BSAI SNOW CRAB

CODY SZUWALSKI

ESP, ASSESSMENT, AND REBUILDING

ECOSYSTEM AND SOCIOECONOMIC PROFILE

Indicator category	Indicator	2018 Status	2019 Status	2020 Status	2021 Status	2022 Status
Physical	Winter Spring Arctic Oscillation Index- Model	neutral	neutral	**high**	neutral	neutral
	Summer Cold Pool- SEBS Survey	**low**	**low**	NA	**low**	neutral
	Winter Sea Ice Advance BS- Satellite	**low**	neutral	neutral	neutral	neutral
Lower Trophic	Chlorophyll-*a* Biomass SEBS- Satellite	neutral	neutral	*high*	neutral	*high*
	Summer Benthic Invertebrate Density- SEBS Survey	neutral	neutral	NA	neutral	NA

Courtesy Erin Fedewa et al.

ECOSYSTEM AND SOCIOECONOMIC PROFILE

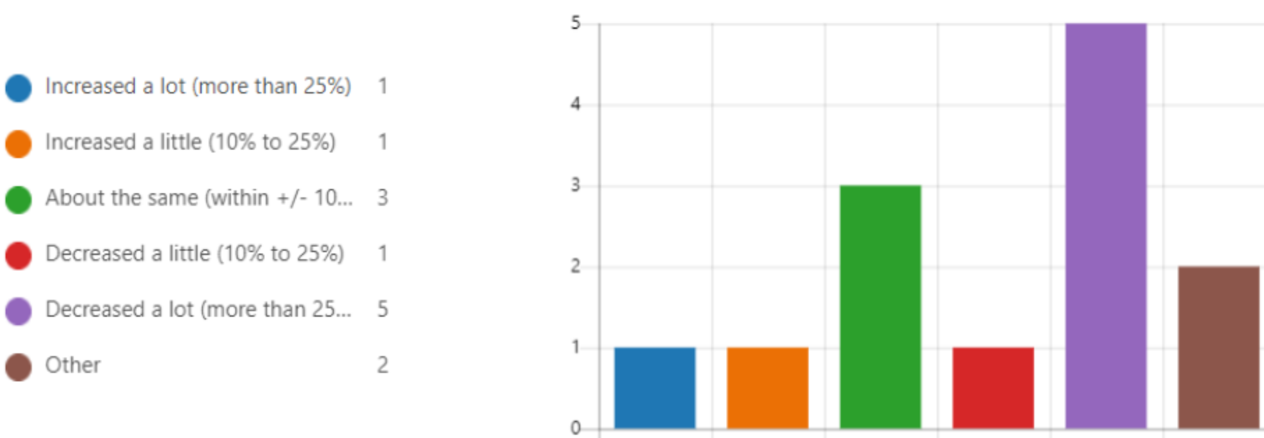
Indicator category	Indicator	2018 Status	2019 Status	2020 Status	2021 Status	2022 Status
Upper Trophic	Summer Snow Crab Juvenile Temperature Occupancy	**high**	**high**	NA	**high**	neutral
	Summer Snow Crab Juvenile Disease Prevalence	neutral	neutral	NA	neutral	neutral
	Annual Snow Crab Male Size Maturity- Model	**low**	neutral	NA	**low**	neutral
	Summer Snow Crab Male Area Occupied- SEBS Survey	**low**	**low**	NA	neutral	neutral
	Summer Snow Crab Male Center Distribution- SEBS Survey	neutral	neutral	NA	*high*	*high*
	Summer Snow Crab Consumption Pacific Cod- Model	**high**	neutral	NA	neutral	NA

Courtesy Erin Fedewa et al.

ECOSYSTEM AND SOCIOECONOMIC PROFILE

Development of future community indicators:
ABSC Skipper Survey

1. Based on your observations this snow crab season, how did the amount of industry preferred males that you encountered during the fishery change in comparison to the last snow crab season?



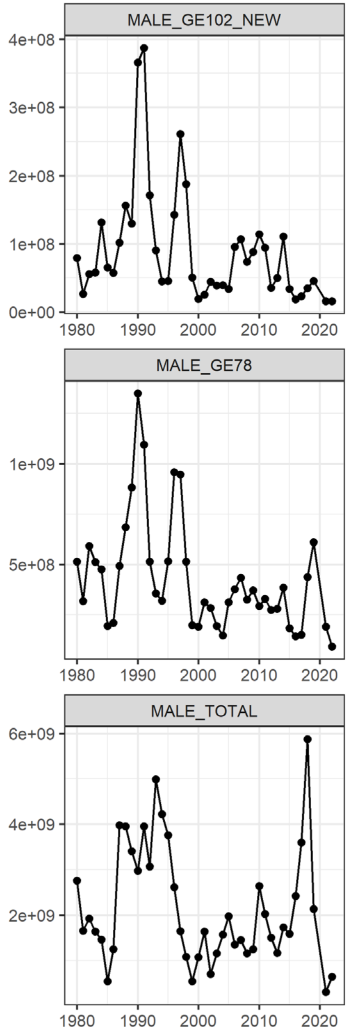
Courtesy Erin Fedewa et al. and thanks to ABSC

ECOSYSTEM AND SOCIOECONOMIC PROFILE

Indicator category	Indicator	2018 Status	2019 Status	2020 Status	2021 Status	2022 Status
Fishery Performance	Annual Snow Crab Active Vessels EBS Fishery	neutral	neutral	neutral	neutral	low
	Annual Snow Crab CPUE Fishery	neutral	neutral	neutral	neutral	neutral
	Annual Snow Crab Potlift Fishery	neutral	neutral	neutral	neutral	neutral
	Annual Snow Crab Center Distribution EBS Fishery	neutral	high	neutral	high	high
	Annual Snow Crab Incidental Catch EBS Fishery	neutral	neutral	neutral	neutral	NA
Economic	Annual Snow Crab TAC Utilization EBS Fishery	neutral	neutral	neutral	neutral	neutral
	Annual Snow Crab Exvessel Value EBS Fishery	neutral	neutral	neutral	neutral	NA
	Annual Snow Crab Exvessel Price EBS Fishery	high	high	high	high	NA
	Annual Snow Crab Exvessel Revenue Share EBS Fishery	neutral	neutral	high	high	NA

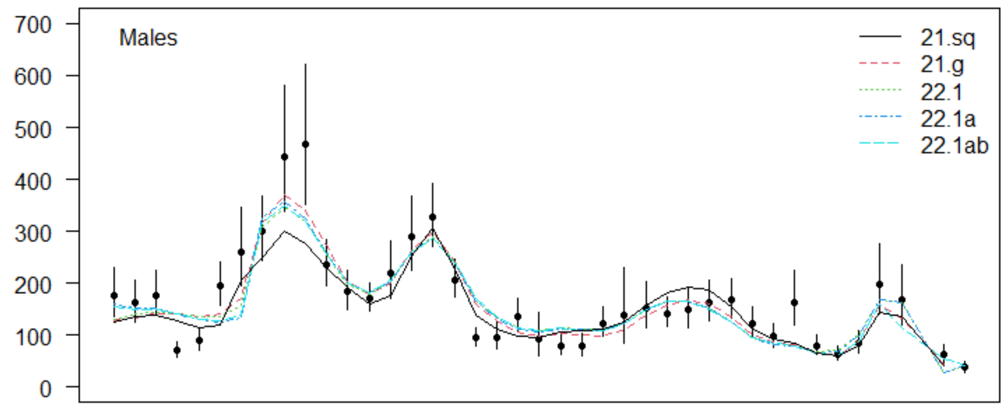
Courtesy Brian Garber Yonts

STOCK STATUS

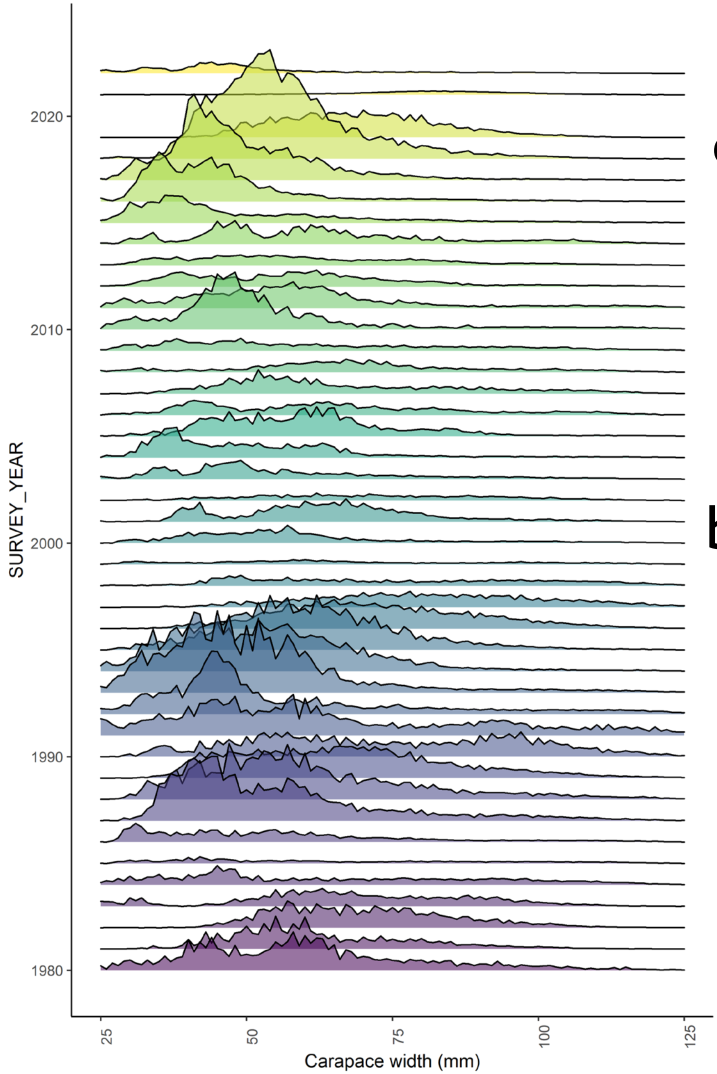


All measures of survey abundance are at or near **all-time lows**.

Survey MMB (morphometrically mature) was -40% compared to last year's all time low.



STOCK STATUS

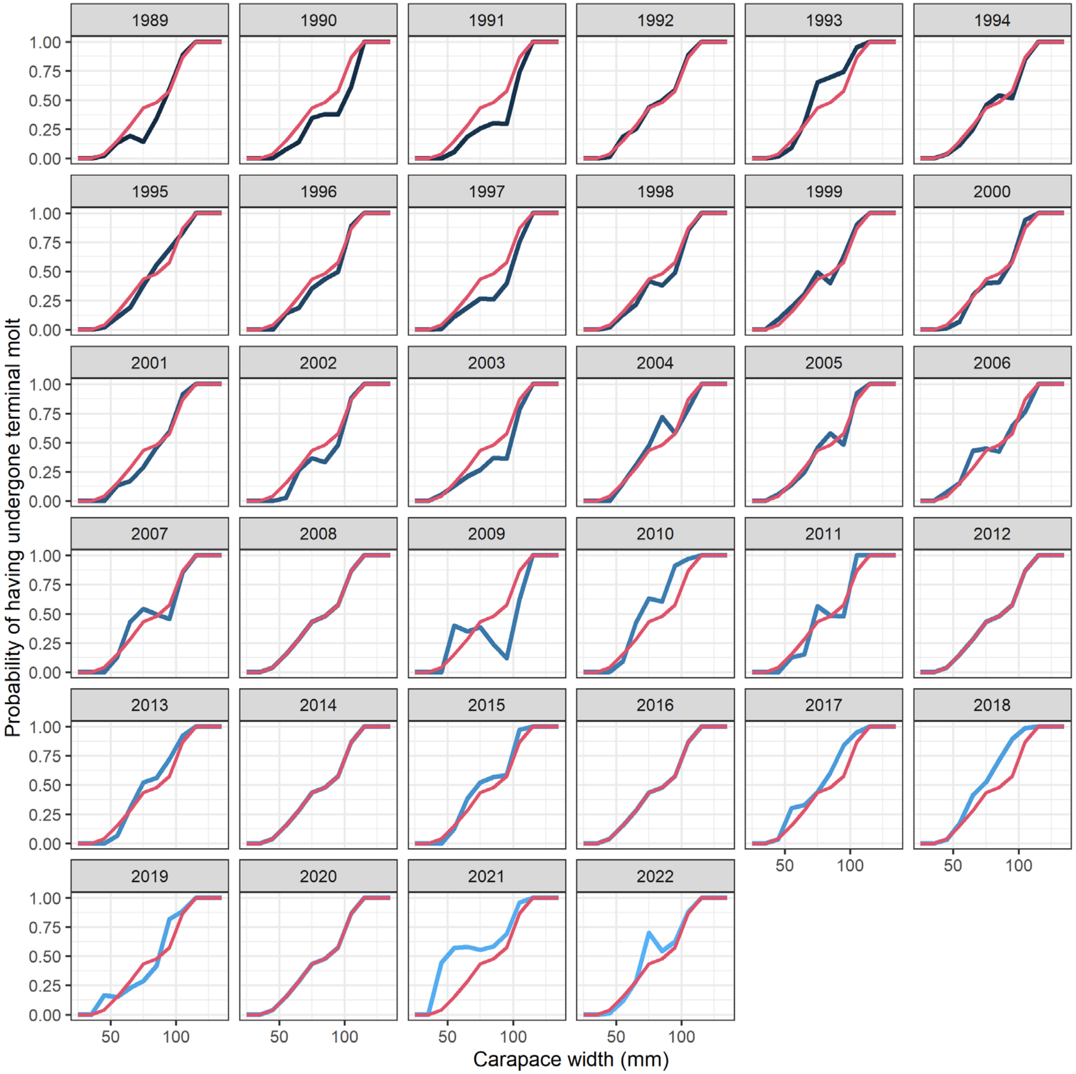


Small male recruitment signal in <50 mm carapace width range, but need more years to corroborate given false starts in the past.

If this recruitment follows through, it will be 4 to 5 years before it potentially hits the fishery.

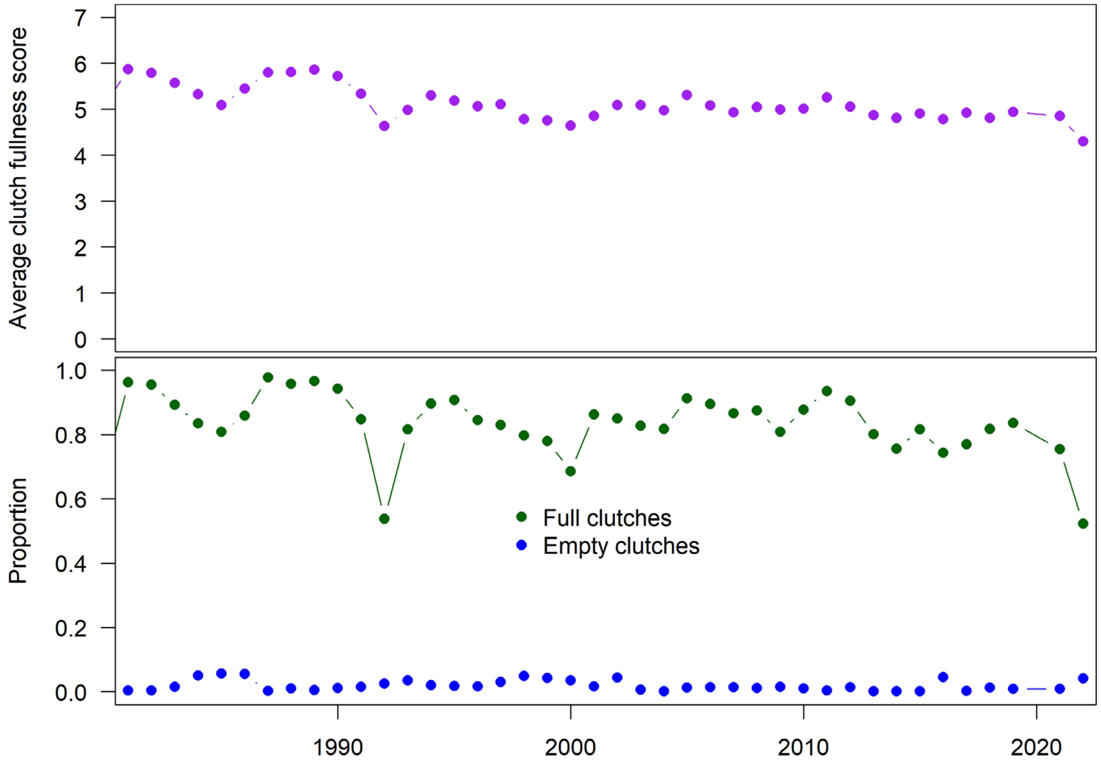
Until then, the commercially preferred fraction of the population will likely continue to decline.

