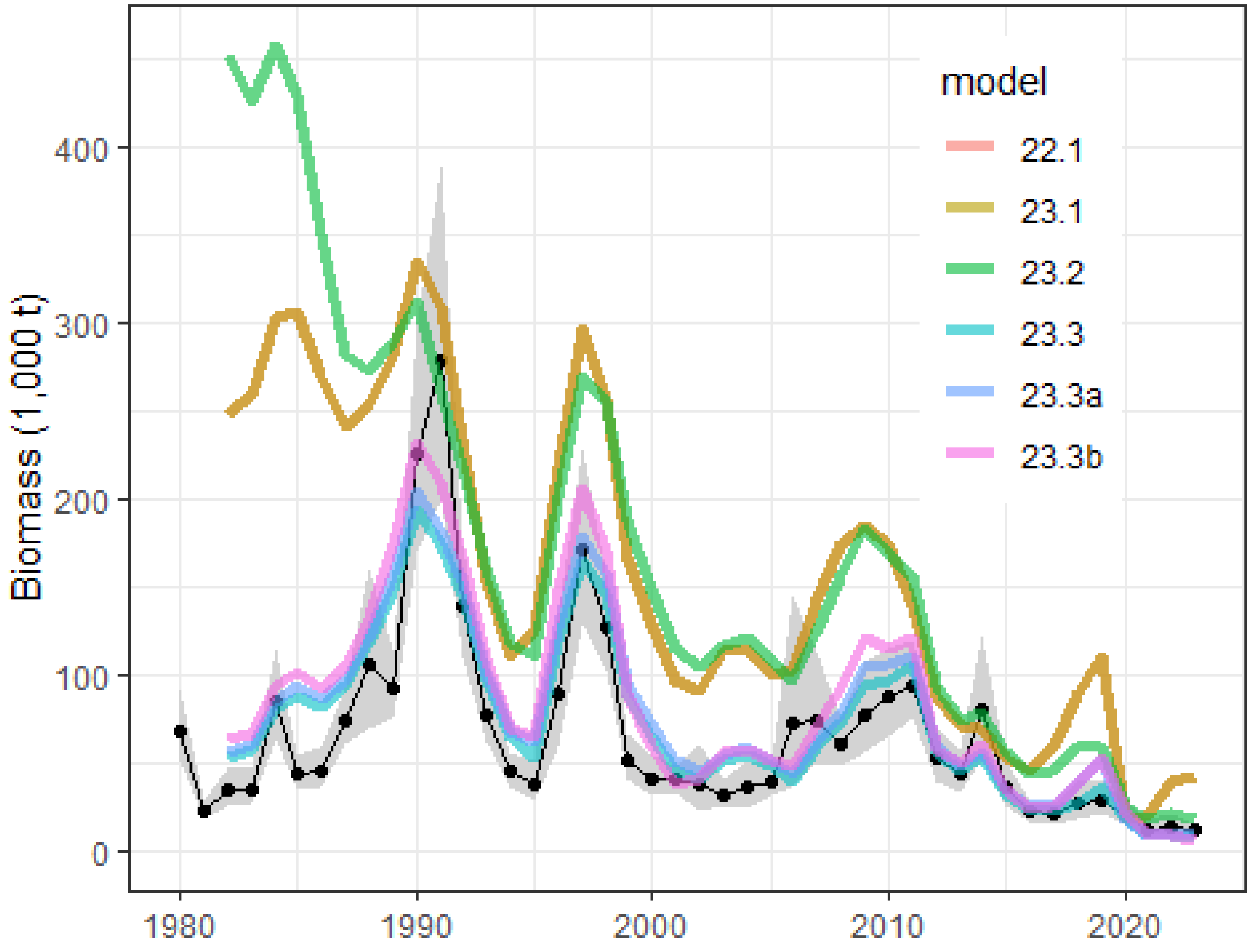
- Survey estimate of 95 or 100mm male crab
- Decrement by M to time of fishery
- Apply some exploitation rate (e.g. M)



What I would do?

Rationale

- Under uncertainty in reproductive dynamics, focus management on the portion of the stock for which management levers exist
- Reference points should reflect the dire circumstances of exploitable biomass
- Discrepancies between State and Federal catch advice is confusing



Projections under a changing climate

Population dynamics model

- Male only
- 30-135 mm CW
- Growth and maturity input
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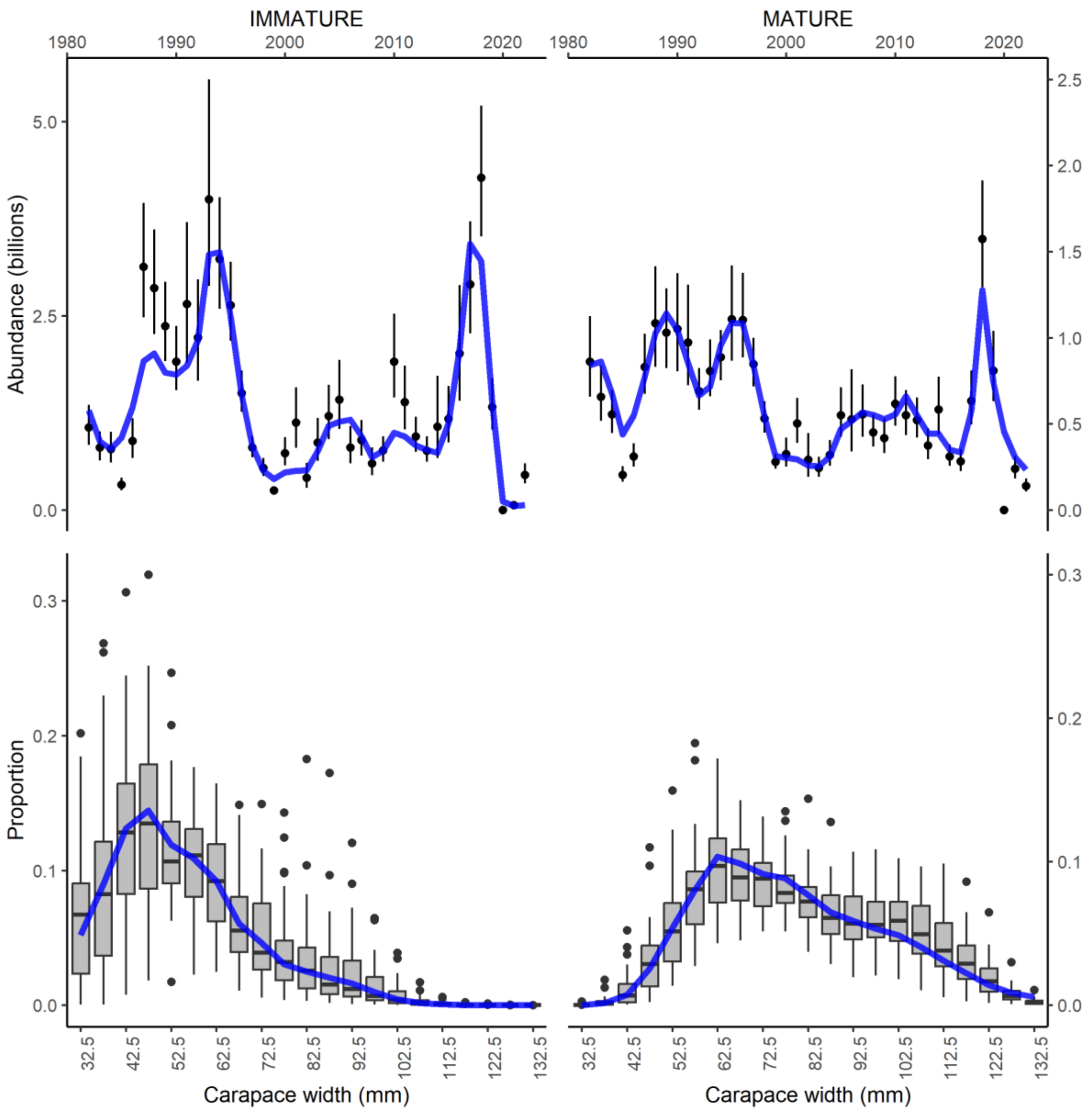