POINTS FOR CONCERN



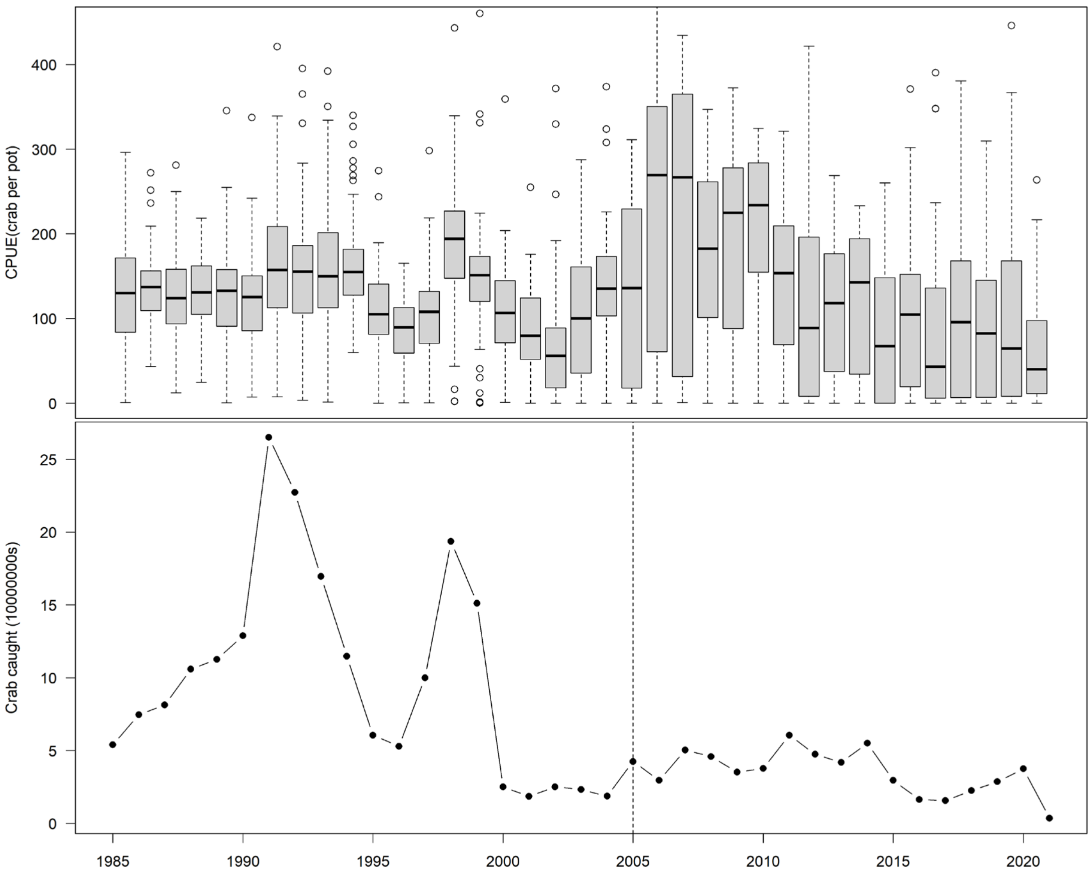
Increased probability of having undergone terminal molt at small sizes in 2021

POINTS FOR CONCERN



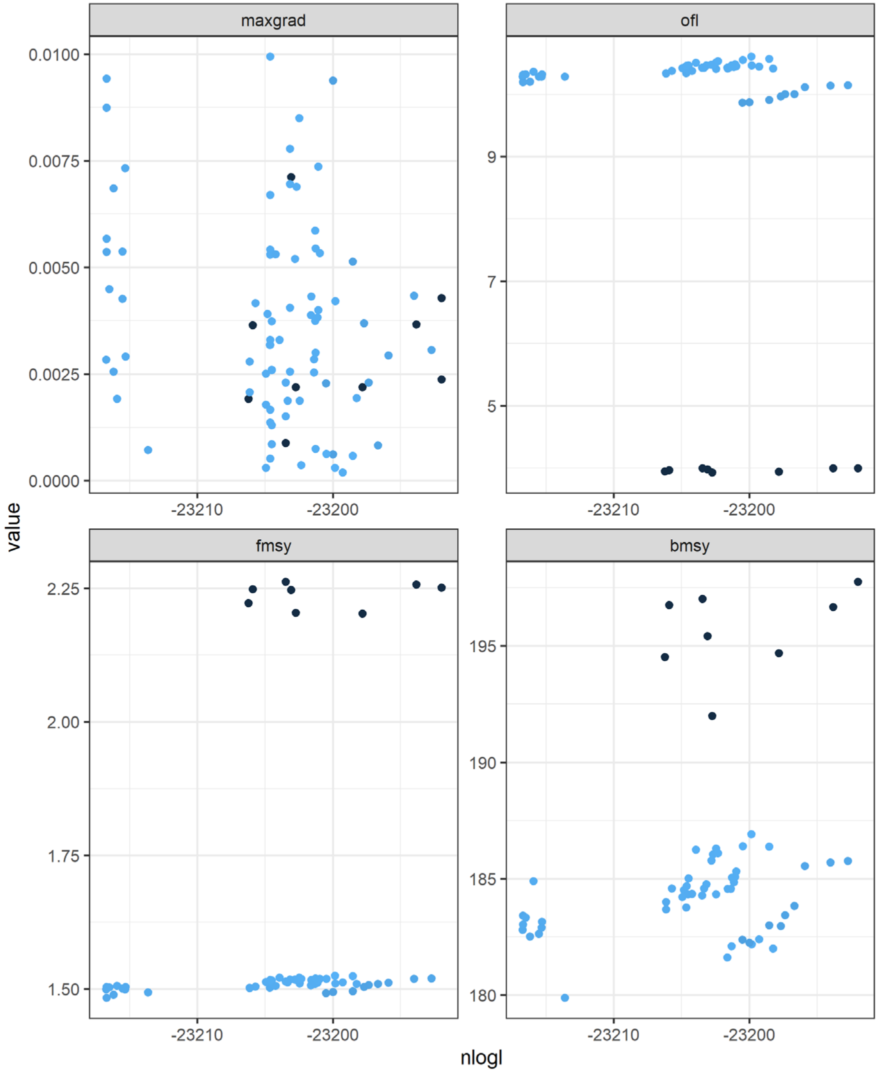
Average clutch fullness scores at all-time lows

POINTS FOR CONCERN



Fishery CPUEs at all time lows

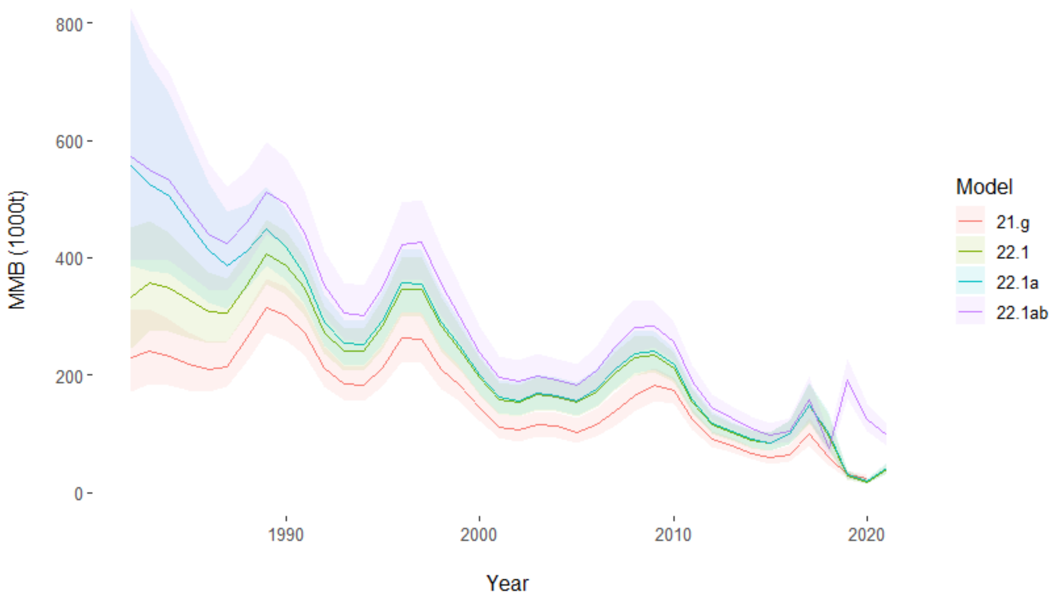
MODELING ISSUES

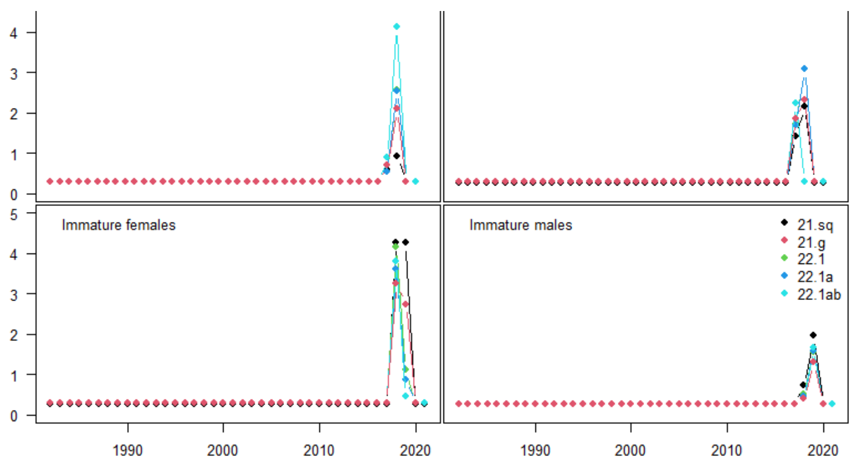


Move to GMACS was useful

New data resulted in bimodal management quantities

MODELING ISSUES





Move to GMACS was useful

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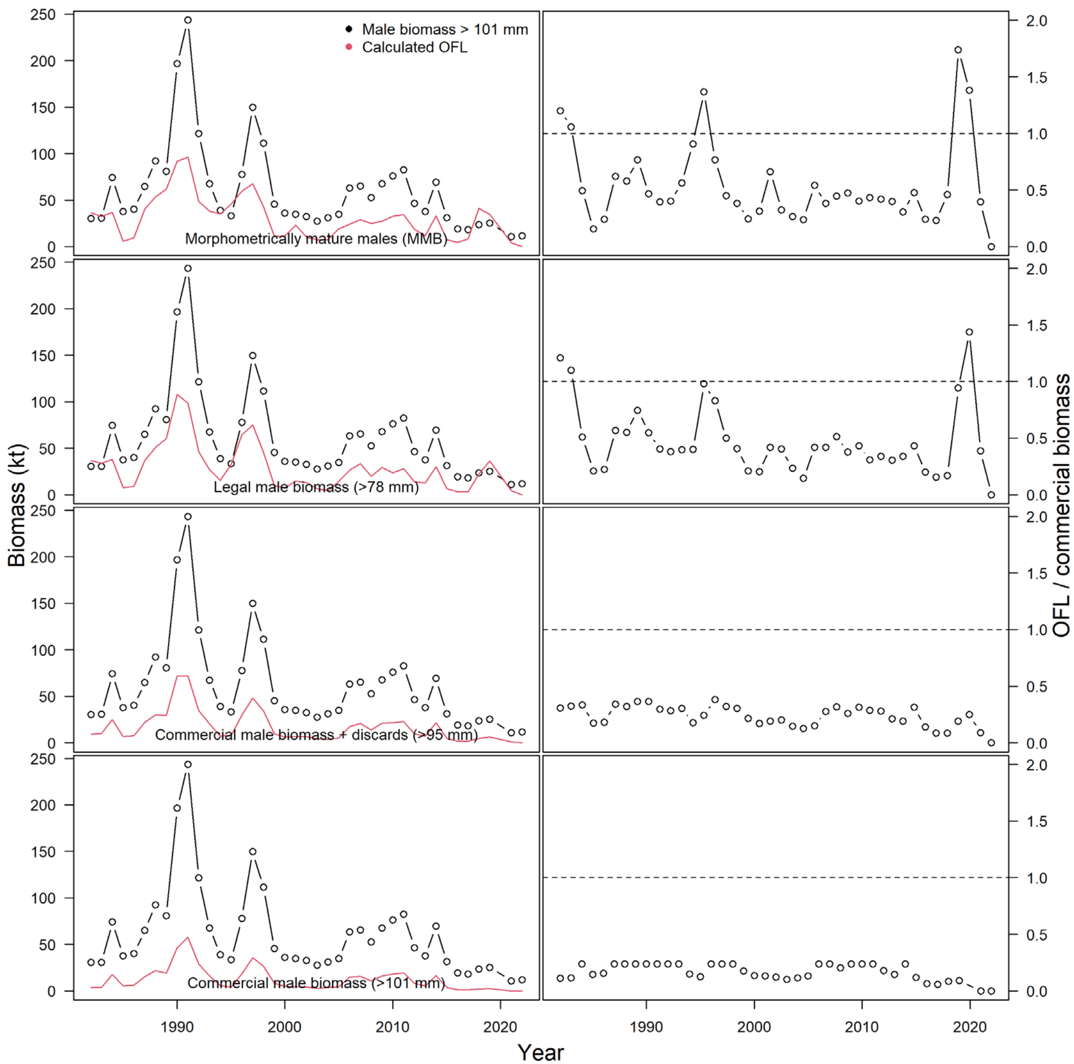
Bimodality results from two different interpretations about what happened in 2019-2020 and mortality events

MODELING ISSUES



Move to GMACS was useful

New data resulted in bimodal management quantities

Bimodality results from two different interpretations about what happened in 2019-2020 and mortality events

Tier 4 rules all close the fishery

SNOW CRAB ASSESSMENT

MODELS

Tier 3

- 21.1: GMACS model accepted by SSC in June 2022 with prior on M to match status quo model
- 22.1: 21.1 with updated data
- 22.1a: 22.1 with initial numbers at size estimated as parameters rather than composition and a scaling factor
- 22.1ab: 22.1a but from a different mode from the jittering analysis

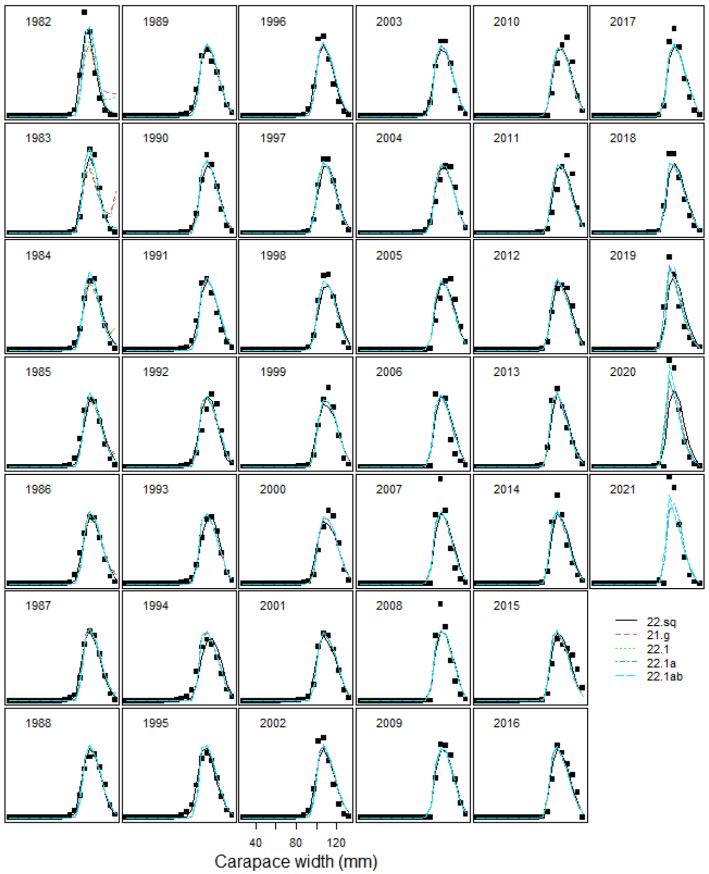
Tier 4

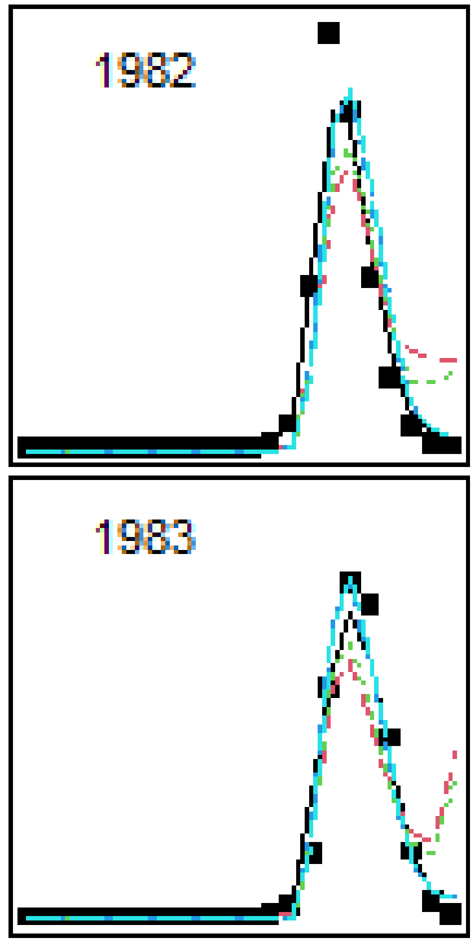
- Morphometrically mature male biomass
- Legal males (>78 mm carapace width)
- Males >95 mm carapace width
- Preferred males (>101 mm carapace width)
- FMSY proxy = natural mortality (0.27)
- BMSY proxy = average MMB from 1982-present

DECISION POINTS

- How should a bimodal model be considered?
- What criteria are important to consider for accepting a model?
    - Model fits: negative log likelihoods of data components
    - plausibility of estimated processes: fishing mortality, recruitment
    - Stability: jittering analyses
    - Convergence: maximum gradient component + invertible hessian
- Is there justification for using a tier 4 model?

MODEL FITS

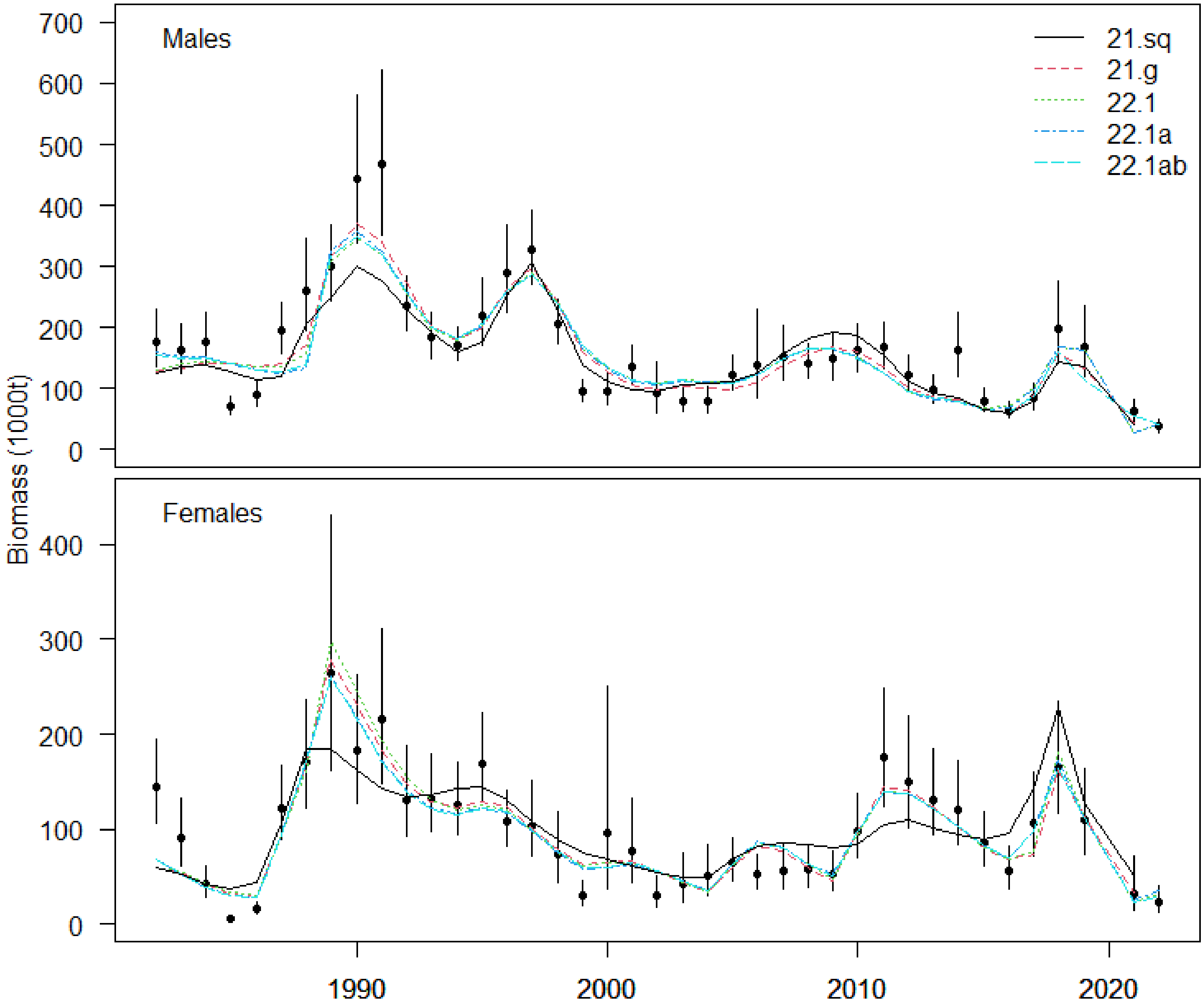


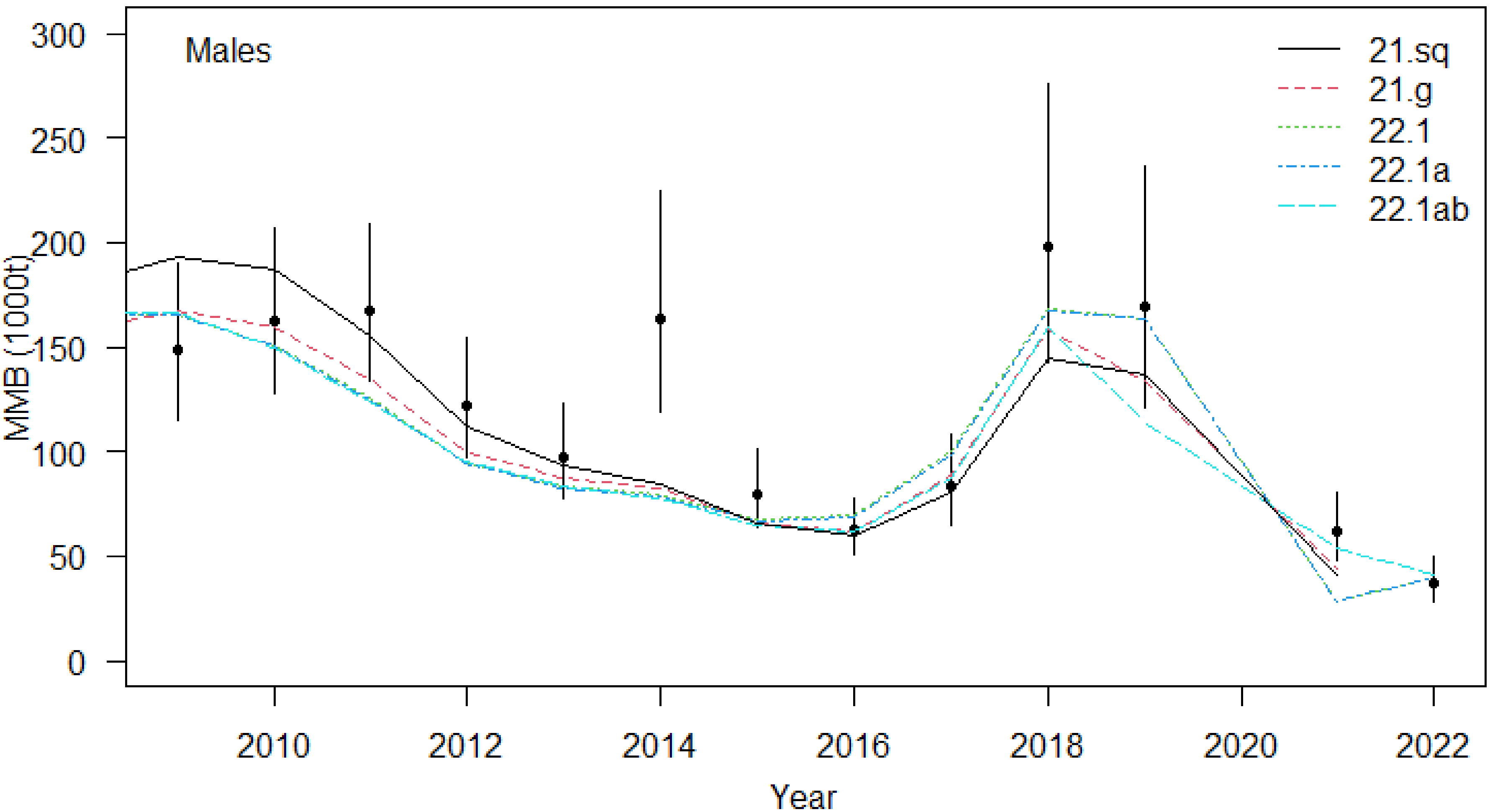


Model 22.1 produced 'pigtails' in early years.

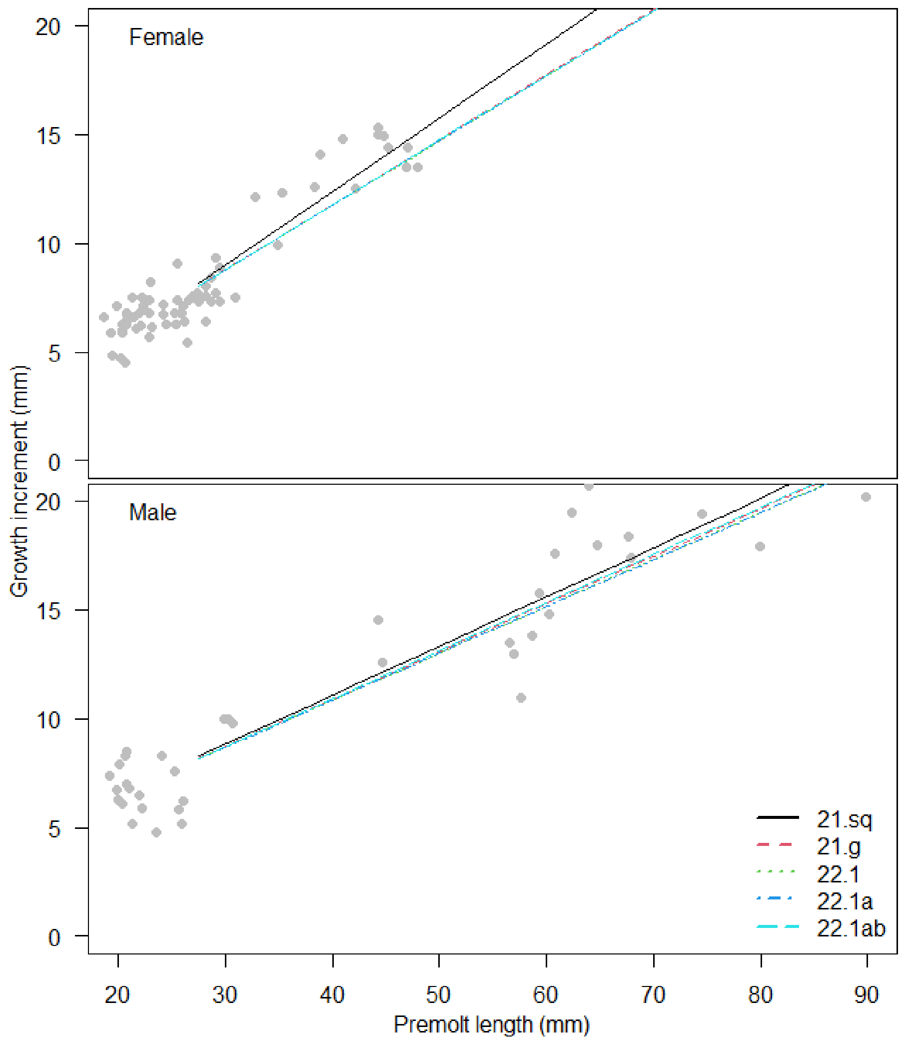
Model 22.1a/b solved this issue.

	Model 22.1a		Model 22.1ab	
Fits/Process	**Fits**	**Plausibility**	**Fits**	**Plausibility**
Survey MMB				
Growth				
Catch				
Size comps (catch)				
Size comps (survey M)				
Size comps (survey F)				
MMB				
Selectivity				
Maturity				
Fishing mortality				
Recruitment				
Natural mortality				

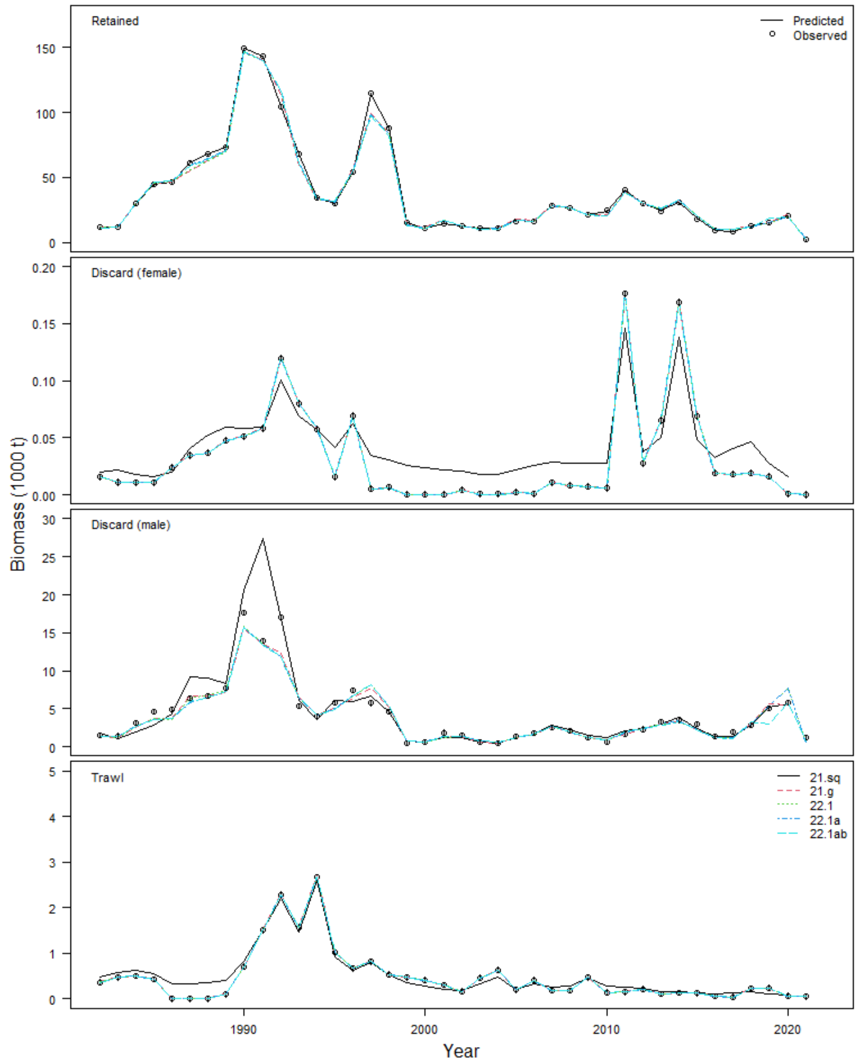

Males
Females
21.sq
21.g
22.1
22.1a
22.1ab
Biomass (1000t)
0
100
200
300
400
500
600
700
1990
2000
2010
2020


Males
21.sq
21.g
22.1
22.1a
22.1ab
MMB (1000t)
0
50
100
150
200
250
300
2010
2012
2014
2016
2018
2020
2022
Year

	Model 22.1a		Model 22.1ab	
Fits/Process	**Fits**	**Plausibility**	**Fits**	**Plausibility**
Survey MMB			better	
Growth				
Catch				
Size comps (catch)				
Size comps (survey M)				
Size comps (survey F)				
MMB				
Selectivity				
Maturity				
Fishing mortality				
Recruitment				
Natural mortality				

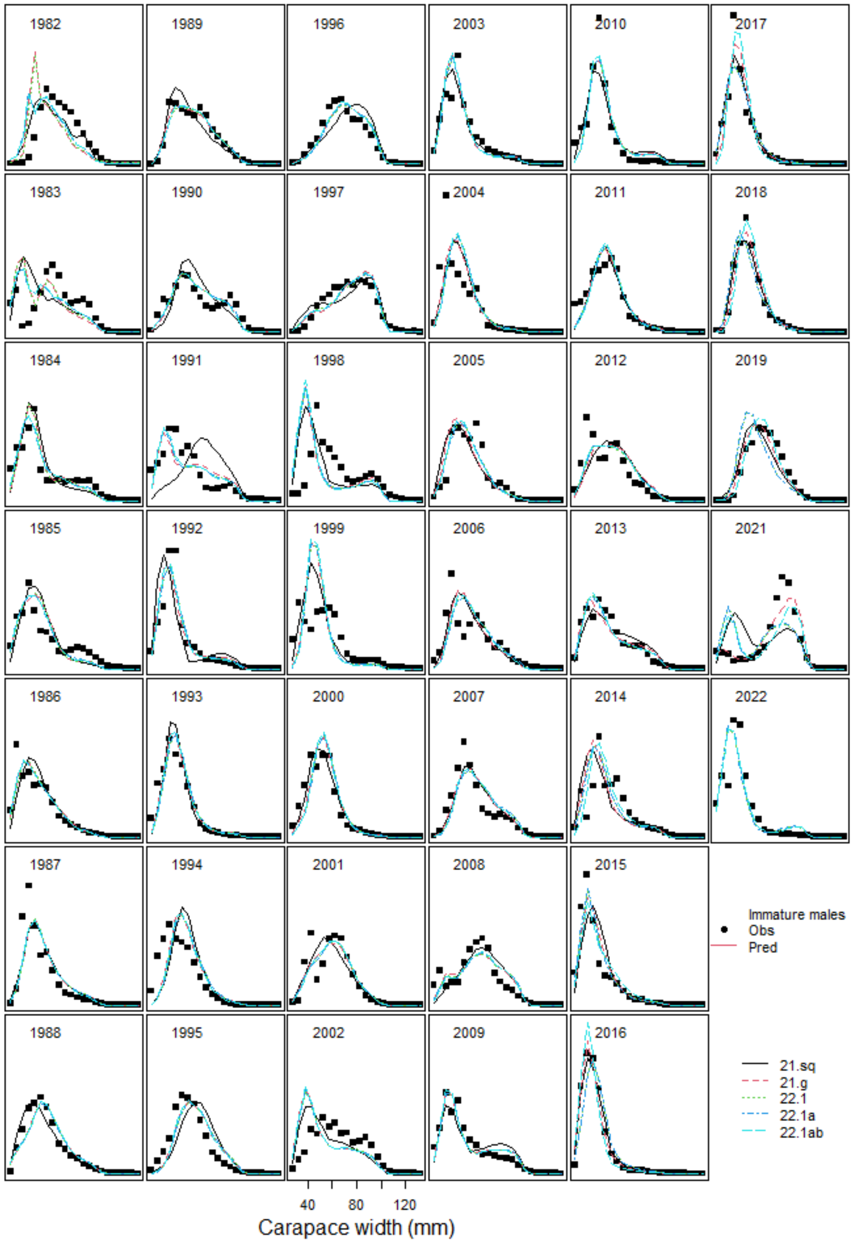


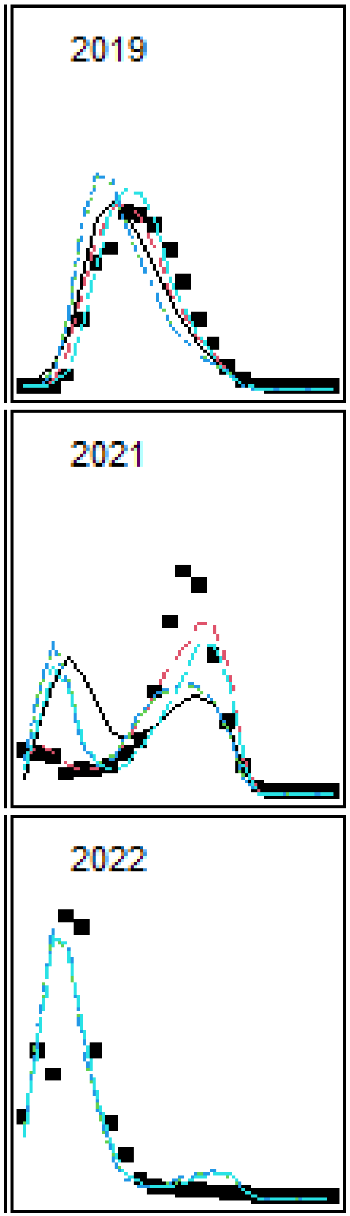
Female
Male
Growth increment (mm)
Premolt length (mm)
21.sq
21.g
22.1
22.1a
22.1ab

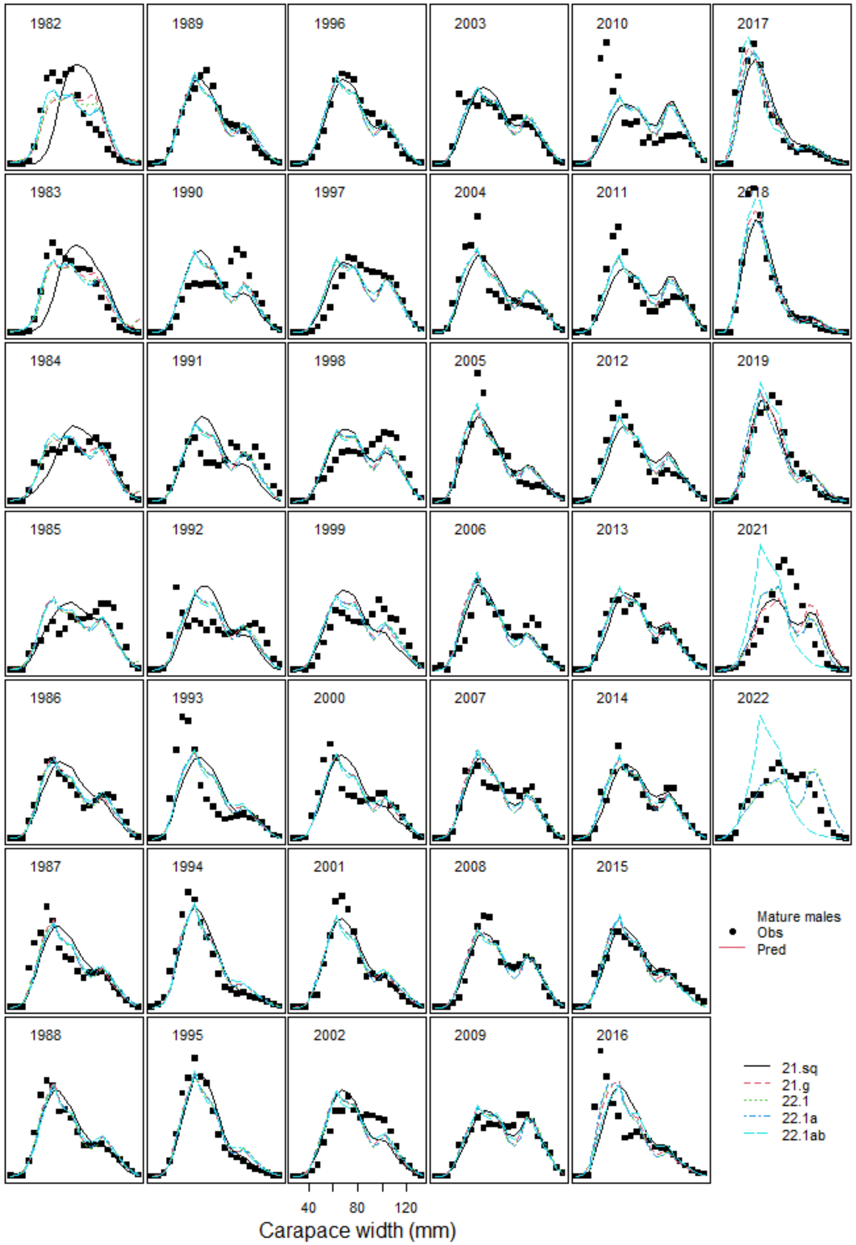


Retained
Predicted
Observed
Discard (female)
Discard (male)
Trawl
21.sq
21.g
22.1
22.1a
22.1ab
Biomass (1000 t)
Year