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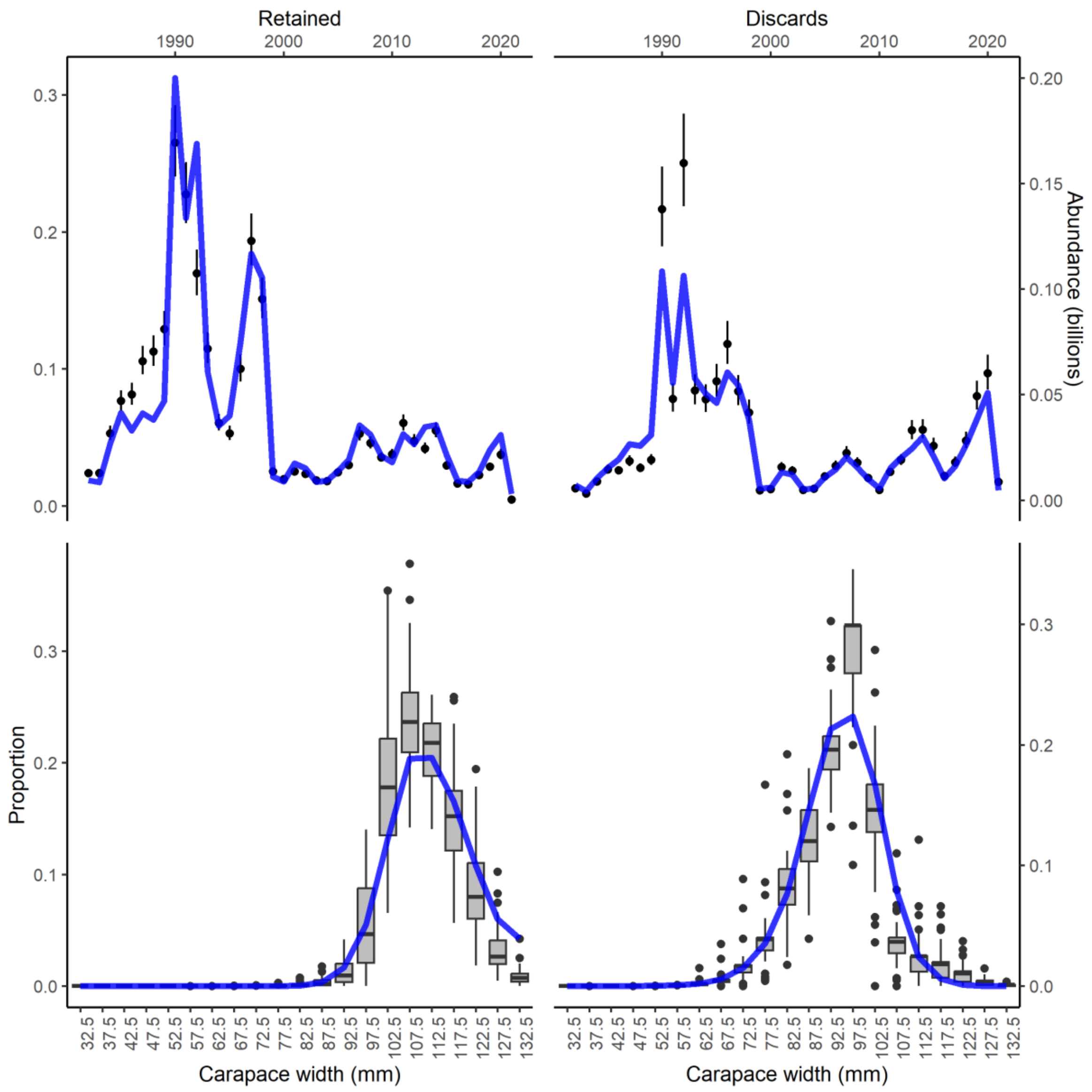
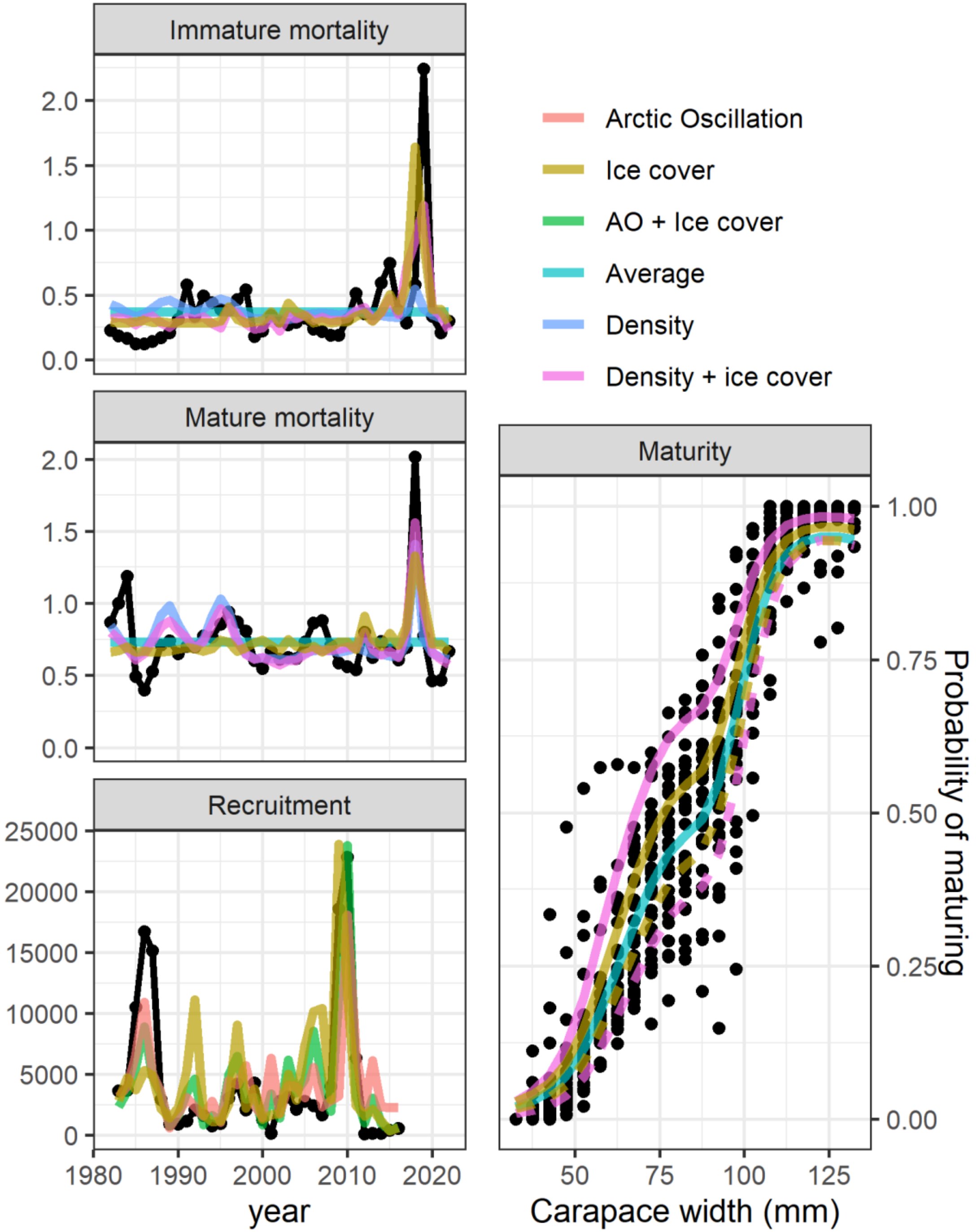