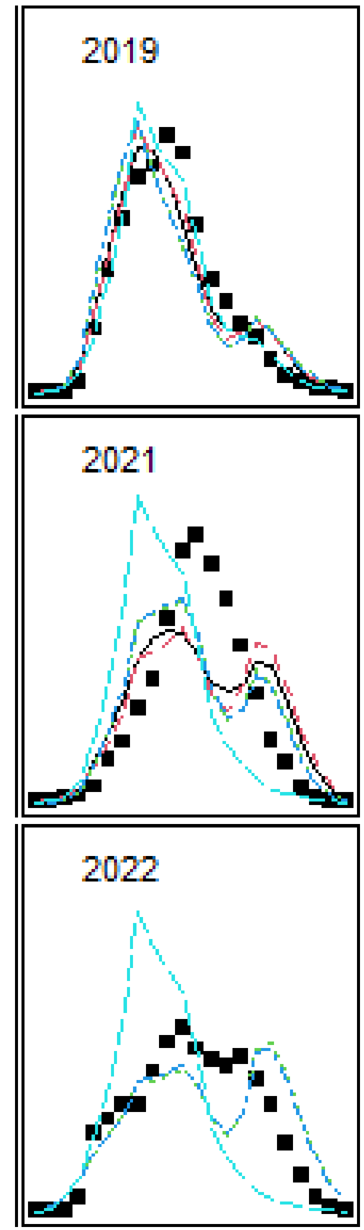
	Model 22.1a		Model 22.1ab	
Fits/Process	**Fits**	**Plausibility**	**Fits**	**Plausibility**
Survey MMB			better	
Growth			better	
Catch			better retained, better discard	
Size comps (catch)	Better to total			
Size comps (survey M)				
Size comps (survey F)				
MMB				
Selectivity				
Maturity				
Fishing mortality				
Recruitment				
Natural mortality				


1982
1989
1996
2003
2010
2017
1983
1990
1997
2004
2011
2018
1984
1991
1998
2005
2012
2019
1985
1992
1999
2006
2013
2021
1986
1993
2000
2007
2014
2022
1987
1994
2001
2008
2015
1988
1995
2002
2009
2016
Immature males
Obs
Pred
21.sq
21.g
22.1
22.1a
22.1ab
40
80
120
Carapace width (mm)


2019
2021
2022

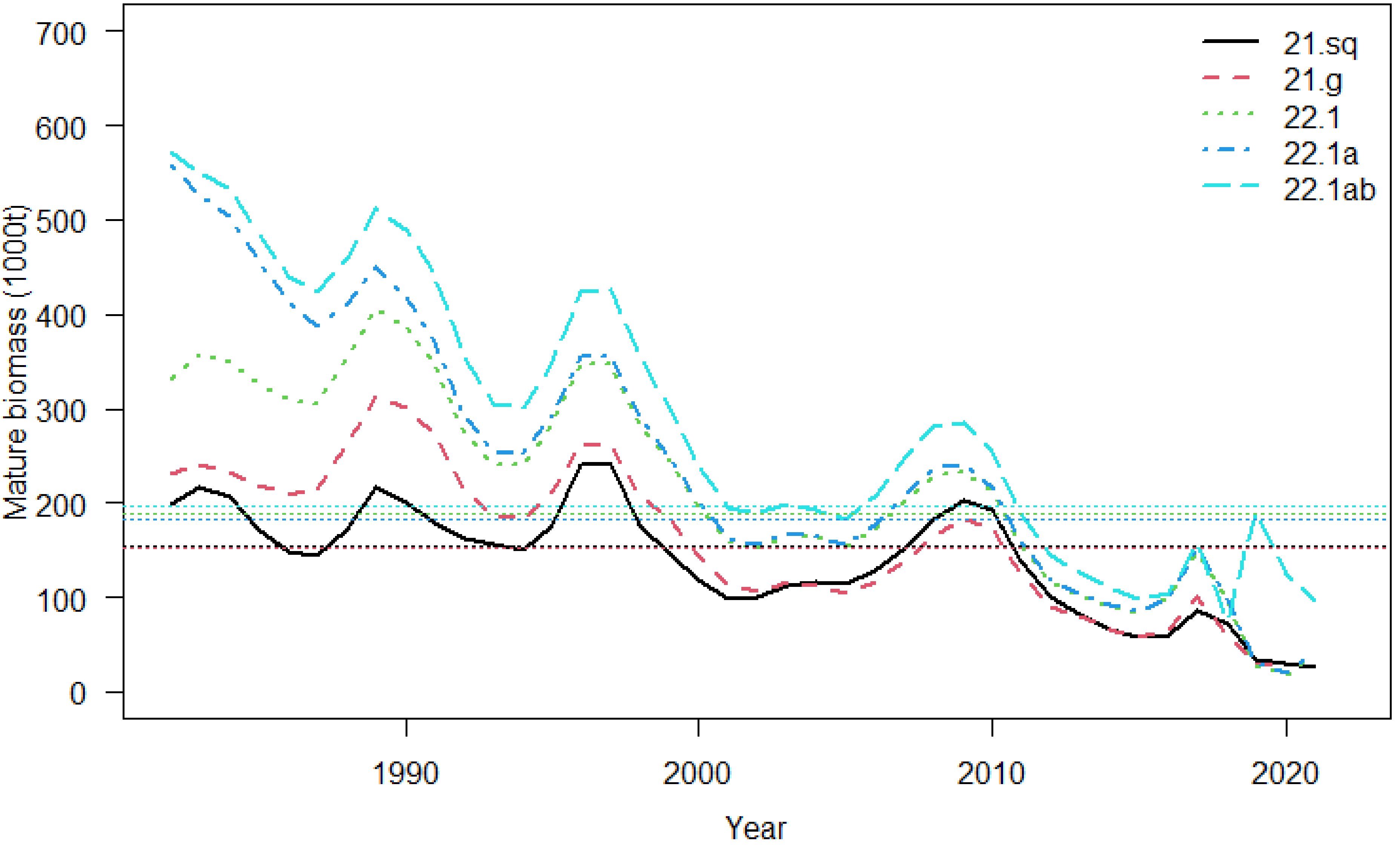


1982
1989
1996
2003
2010
2017
1983
1990
1997
2004
2011
2018
1984
1991
1998
2005
2012
2019
1985
1992
1999
2006
2013
2021
1986
1993
2000
2007
2014
2022
1987
1994
2001
2008
2015
1988
1995
2002
2009
2016
Mature males
Obs
Pred
21.sq
21.g
22.1
22.1a
22.1ab
40
80
120
Carapace width (mm)

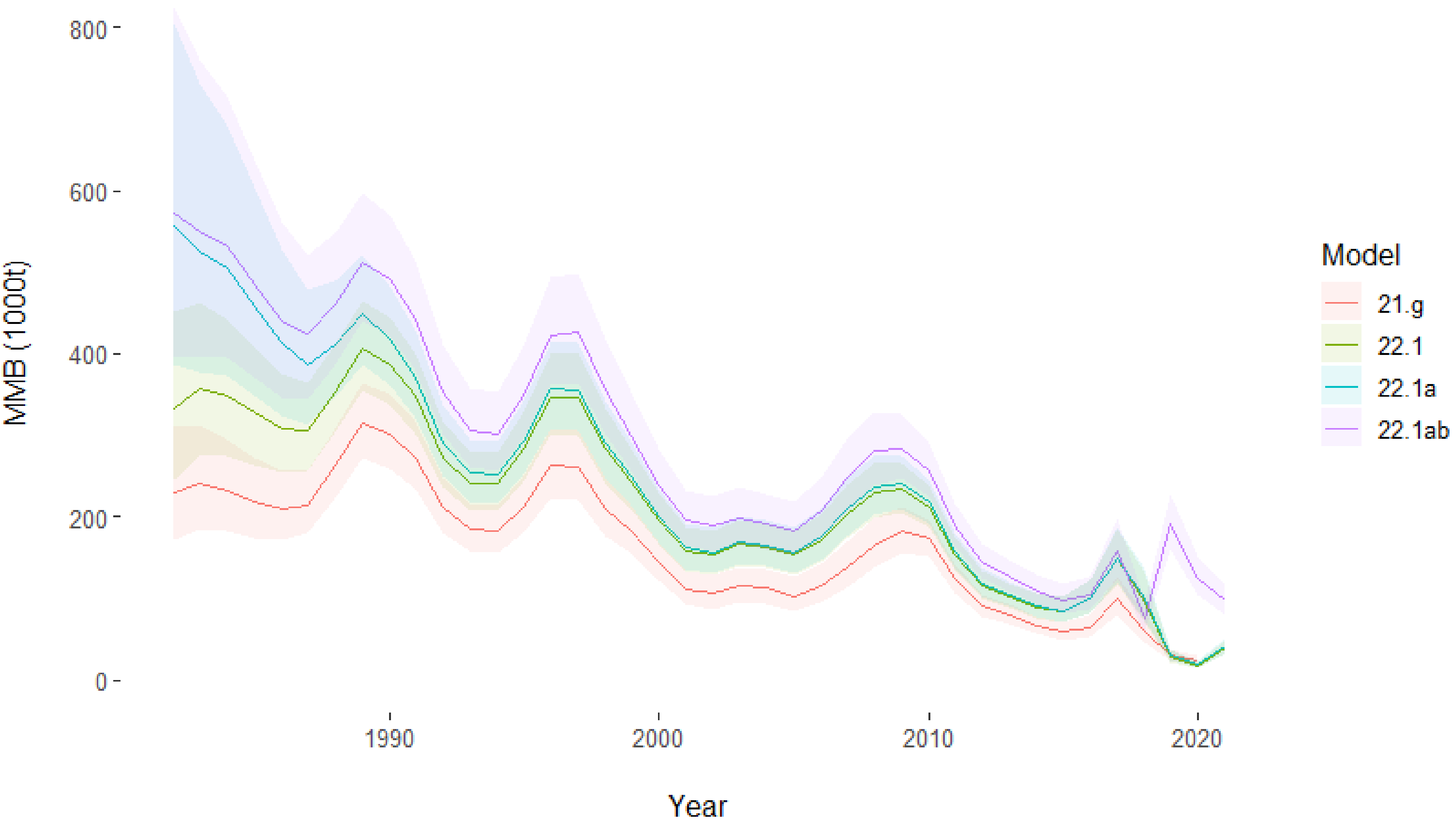


2019
2021
2022

	Model 22.1a		Model 22.1ab	
Fits/Process	**Fits**	**Plausibility**	**Fits**	**Plausibility**
Survey MMB			better	
Growth			better	
Catch			better retained, better discard	
Size comps (catch)	Better to total			
Size comps (survey M)	Better to mature		Better to immature	
Size comps (survey F)				
MMB				
Selectivity				
Maturity				
Fishing mortality				
Recruitment				
Natural mortality				

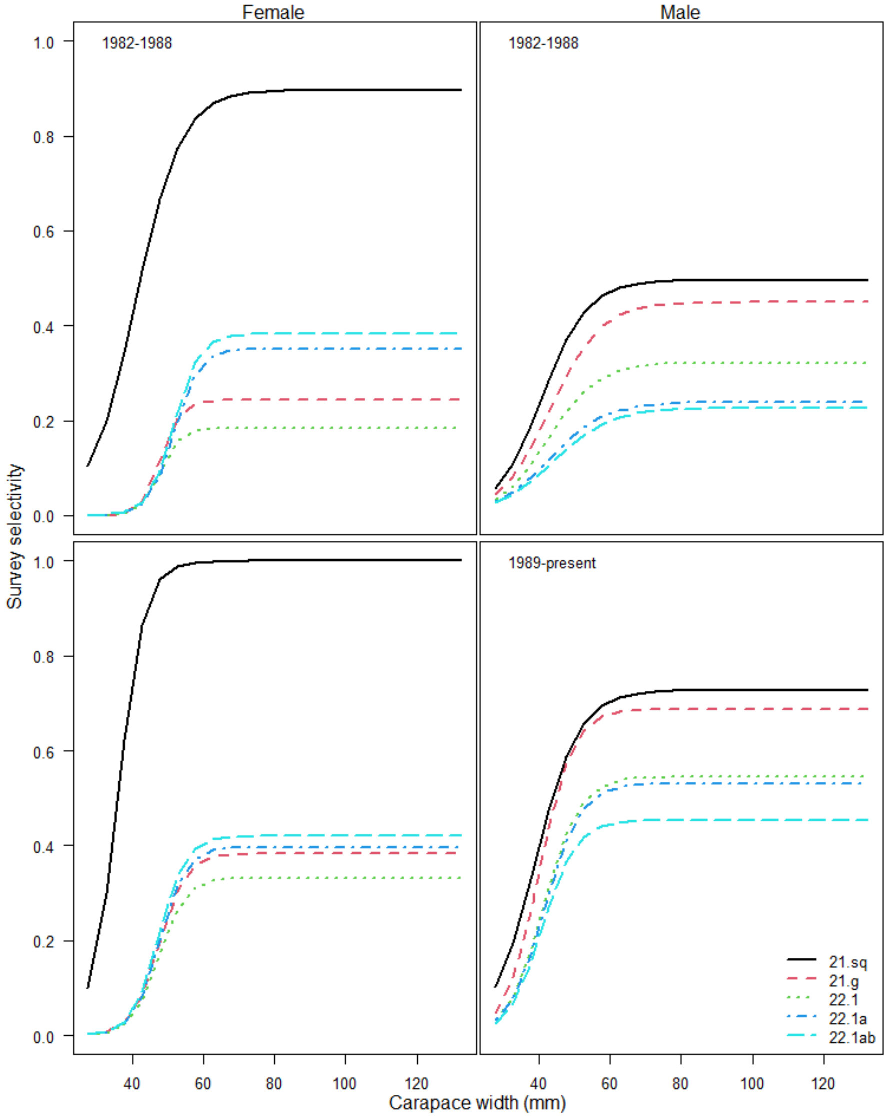


Mature biomass (1000t)
0
100
200
300
400
500
600
700
1990
2000
2010
2020
Year
21.sq
21.g
22.1
22.1a
22.1ab



MMB (1000t)
800
600
400
200
0
1990
2000
2010
2020
Year
Model
21.g
22.1
22.1a
22.1ab

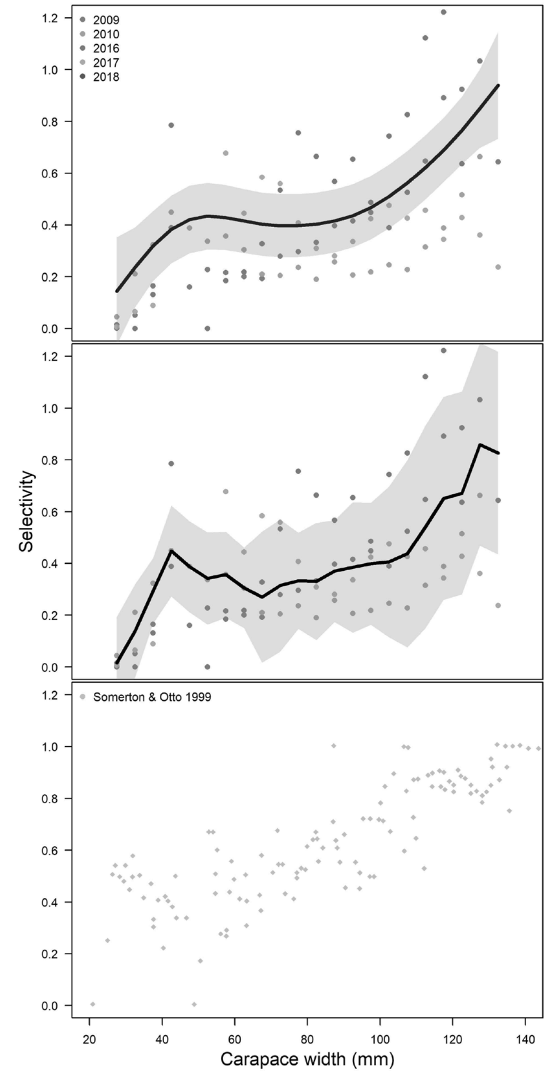
	Model 22.1a		Model 22.1ab	
Fits/Process	**Fits**	**Plausibility**	**Fits**	**Plausibility**
Survey MMB			better	
Growth			better	
Catch			better retained, better discard	
Size comps (catch)	Better to total			
Size comps (survey M)	Better to mature		Better to immature	
Size comps (survey F)	~		~	
MMB		~		~
Selectivity				
Maturity				
Fishing mortality				
Recruitment				
Natural mortality				



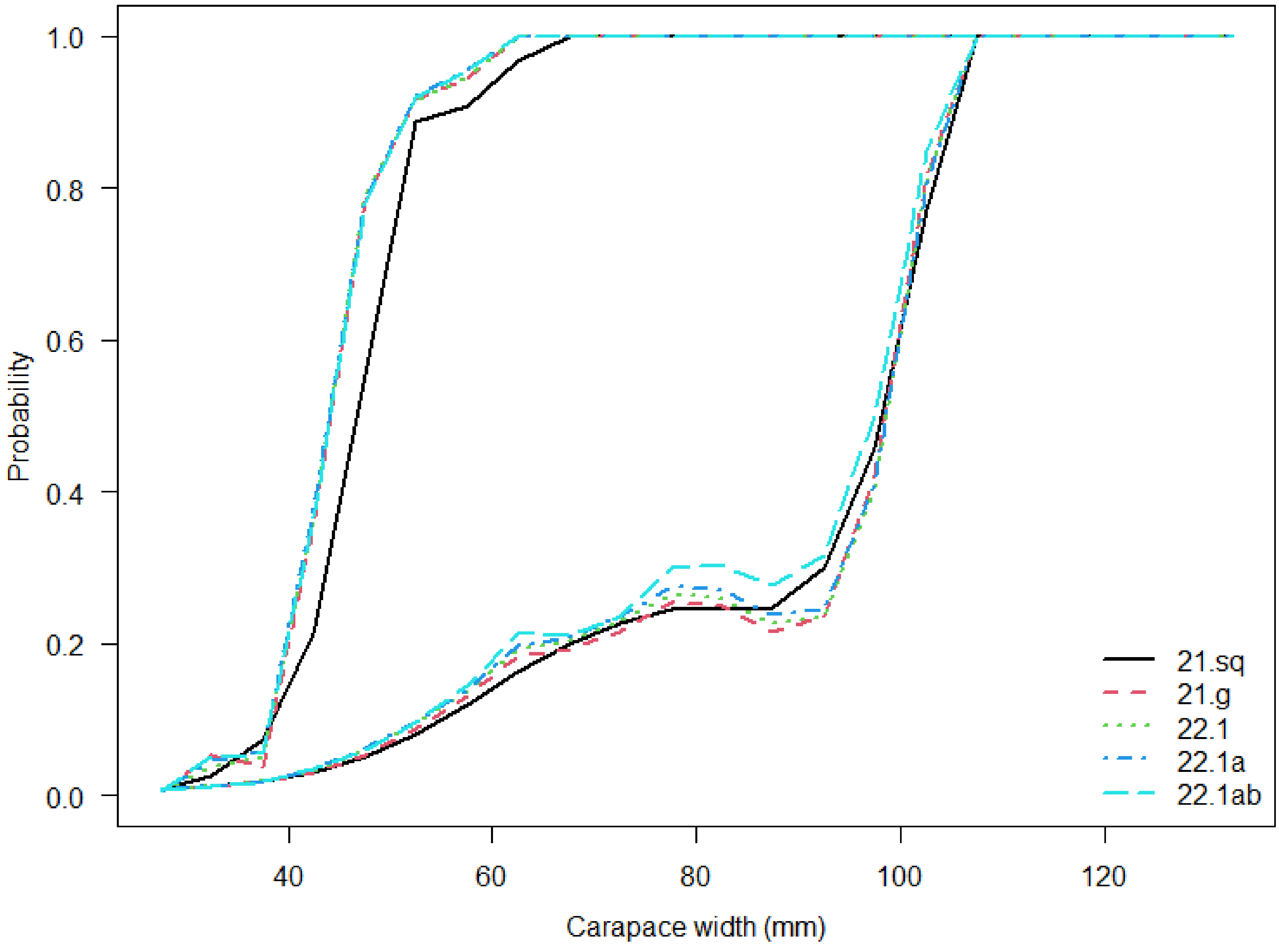
Model 22.1ab estimates of survey q lower than 22.1 or 22.1a, but closer to the implied q of the BSFRF data.