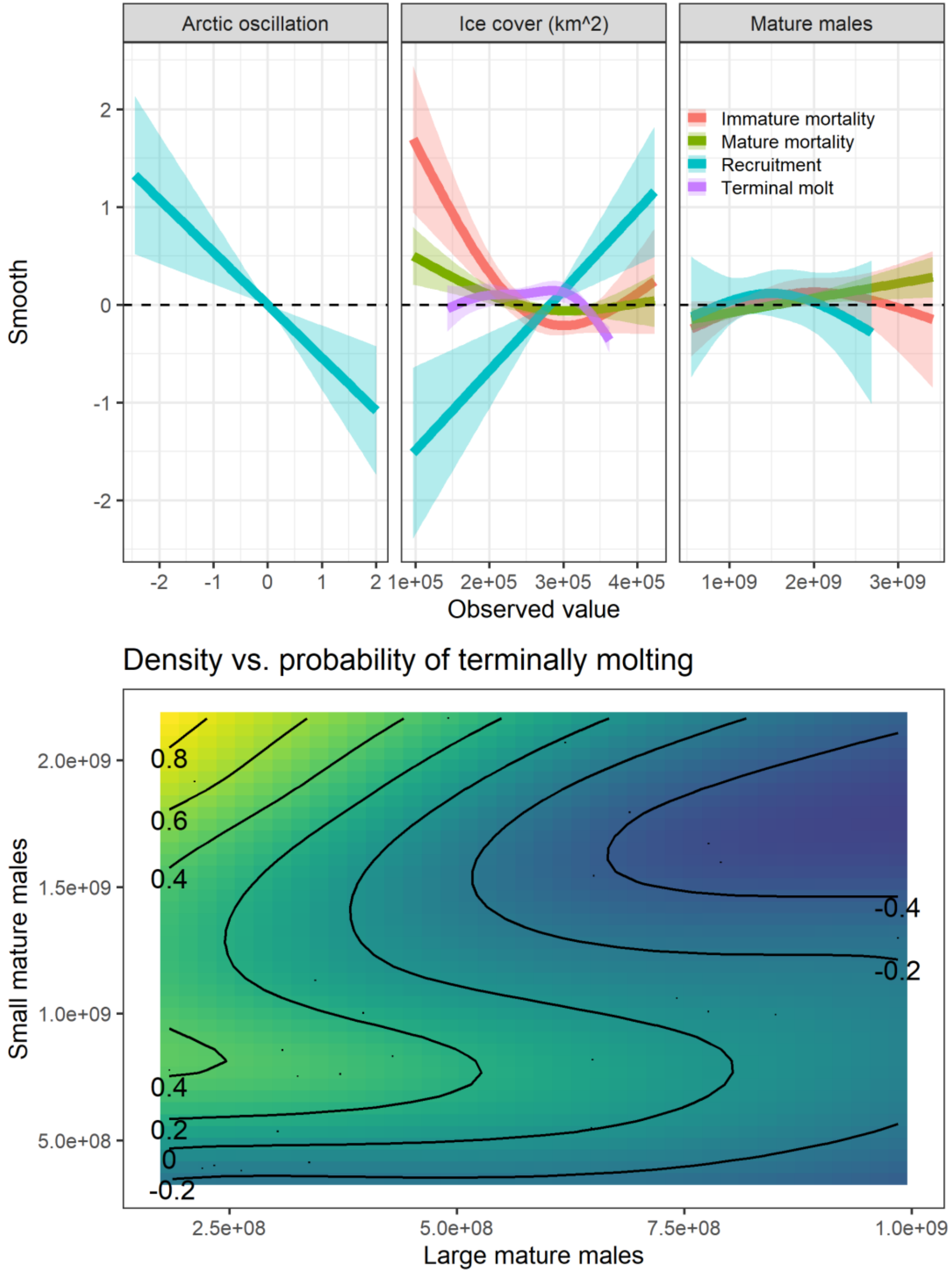