However, the q for large animals is uncertain and this has large impacts on the OFL.

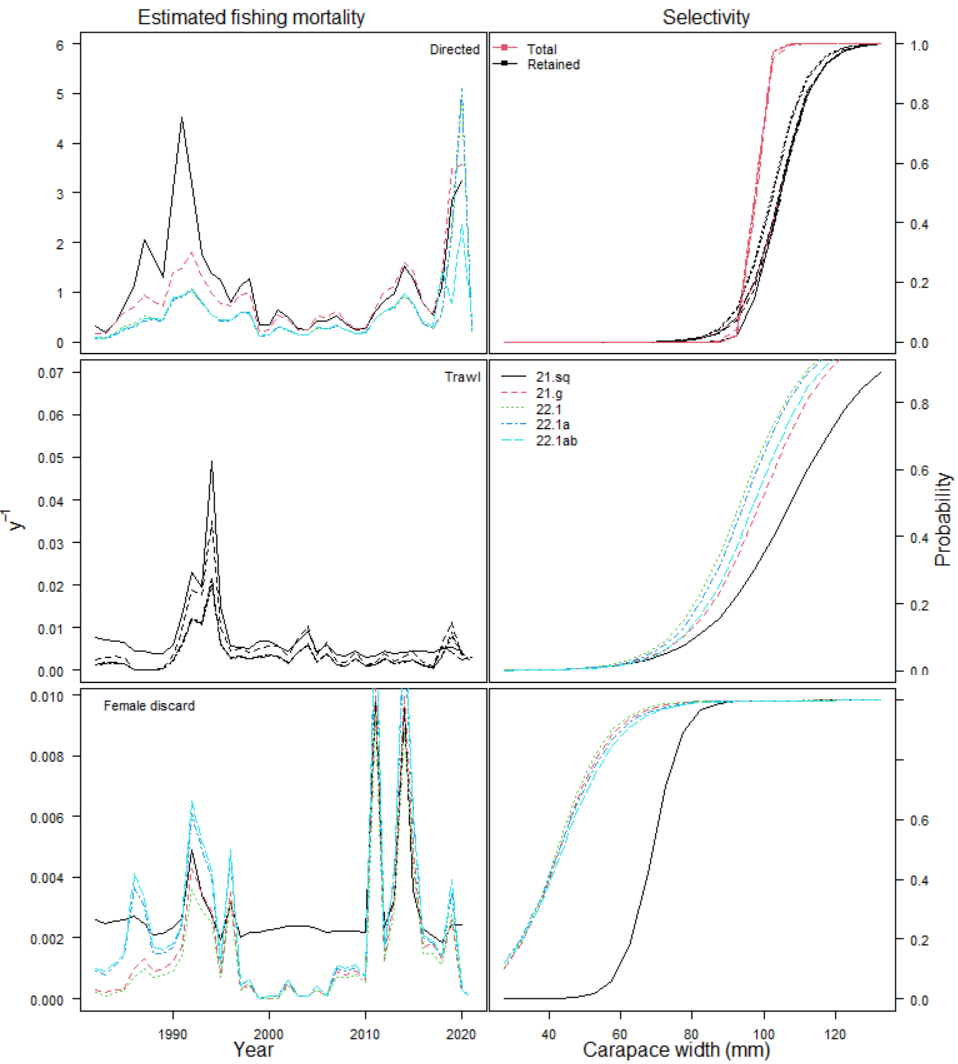
Continued exploration of non-parametric survey selectivity would be useful



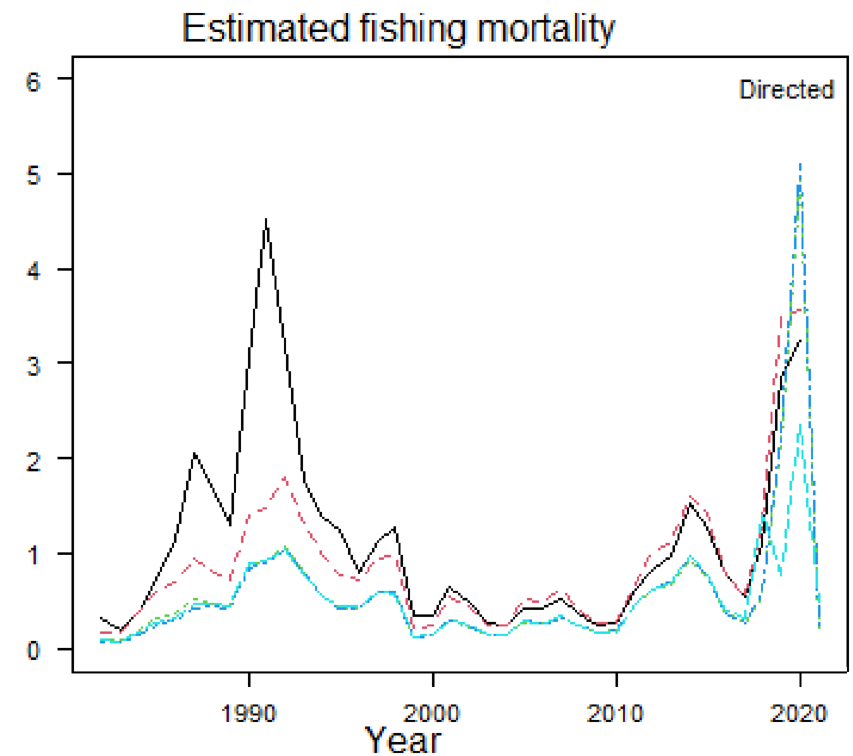
	Model 22.1a		Model 22.1ab	
Fits/Process	**Fits**	**Plausibility**	**Fits**	**Plausibility**
Survey MMB			better	
Growth			better	
Catch			better retained, better discard	
Size comps (catch)	Better to total			
Size comps (survey M)	Better to mature		Better to immature	
Size comps (survey F)	~		~	
MMB		~		~
Selectivity		status quo		BSFRF
Maturity				
Fishing mortality				
Recruitment				
Natural mortality				



1.0
0.8
0.6
0.4
0.2
0.0
Probability
40
60
80
100
120
Carapace width (mm)
21.sq
21.g
22.1
22.1a
22.1ab

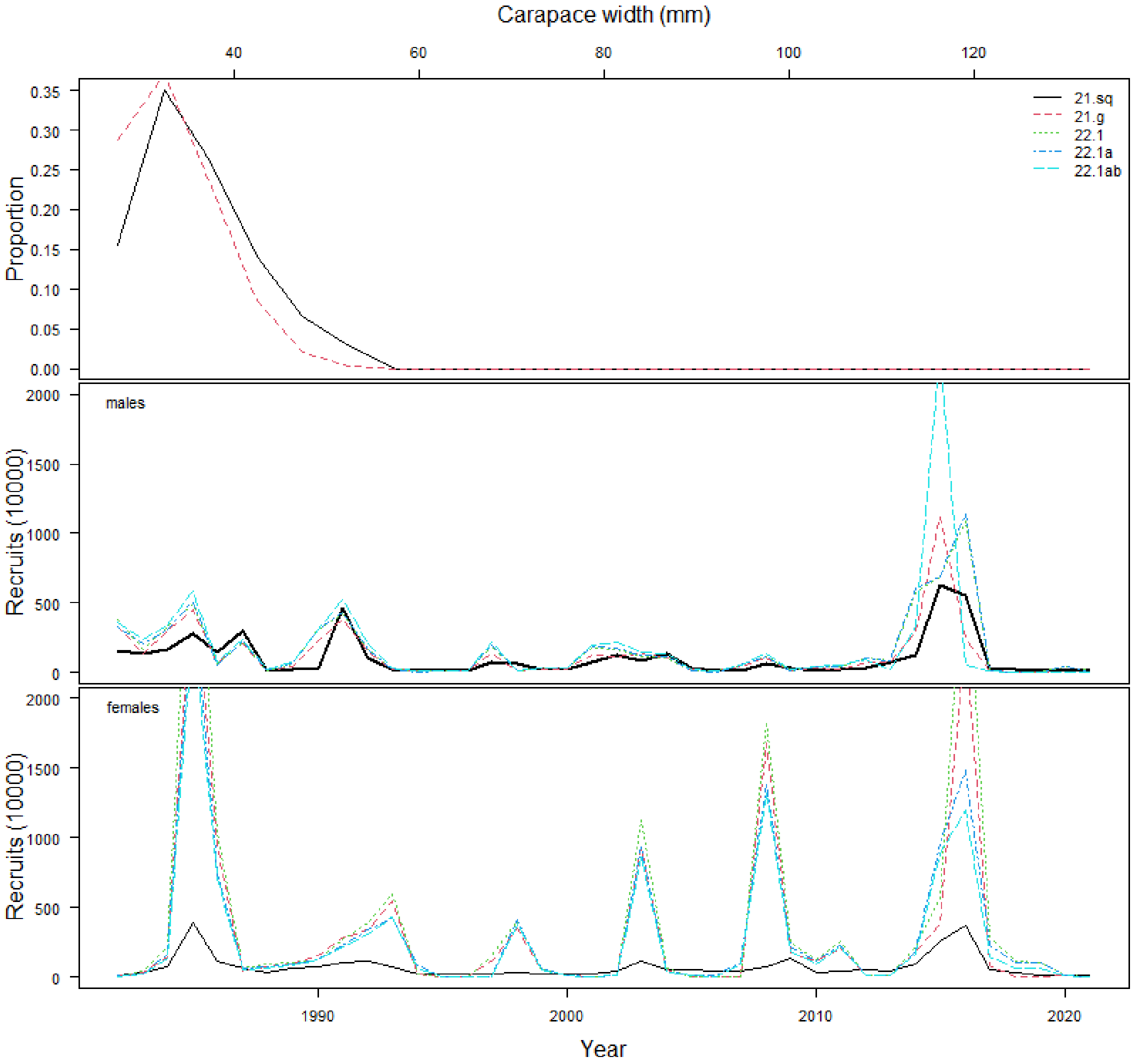


Estimated fishing mortality
Selectivity
Directed
Total
Retained
Trawl
21.sq
21.g
22.1
22.1a
22.1ab
Female discard
y^{-1}
Probability
Year
Carapace width (mm)

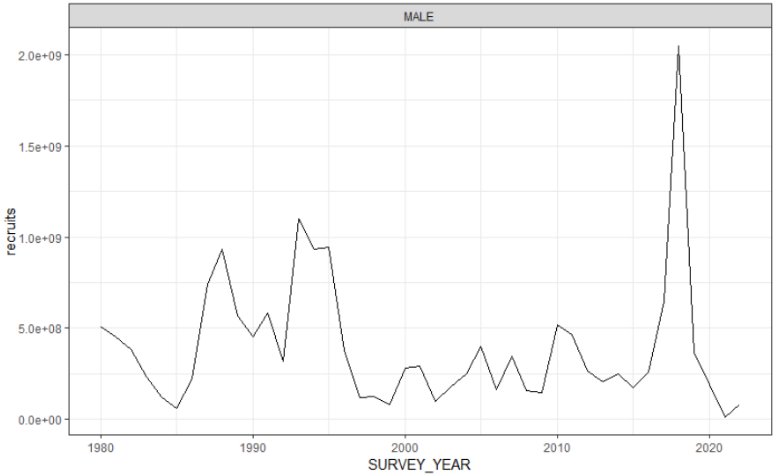


Estimated fishing mortality
Directed
Year

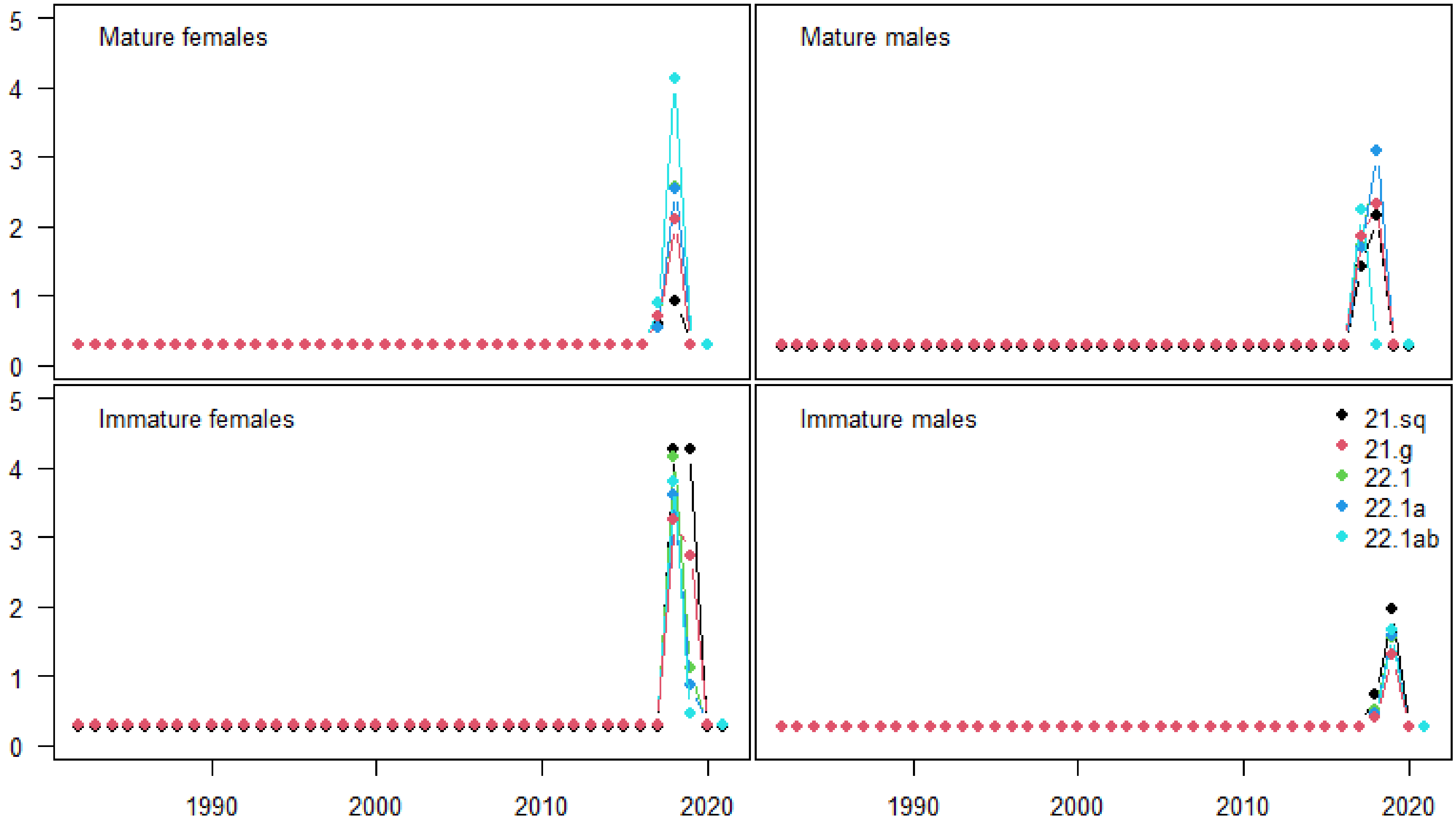
	Model 22.1a		Model 22.1ab	
Fits/Process	**Fits**	**Plausibility**	**Fits**	**Plausibility**
Survey MMB			better	
Growth			better	
Catch			better retained, better discard	
Size comps (catch)	Better to total			
Size comps (survey M)	Better to mature		Better to immature	
Size comps (survey F)	~		~	
MMB		~		~
Selectivity		status quo		BSFRF
Maturity		~		~
Fishing mortality		99.5% removals not plausible		
Recruitment				
Natural mortality				



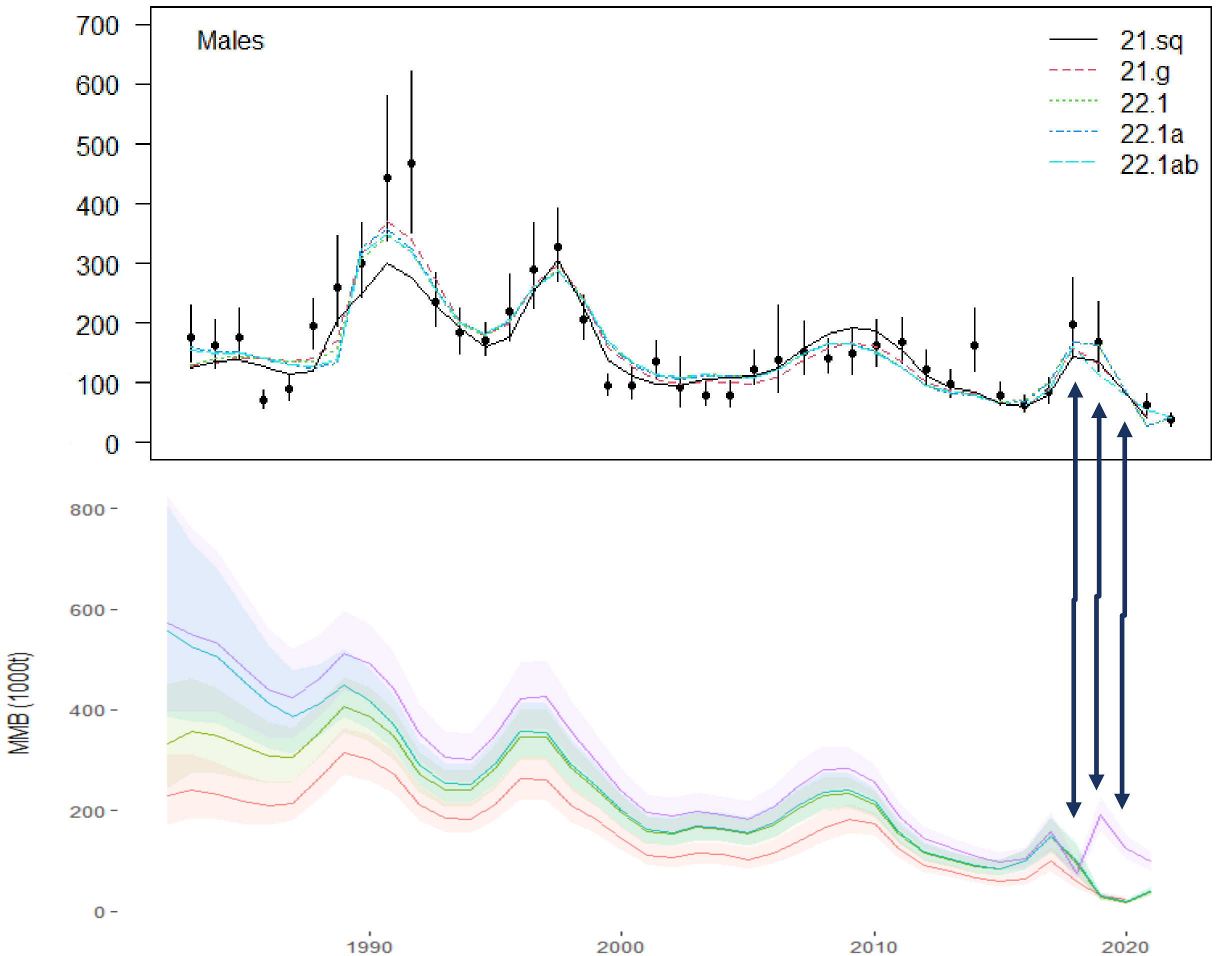
Observed males
50 < carapace width < 60



	Model 22.1a		Model 22.1ab	
Fits/Process	**Fits**	**Plausibility**	**Fits**	**Plausibility**
Survey MMB			better	
Growth			better	
Catch			better retained, better discard	
Size comps (catch)	Better to total			
Size comps (survey M)	mature		immature	
Size comps (survey F)	~		~	
MMB		~		~
Selectivity		status quo		BSFRF
Maturity		~		~
Fishing mortality		implausible		
Recruitment		3 years		2015 recruit
M				



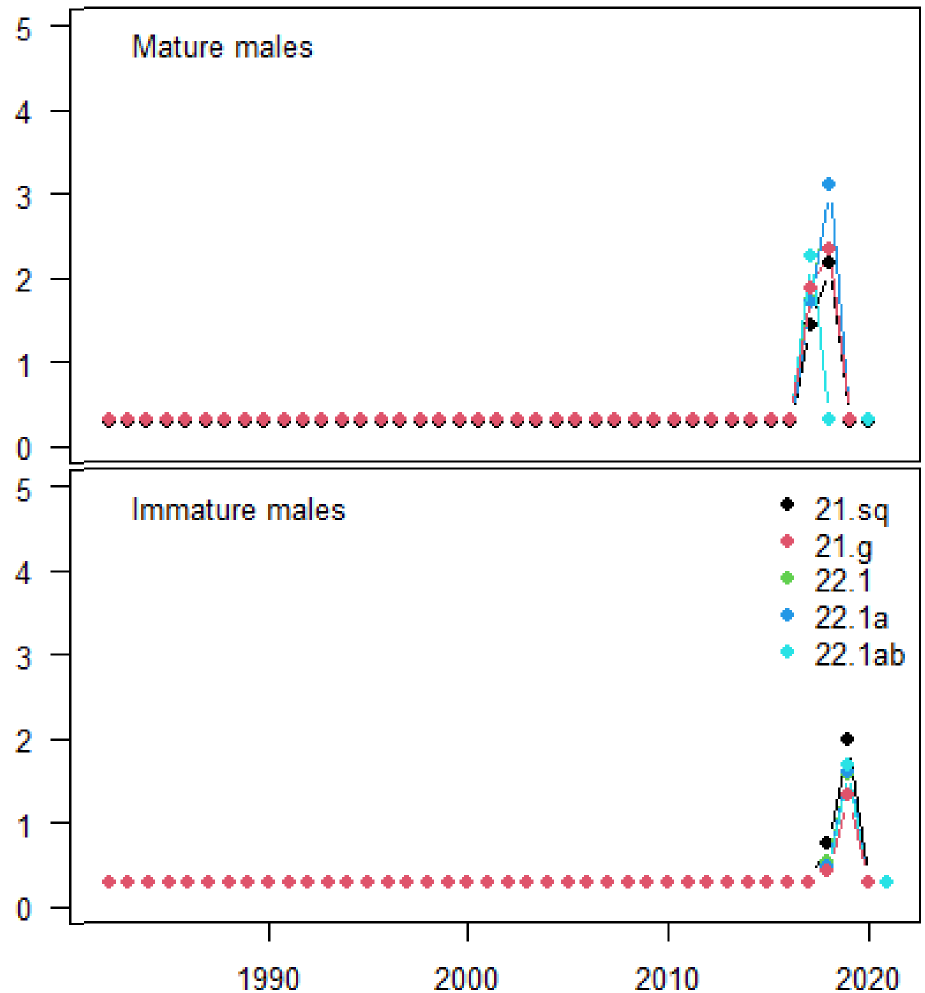
Mature females
Mature males
Immature females
Immature males
21.sq
21.g
22.1
22.1a
22.1ab
0
1
2
3
4
5
1990
2000
2010
2020



Two potential histories:

22.1a:
- ~3 recruitments
- Two large mortalities
- Implausibly high F

22.1ab:
- One recruitment
- One large mortality
- Reasonable Fs



Two potential histories:

22.1a:

~3 recruitments

Two large mortalities

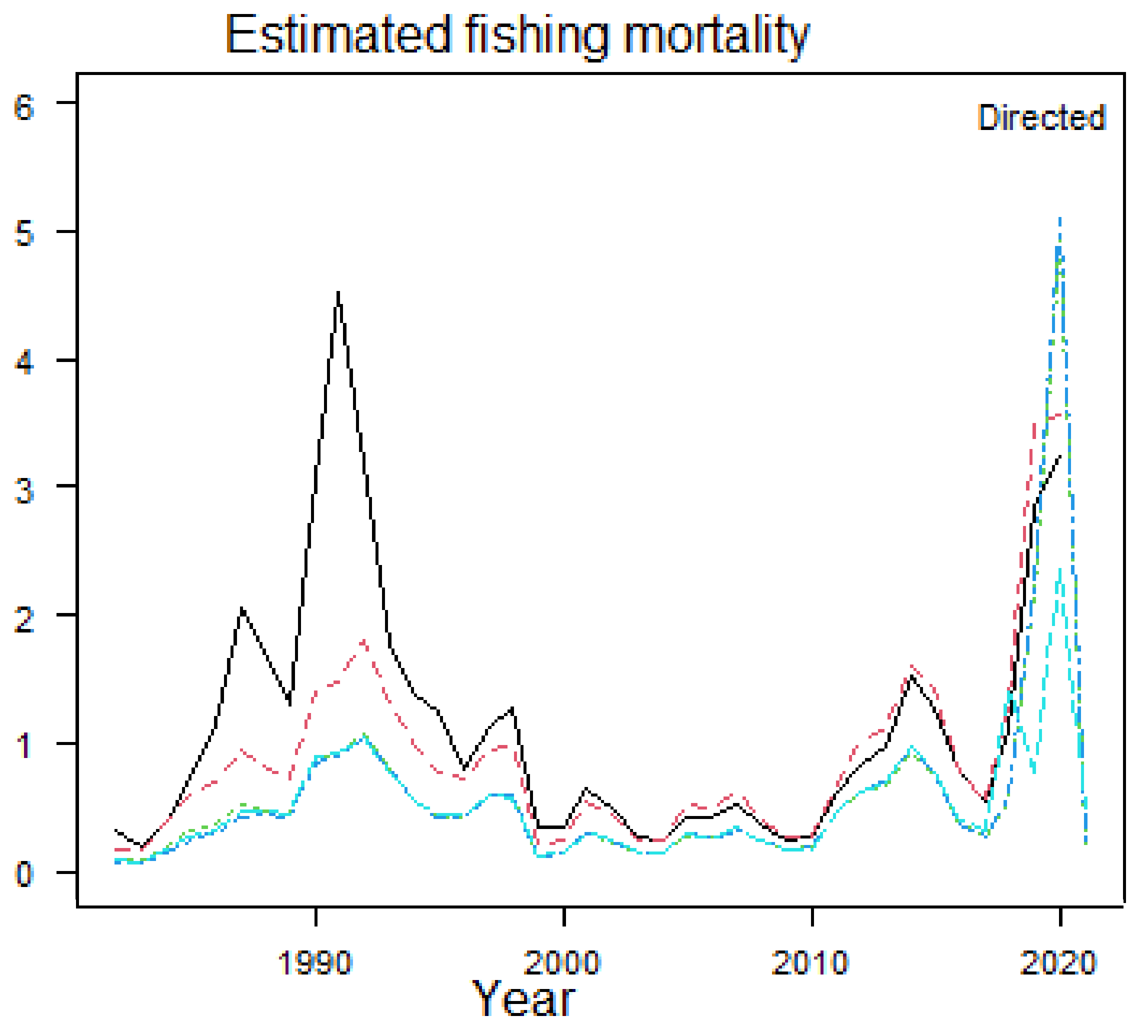
Implausibly high F

22.1ab:

One recruitment

One large mortality

Reasonable Fs



Two potential histories:

22.1a:

~3 recruitments

Two large mortalities

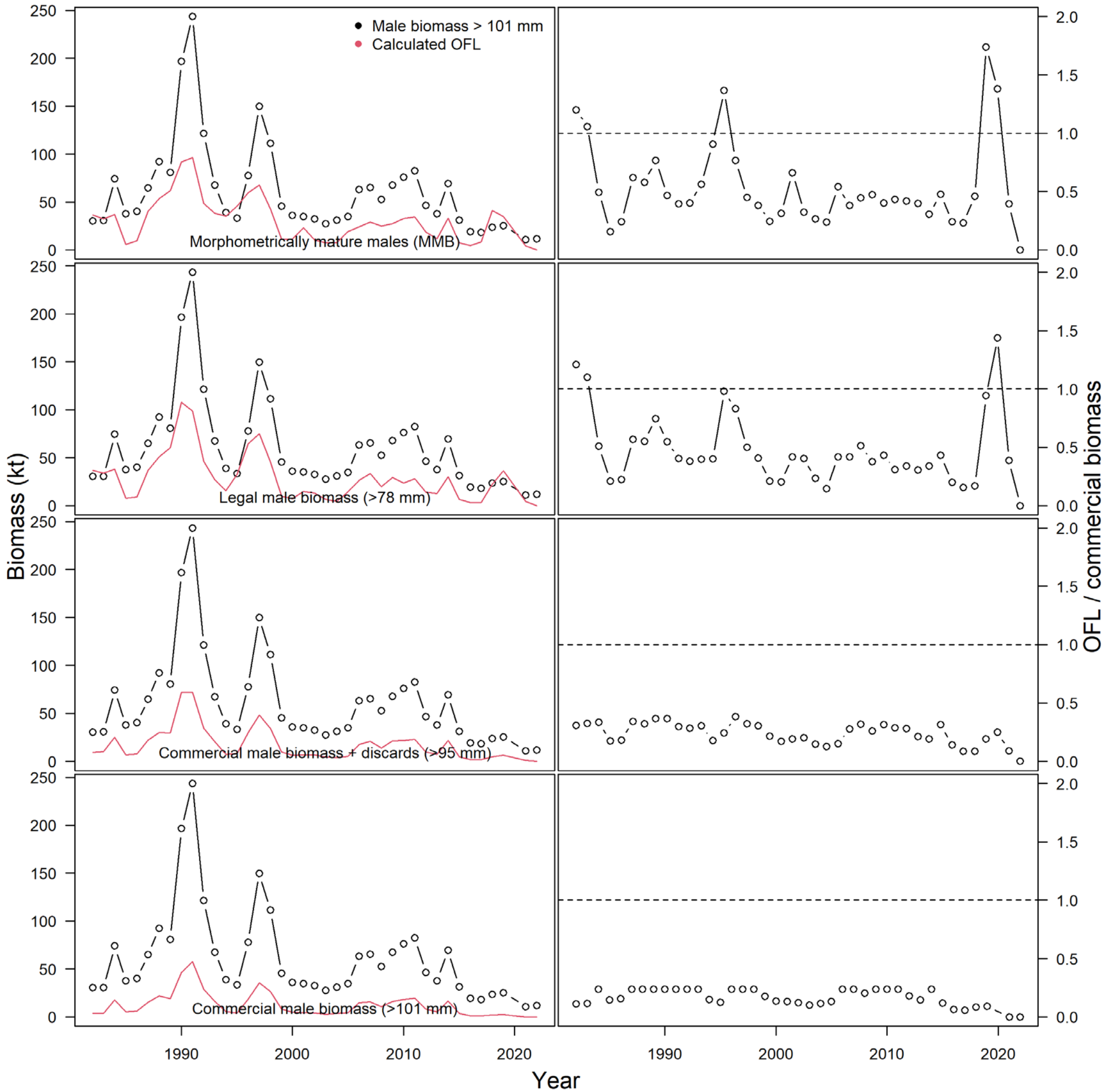
Implausibly high F

22.1ab:

One recruitment

One large mortality

More reasonable Fs



Tier 4

FMP guidance says 'Current biomass' should be a proxy for reproductive potential

BMSY based on 1982-2021

FMSY = 0.27 (M)

All 4 proxies resulted in a closed fishery

Short-comings:

- Not vetted + little discussion
- Lack population dynamics between survey and fishery
- Time period for BMSY not discussed

22.1ab Pros

- No unrealistic fishing mortality in 2020
- Decrease in survey q closer to BSFRF implied q
- Timing of 2015 recruitment matches the survey observations
- Fit more of the likelihood components better

22.1ab Cons

- Not the best overall fit (but size composition over-weighted)
- Decrease in survey q a fairly large departure from the status quo ('how could MMB go up if the survey went down?')
- Larger recruitment event in 2015 than observed

Trade-offs

- Large fishing mortality vs. large recruitment vs. mortality events
- Fits to size composition data

Overarching issues

- No 2020 data
- Probability of having undergone terminal molt
- Two weeks is not enough time to do an assessment when problems arise

Model	MMB	B35	F35	FOFL	OFL	M	avg_rec	Status
21.sq	26.74	153.42	1.43	0.37	7.50	0.27	106.14	0.17
21.g	23.71	153.33	1.59	0.36	7.89	0.28	131.71	0.15
22.1	39.85	189.12	1.37	0.28	9.06	0.28	161.82	0.21
22.1a	41.21	183.15	1.50	0.32	10.32	0.28	164.02	0.23
22.1ab	96.67	196.38	2.26	0.67	3.98	0.29	180.36	0.49

Among the updated models, 22.1a or 22.1ab are both an improvement over 22.1

Given the listed pros and cons,
22.1ab was the author-preferred model

CPT RECOMMENDATIONS

Tier 3 stock using Model 22.0a – MLE estimate

- CPT could not find scientific basis for choosing a model solution that differed from MLE
- Consistent with our past processes
- Concern with high fishing mortality estimate in 2020/21 with this model
  - Comes right after high mortality 2018, 2019
  - Lack of 2020 survey data leads to uncertainties associated with timing and the dynamics of the snow crab collapse
  - Caution with overinterpreting this result, potential for mixed population fishing near border with Russia brought up in public comment

TIER DISCUSSION

Discussion of Tier 4 specification from survey data

- Used on four metrics of males from survey data, currently use morphometrically mature male biomass
- Discussion would be needed to determine which metric to use in a survey-only Tier 4 specification.
- OFL calculated using Tier 4 survey data exceeded the estimated biomass of commercially targeted males in some years (not ideal)

CPT concluded that life history information remains adequate for estimating reference points, stock should remain in Tier 3

- Use of ABC buffer considers model uncertainties or potential misspecifications
- Increasing a buffer could account for model uncertainties at times of instability

ABC BUFFER RECOMMENDATIONS

25% buffer recommended (same as 2021)

- Concern over lack of model vetting (reduced but still present)
- Presence of multiple minima in likelihood surface and irregular model convergence
- Timing of mortality event and relative attribution to ecological/environmental process or fishing mortality still uncertain
- Retrospective patterns

SNOW CRAB REBUILDING

CPT PREFERRED MODEL

- CPT recommended model 22.1a, which is a different model than projections were performed (22.1ab)
- Projections from 22.1ab can still be useful strategically and projections from 22.1a were similar in character
- Projected population status
  - Model 22.1a : 0.30
  - Model 22.1ab : 0.36
- Added a figure and table from 22.1a, but no unobserved bycatch

DISCUSSION POINTS

Rebuilding specifications

Rebuilding projections

Unobserved mortality

Projection selection

PROJECTION SPECIFICATIONS

- Performed in GMACS
- Include updated data to 2022
- 2000 iterations per scenario
- Started from the local minimum of 22.1ab for the document
    - One run from 22.1a was included after discussion at the plan team
- Sample natural mortality and recruitment from a range of years
- No stochasticity in initial status or parameter values

PROJECTION SCENARIOS

Productivity

- Sample M and recruitment from two time periods
- 1982-2017: More optimistic case; no mortality events.
- 2005-2019: Most recent period of alternating warm/cool with 1 in 7 chance of mortality event.
- Three target biomasses presented
  - 1982-2021 (status quo)
  - 1982-2017 (productivity scenario 1)
  - 2005-2019 (productivity scenario 2)
  - No additional mortality events are considered in target biomass

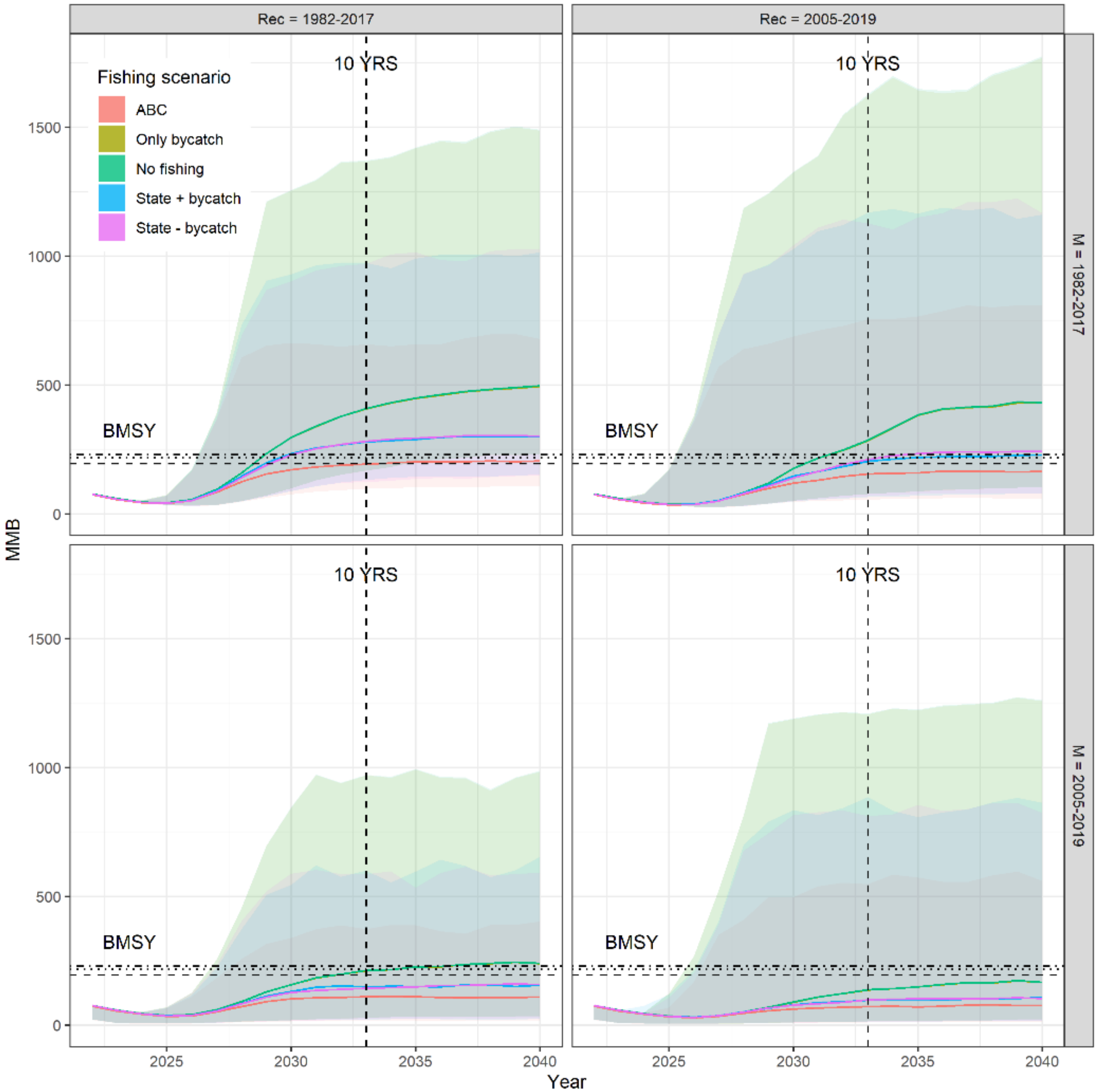
Fishing

- No fishing
- Bycatch only
- State HCR – bycatch
  - State HCR set as a fraction of the calculated ABC
  - Fraction was determined by the average ratio between TAC and ABC over the last 10 years
- State HCR + bycatch
- ABC: 25% buffer on OFL
  - OFL is calculated based on known population parameter values