What happens next?

- **Density dependence** and **environmental covariates** explain variability in *mortality*, *recruitment* and *maturity* better than no covariates.



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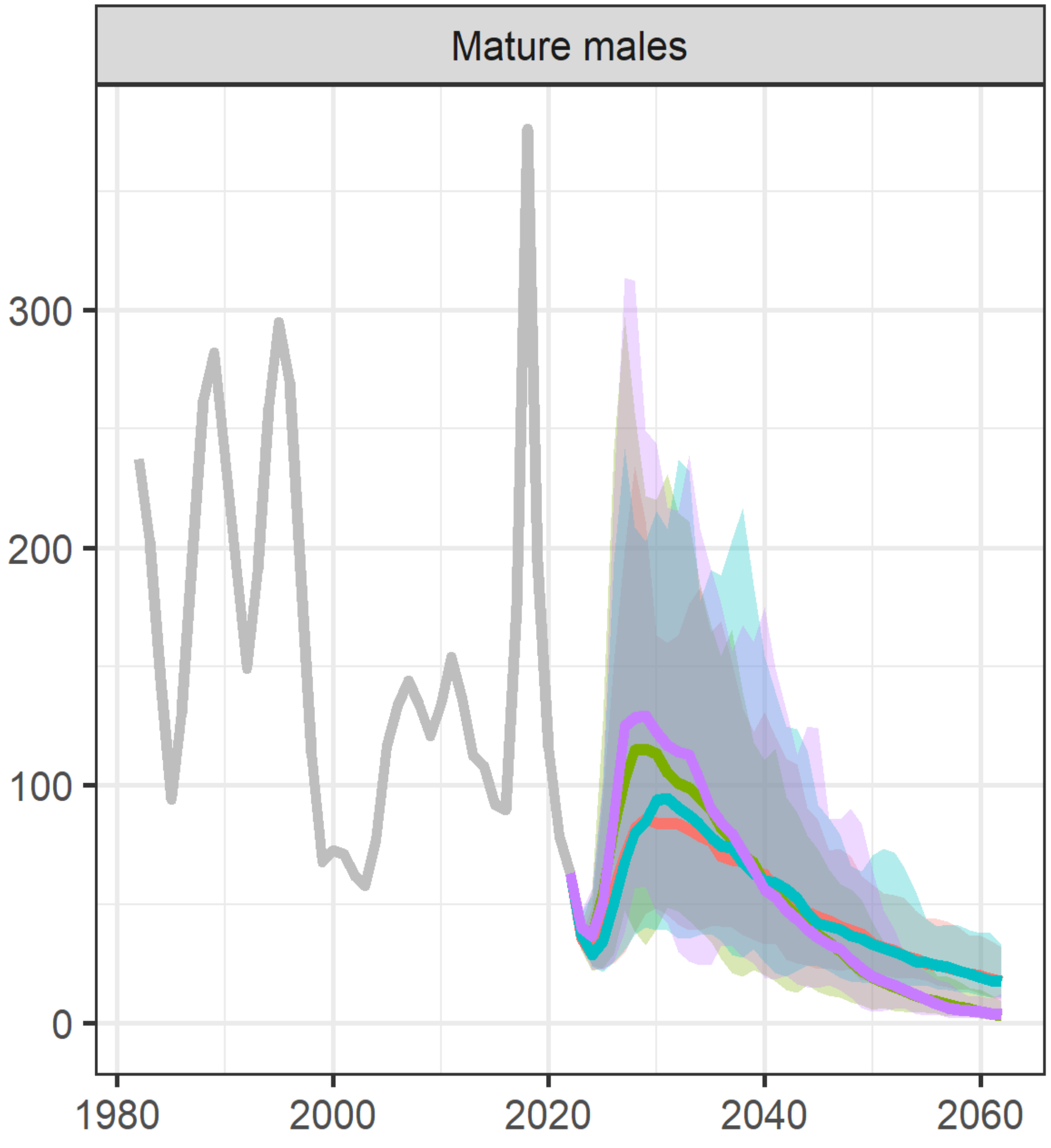
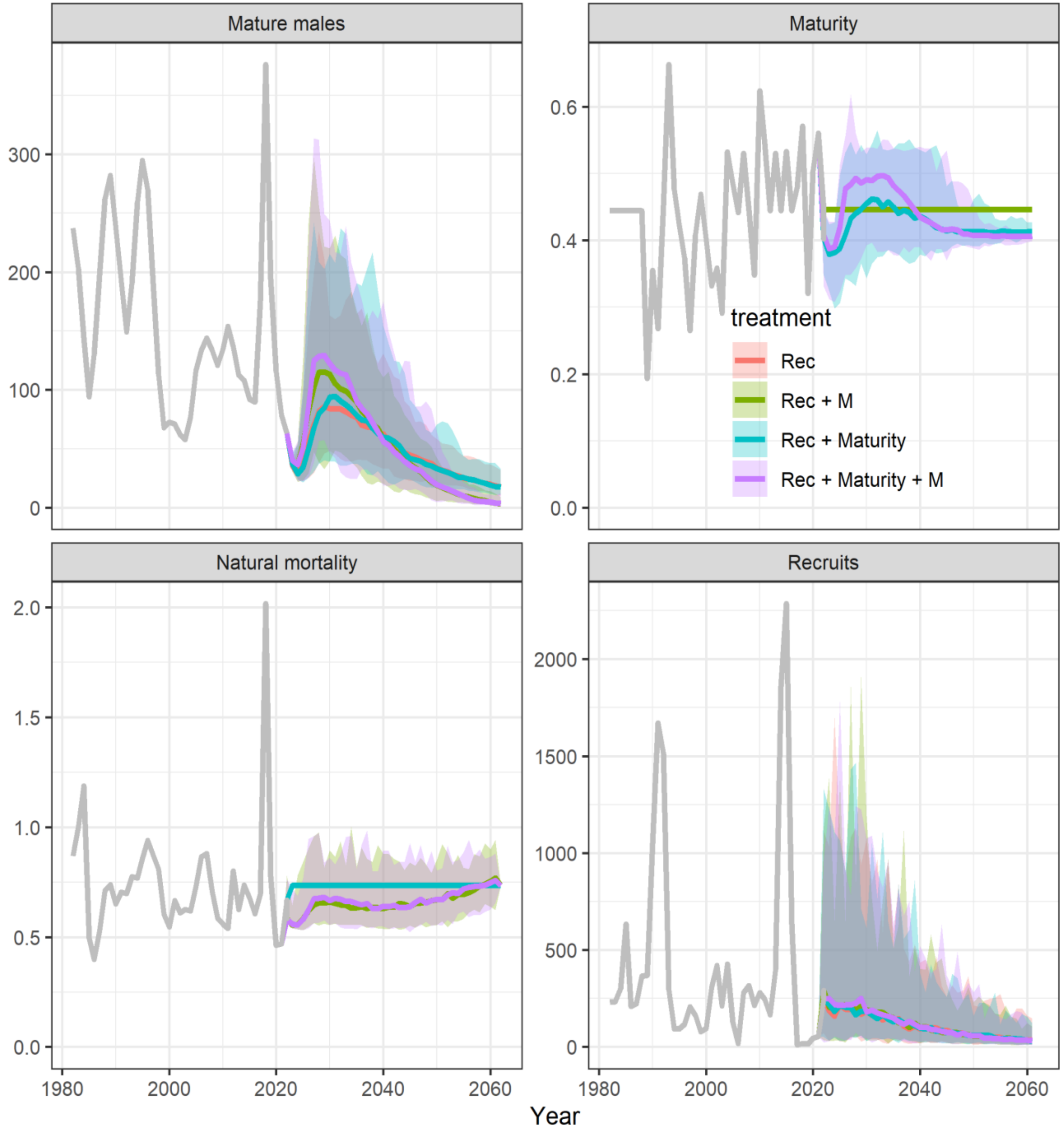
- **Density dependence** and **environmental covariates** explain variability in *mortality*, *recruitment* and *maturity* better than no covariates.
- Impacts of changes in **ice** are strong for *mortality* and *recruitment*



What happens next?

- **Density dependence** and **environmental covariates** explain variability in *mortality*, *recruitment* and *maturity* better than no covariates.
- Impacts of changes in **ice** are strong for *mortality* and *recruitment*
- **Density dependence** in *mortality* allows for a short window for rebound, after which the population declines



What happens next?

- **Density dependence** and **environmental covariates** explain variability in *mortality*, *recruitment* and *maturity* better than no covariates.
- Impacts of changes in **ice** are strong for *mortality* and *recruitment*
- **Density dependence** in *mortality* allows for a short window for stronger rebound, after which the population declines

If you believe the projection, what do you do?

- Strategic
  - Change reference points?
  - Thresholds in HCRs?
  - Impacts of quotas and allocation of booming stocks
- Tactical
  - Harvest ahead of heatwave or implement closures?
  - Does this have any use when thinking about size at retention?