Unobserved mortality

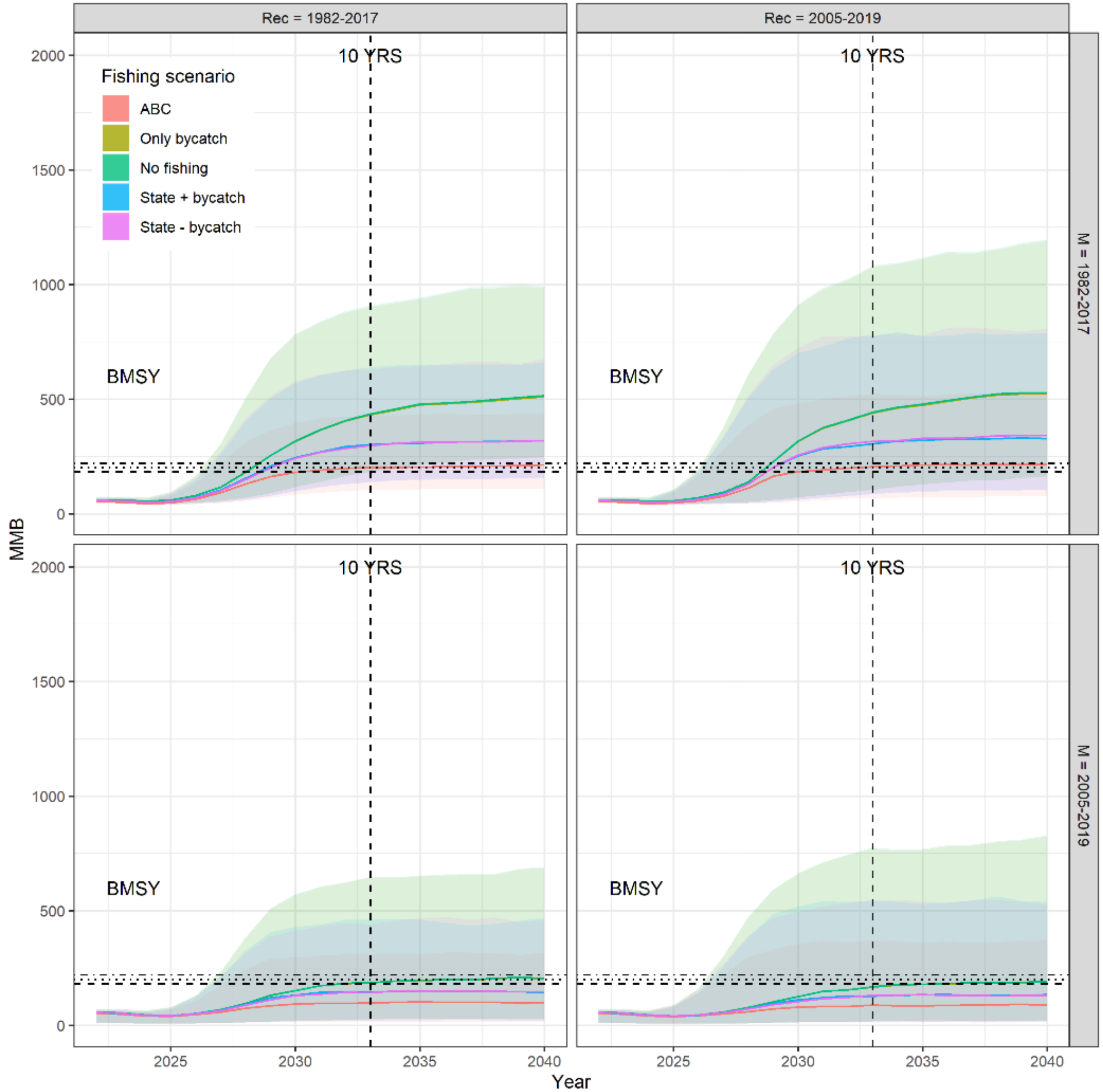
- 5x bycatch
- 100x bycatch
- How to consider unobserved mortality (in the assessment or the rebuilding plan) would need some thought

PROJECTIONS (22.1AB)



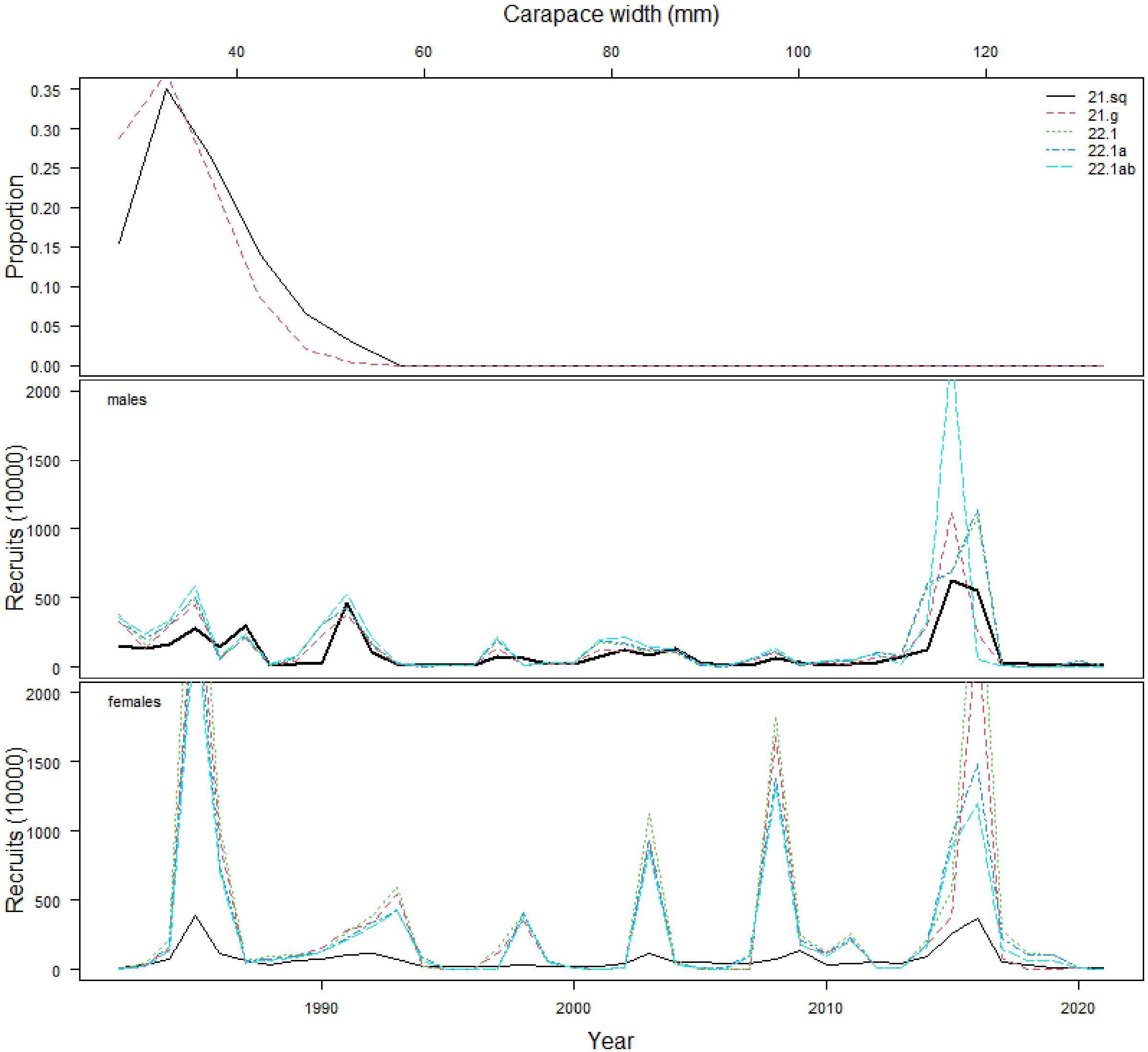
- Scenarios with and without bycatch are indiscernible from one another
- 2005-2019 rebuilds more slowly, but has similar average recruitment
- Mortality events prevent the stock from rebuilding when paired with recent recruitment
- Tmin ranged from 2029 to never depending on scenario as a result of infrequent large recruitments + more frequent mortality events

PROJECTIONS (22.1A)



- Smaller scale than 22.1ab because of the magnitude of the 2015 estimated recruitment
- Average recruitment from both periods are similar
- Tmin ranged from 2029 to never depending on scenario

RECRUITMENT INFLUENCED SCALE



Estimated recruitment from the different jitter modes in the sampled time periods were different, which impacted the scale of projected populations and the trajectory shape of rebuilding

TABLES FOR TMIN (MODEL 22.1AB)

Fishing	Recruitment	Natural mortality	BMSY_sq	BMSY_17	BMSY_19
No fishing	Rec = 1982-2017	M = 1982-2017	2029	2029	2029
No fishing	Rec = 1982-2017	M = 2005-2019	2032	2035	2037
No fishing	Rec = 2005-2019	M = 1982-2017	2031	2032	2032
No fishing	Rec = 2005-2019	M = 2005-2019	Inf	Inf	Inf
ABC	Rec = 1982-2017	M = 1982-2017	2034	Inf	Inf
ABC	Rec = 1982-2017	M = 2005-2019	Inf	Inf	Inf
ABC	Rec = 2005-2019	M = 1982-2017	Inf	Inf	Inf
ABC	Rec = 2005-2019	M = 2005-2019	Inf	Inf	Inf
bycatch	Rec = 1982-2017	M = 1982-2017	2029	2029	2029
bycatch	Rec = 1982-2017	M = 2005-2019	2032	2035	2037
bycatch	Rec = 2005-2019	M = 1982-2017	2031	2032	2032
bycatch	Rec = 2005-2019	M = 2005-2019	Inf	Inf	Inf
State + bycatch	Rec = 1982-2017	M = 1982-2017	2029	2030	2030
State + bycatch	Rec = 1982-2017	M = 2005-2019	Inf	Inf	Inf
State + bycatch	Rec = 2005-2019	M = 1982-2017	2033	2035	Inf
State + bycatch	Rec = 2005-2019	M = 2005-2019	Inf	Inf	Inf
State - bycatch	Rec = 1982-2017	M = 1982-2017	2030	2030	2030
State - bycatch	Rec = 1982-2017	M = 2005-2019	Inf	Inf	Inf
State - bycatch	Rec = 2005-2019	M = 1982-2017	2033	2034	2035
State - bycatch	Rec = 2005-2019	M = 2005-2019	Inf	Inf	Inf

TABLES FOR TMIN (MODEL 22.1A)

Fishing	Recruitment	Natural mortality	BMSY_sq	BMSY_17	BMSY_19
No fishing	Rec = 1982-2017	M = 1982-2017	2029	2029	2029
No fishing	Rec = 1982-2017	M = 2005-2019	2032	2038	Inf
No fishing	Rec = 2005-2019	M = 1982-2017	2029	2029	2029
No fishing	Rec = 2005-2019	M = 2005-2019	2036	Inf	Inf
ABC	Rec = 1982-2017	M = 1982-2017	2031	2034	Inf
ABC	Rec = 1982-2017	M = 2005-2019	Inf	Inf	Inf
ABC	Rec = 2005-2019	M = 1982-2017	2031	2033	Inf
ABC	Rec = 2005-2019	M = 2005-2019	Inf	Inf	Inf
bycatch	Rec = 1982-2017	M = 1982-2017	2029	2029	2029
bycatch	Rec = 1982-2017	M = 2005-2019	2032	2038	Inf
bycatch	Rec = 2005-2019	M = 1982-2017	2029	2029	2029
bycatch	Rec = 2005-2019	M = 2005-2019	2036	Inf	Inf
State + bycatch	Rec = 1982-2017	M = 1982-2017	2029	2029	2030
State + bycatch	Rec = 1982-2017	M = 2005-2019	Inf	Inf	Inf
State + bycatch	Rec = 2005-2019	M = 1982-2017	2029	2030	2030
State + bycatch	Rec = 2005-2019	M = 2005-2019	Inf	Inf	Inf
State - bycatch	Rec = 1982-2017	M = 1982-2017	2029	2030	2030
State - bycatch	Rec = 1982-2017	M = 2005-2019	Inf	Inf	Inf
State - bycatch	Rec = 2005-2019	M = 1982-2017	2029	2030	2030
State - bycatch	Rec = 2005-2019	M = 2005-2019	Inf	Inf	Inf

UNOBSERVED MORTALITY

	Model	MMB	B35	F35	FOFL	OFL	M	avg_rec	Status
1	21.sq	26.74	153.42	1.43	0.37	7.50	0.27	106.14	0.17
3	22.1a	41.21	183.15	1.50	0.32	10.32	0.28	164.02	0.23
4	22.1ab	96.67	196.38	2.26	0.67	3.98	0.29	180.36	0.49
5	22.1ab_5x	83.31	204.62	1.49	0.35	2.79	0.28	181.00	0.41
6	22.1ab_100x	115.65	336.36	1.12	0.19	4.79	0.28	265.29	0.34

- It’s clear that there must be unobserved mortality (see Dr. Rose’s ppt from May CPT and public comment)
- It’s hard to make a case that unobserved mortality is a large driver of recent population dynamics given we just saw the largest cohort ever establish in the Bering Sea.
- Still, our only management levers are modifying fishing mortality in the directed and non-directed fisheries, so this deserves attention.

- Similar OFLs from models with different amounts of unobserved bycatch
- The difference comes in the amount of the OFL allocated to the directed fishery—F35 decreases as unobserved mortality increases
- If the OFL is similar for a given scenario, adding unobserved mortality just decreases the amount of the OFL allocated to the directed fishery.
- Needs a retrospective analysis to understand potential impacts more fully

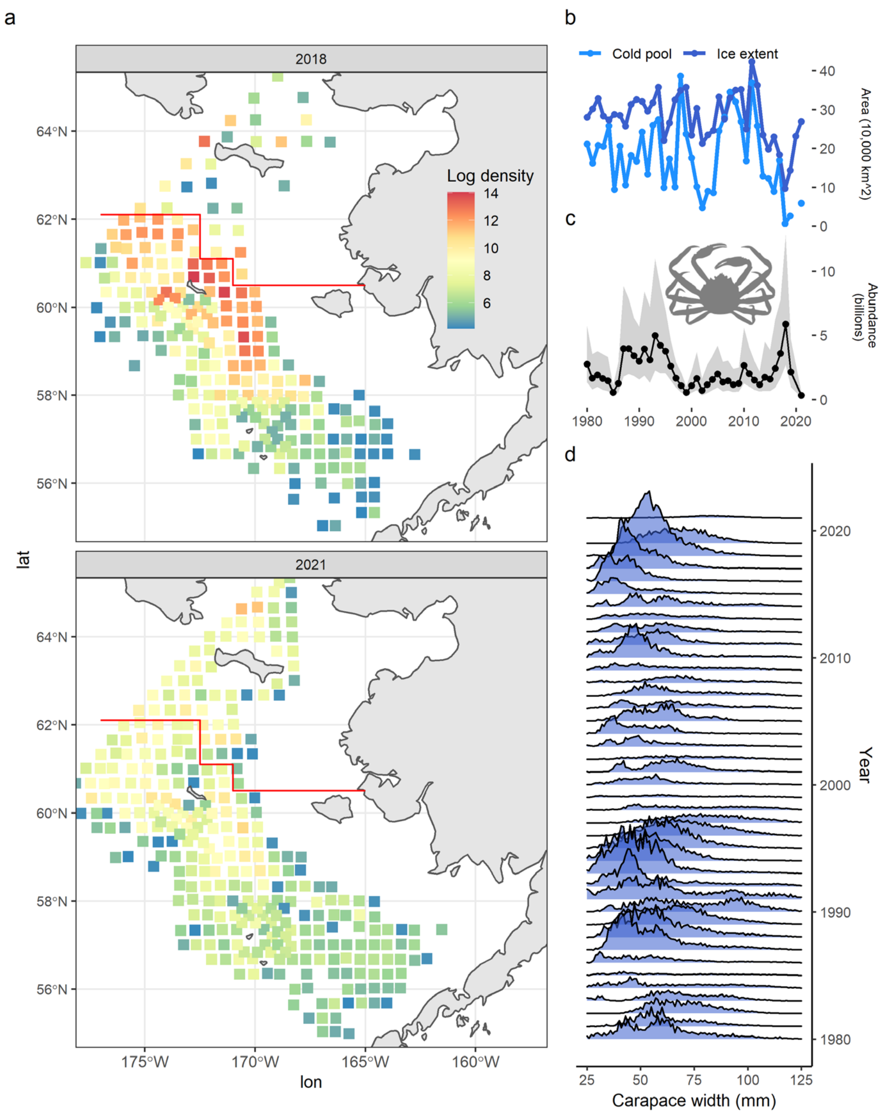
PROJECTION SELECTION

Natural mortality

Recruitment

Unobserved mortality

COLLAPSE OF SNOW CRAB



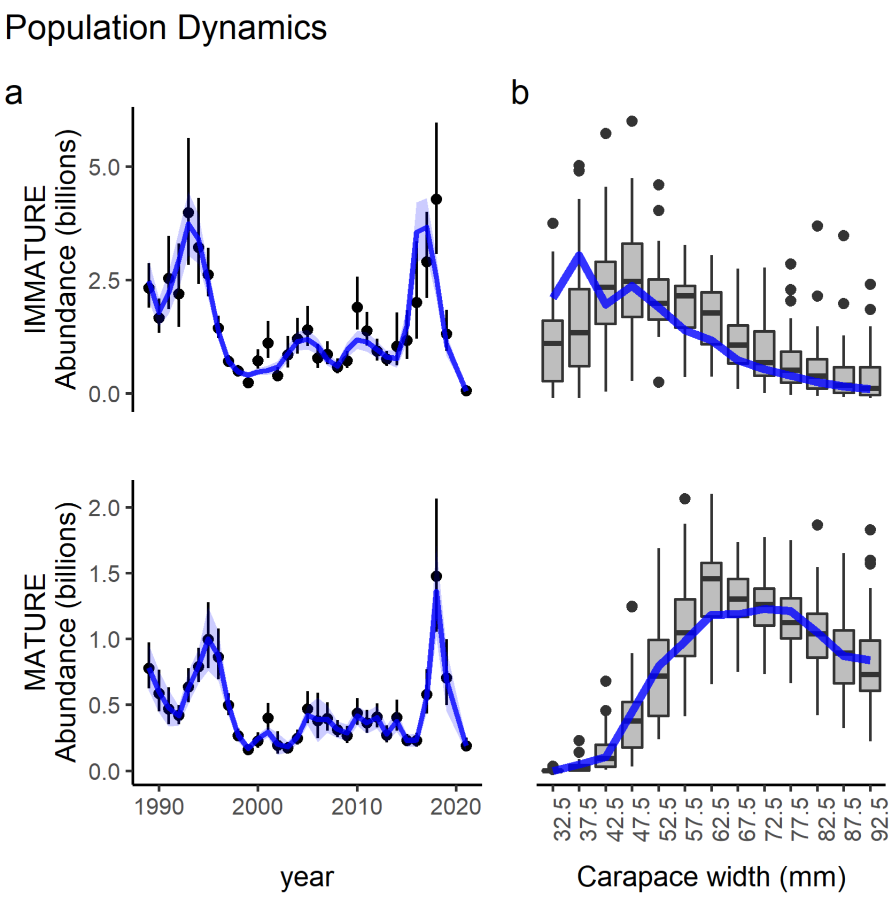
More crab than ever in 2018, fewer crab than ever in 2021, even fewer in 2022 (a, c)

Disappearance of crab was not size dependent (d)

Cold pool was the smallest on record in 2018 and barely larger in 2019 (b)

The stock was declared overfished and a rebuilding plan is underway

ESTIMATE TIME-VARYING TOTAL MORTALITY



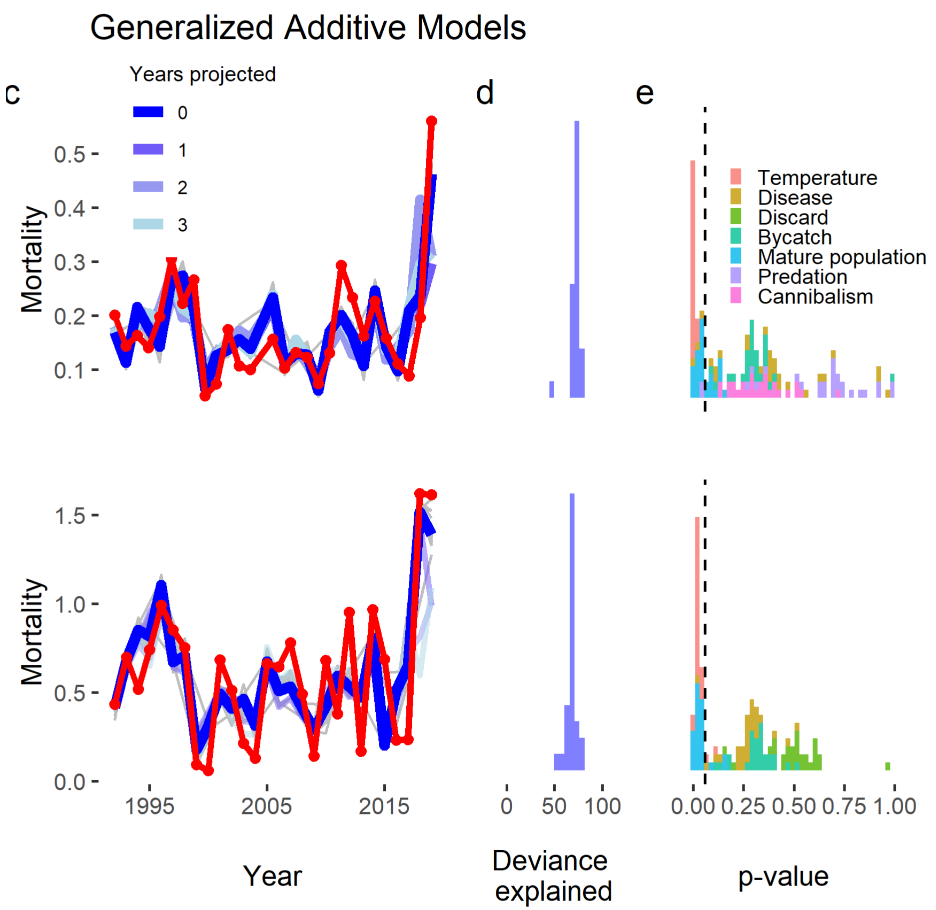
- Population dynamics model
- Male only
- 30-95 mm carapace width
- Total mortality, recruitment, initial numbers at size were estimated parameters
- Growth, maturity, and survey selectivity specified based on experimental data
- Simulation studies to evaluate ability of the model to estimate mortality

Estimated mortality from fits to the simulated data were highly correlated.

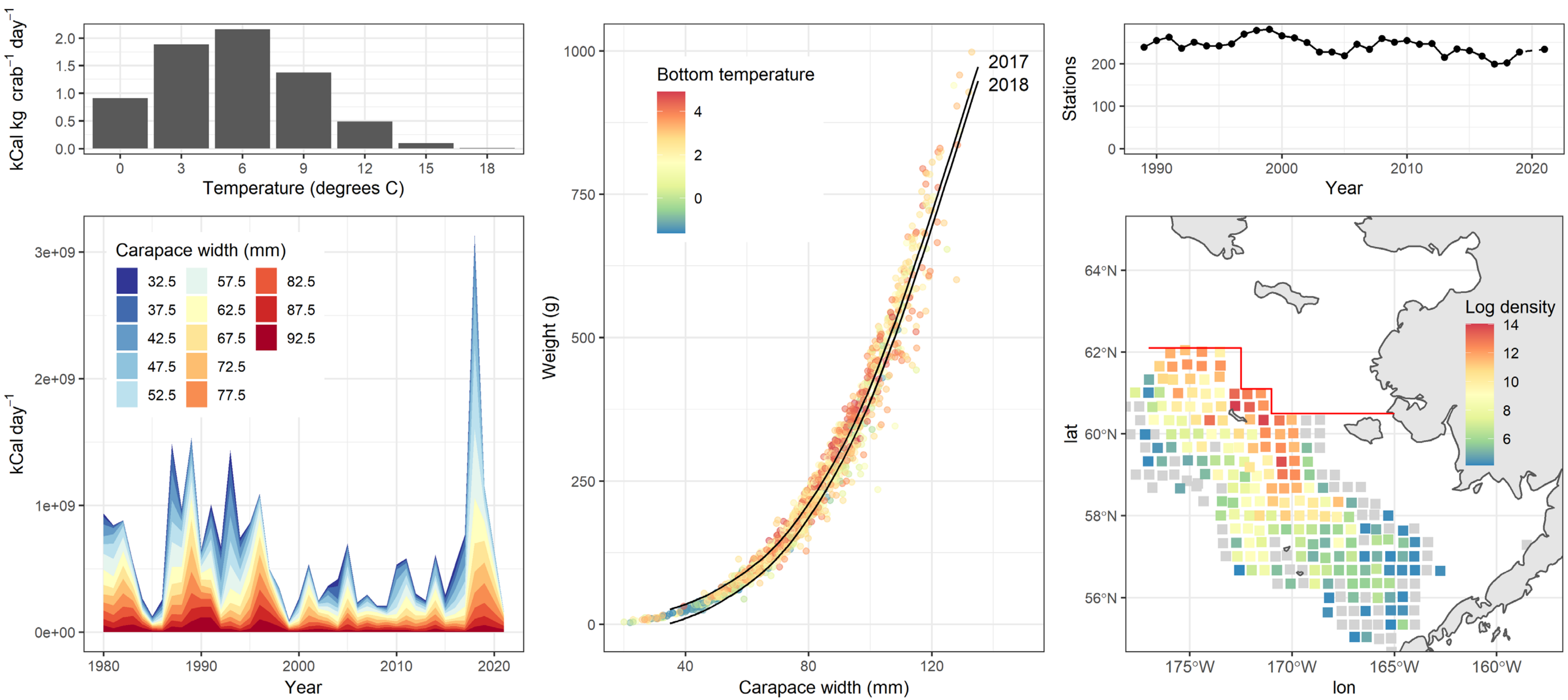
RELATE ESTIMATED MORTALITY TO ENVIRONMENTAL STRESSORS

- Generalized additive models
- Covariate construction
  - Temperature occupied
  - Disease prevalence
  - Discards in directed fishery
  - Cannibalism
  - Bycatch in other fisheries
  - Mature population density
  - Predation by Pacific cod
- Cross-validation
- Prediction capabilities

Temperature and **mature population density** were the consistently significant covariates.



HIGH CALORIC REQUIREMENTS AND SMALL SPATIAL FOOTPRINT



FUTURE RECRUITMENT LIKELY LOWER THAN HISTORICAL

ICES Journal of Marine Science

ICES CIEM International Council for the Exploration of the Sea / Conseil International pour l'Exploration de la Mer

Climate change and the future productivity and distribution of crab in the Bering Sea

Cody Szuwalski [1*], Wei Cheng [2,3], Robert Foy [4], Albert J. Hermann [2,3], Anne Hollowed [1], Kirstin Holsman [1], Jiwoo Lee [5], William Stockhausen [1], and Jie Zheng [6]

Built models predicting recruitment based on environmental variables

Ice and Arctic Oscillation related to snow crab recruits

	Recruitment			Distribution			Latitude			Longitude		
Ice_cover + Cod + Aleutian.Low	0.80	-1.54	3.93	6.16	5.82	-0.80	0.96	7.66	-11.33	3.18	-8.97	3.14
SST + Cod + Aleutian.Low	1.19	-4.67	3.72	6.71	6.31	-2.07	-0.37	7.66	-1.93	3.02	-10.41	3.81
Bottom_temp + Cod + Aleutian.Low	1.78	-12.10	4.49	7.23	6.25	-6.39	2.29	7.62	0.98	2.48	-6.46	-0.82
Ice_cover + Cod + Arctic_oscillation	-4.74	0.45	0.62	7.01	8.06	-0.59	-1.39	7.91	-11.40	-5.65	-8.18	3.21
SST + Cod + Arctic_oscillation	-1.70	-4.14	2.29	7.65	8.26	-2.06	-5.15	7.82	-3.51	-6.84	-10.65	3.74
Bottom_temp + Cod + Arctic_oscillation	-3.94	-12.64	2.85	7.99	8.28	2.33	-0.25	7.92	0.93	-6.61	-5.92	0.55
Ice_cover + Cod + PDO	-3.60	0.45	4.08	6.94	8.27	-0.60	1.92	6.78	-10.17	4.18	-9.48	3.32
SST + Cod + PDO	0.66	-4.30	4.11	7.33	8.40	-2.09	-0.05	6.45	-3.07	3.75	-11.49	4.04
Bottom_temp + Cod + PDO	0.22	-13.17	4.65	7.50	8.40	2.16	2.20	6.93	-0.93	2.97	-6.32	0.30
Ice_cover + Cod + Alaskan_index	3.13	0.41	3.48	7.02	7.98	-0.57	3.28	7.02	-9.44	0.66	-9.97	2.55
SST + Cod + Alaskan_index	5.18	-4.75	3.40	7.49	8.38	-2.09	1.21	7.20	-0.16	0.61	-12.79	2.80
Bottom_temp + Cod + Alaskan_index	4.05	-13.75	4.10	7.71	8.39	2.17	4.08	6.97	2.92	0.40	-6.92	0.46
Ice_cover + Cod	2.46	-2.55	0.85	3.98	5.21	-3.67	0.61	4.84	-12.01	1.19	-10.96	0.30
SST + Cod	3.50	-7.15	0.85	4.57	5.33	-5.15	-1.71	4.74	-3.26	0.73	-13.05	0.95
Bottom_temp + Cod	1.61	-15.16	1.59	4.92	5.33	-0.72	1.59	4.84	-0.12	-0.09	-8.69	-2.48
Ice_cover + Aleutian.Low	-1.63	4.71	3.73	4.12	2.76	-1.83	0.49	5.11	-11.14	3.68	3.28	5.36
SST + Aleutian.Low	-0.18	1.88	2.17	4.52	3.28	-3.60	-0.04	4.96	-3.87	3.89	3.24	5.35
Bottom_temp + Aleutian.Low	-0.09	-12.27	3.62	4.72	3.22	2.51	0.96	5.16	-1.81	3.64	3.29	3.89
Ice_cover + Arctic_oscillation	-7.73	5.35	-0.41	4.72	5.11	-2.21	-3.57	5.13	-12.71	-7.76	1.90	3.87
SST + Arctic_oscillation	-4.04	1.89	0.08	5.09	5.17	-3.72	-6.48	4.94	-6.12	-8.37	1.30	3.89
Bottom_temp + Arctic_oscillation	-6.49	-12.30	1.12	5.26	5.19	2.02	-2.86	5.17	-2.12	-8.34	2.04	2.75
Ice_cover + PDO	-5.21	5.01	3.68	4.48	5.22	-1.91	1.56	3.93	-9.83	4.98	2.91	5.35
SST + PDO	0.07	-0.35	2.75	4.67	5.31	-3.70	0.81	3.51	-4.76	5.02	2.99	5.28
Bottom_temp + PDO	-0.97	-14.30	4.06	4.70	5.31	2.45	1.51	4.25	-3.48	4.70	2.96	4.08
Ice_cover + Alaskan_index	0.10	5.35	3.66	4.66	4.94	-1.79	3.41	4.44	-8.35	1.93	4.37	4.48
SST + Alaskan_index	2.63	0.69	2.60	4.92	5.29	-3.63	2.47	4.46	-1.44	2.28	3.91	4.08
Bottom_temp + Alaskan_index	1.37	-13.09	3.74	4.97	5.29	2.36	3.56	4.37	0.50	2.68	4.40	4.06
Ice_cover	-0.28	2.56	1.16	1.92	2.44	-4.59	1.09	2.46	-10.85	2.55	2.32	2.55
SST	1.10	-0.90	-0.02	2.30	2.52	-6.39	-0.11	2.23	-4.24	2.49	2.07	2.54
Bottom_temp	-0.82	-14.13	1.27	2.46	2.52	-0.27	1.28	2.51	-2.26	1.99	2.35	1.37
Cod	1.79	-4.32	1.33	2.37	2.57	-2.22	1.38	2.02	2.57	-0.66	-8.02	-1.33
Aleutian.Low	1.15	2.11	2.70	2.27	0.54	1.89	-1.70	2.35	-2.23	0.91	0.49	2.57
Arctic_oscillation	-5.40	2.60	0.61	2.56	2.42	2.20	-4.32	2.43	0.04	-10.54	-0.61	1.08
PDO	1.04	2.23	2.73	1.88	2.57	1.66	-1.13	1.67	-4.39	2.20	0.18	2.54
Alaskan_index	2.43	2.57	1.44	2.15	2.49	1.02	1.08	1.66	0.79	-0.12	2.34	1.80

FUTURE RECRUITMENT LIKELY LOWER THAN HISTORICAL


ICES Journal of
Marine Science

Climate change and the future productivity and distribution of crab in the Bering Sea

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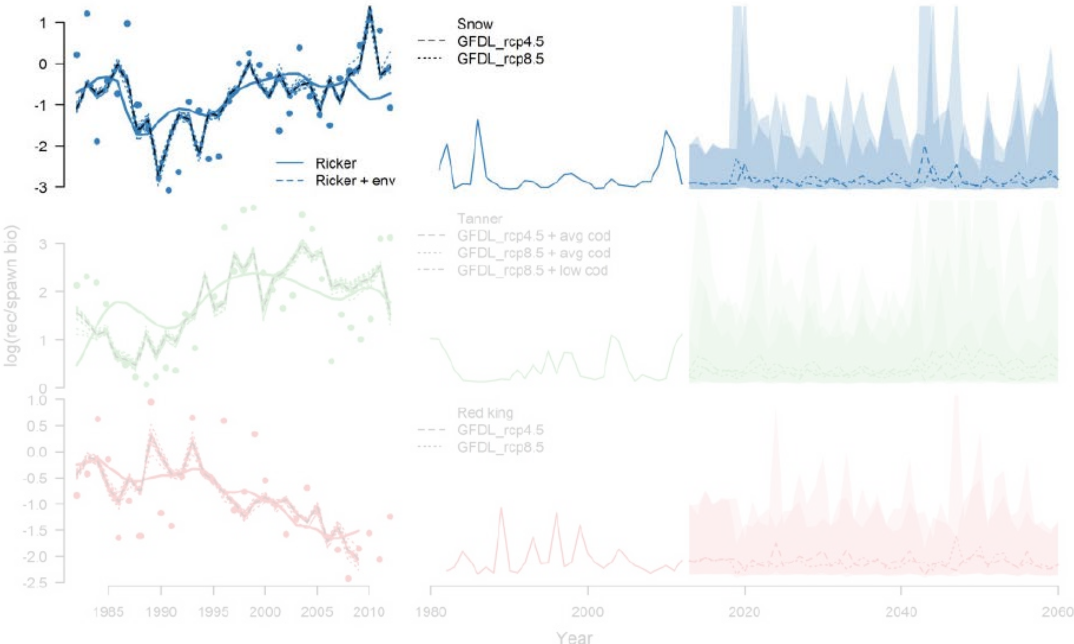
- Built models predicting recruitment based on environmental variables
- Ice and Arctic Oscillation related to snow crab recruits
- Lower recruitment when projected forward under linkages to global climate models



AUTHOR RECOMMENDATIONS FOR PROJECTIONS

Lower projected recruitment (1982-2017)

- Szuwalski et al. 2020
- However even the lowest scenario is probably optimistic

Average natural mortality (1982-2017)

- SAFE appendix B & C
- Temperatures may be high, but densities won’t be

Status quo unobserved mortality

SNOW CRAB REBUILDING

CPT RECOMMENDATIONS FOR INITIAL REVIEW

M, *R*, AND UNOBSERVED MORTALITY

CPT recommendations:

- ***M*** **modeled with draws from the 1982-2017 time block**
  - The 2005-2019 time block is considered to be a better choice for simulating climate conditions during rebuilding
  - Available data suggest that high population density was a cause of the post-2018 collapse; high density will not be a concern during rebuilding
- ***R*** **modeled with draws from the 1982-2017 time block**
  - Lower *R* is consistent with expectations for low ice cover during rebuilding, and resulting reduction in average *R*
- **Status quo approach for estimating unobserved mortality**
  - Unobserved mortality had little effect on rebuilding when estimated at five times observed mortality
  - Estimating unobserved mortality at 100 times observed mortality creates complexities in population model and catch allocation that require more study before being implemented

RECOMMENDED T_{MIN} AND T_{MAX}

- **Rebuilding timeline**
  - The recommended approach for projecting *M*, *R*, and unobserved mortality results in T_{min} = 2029 (6 years from 2023)
  - Since T_{min} is less than ten years, the recommended T_{max} = 2033 (10 years from 2023)
  - CPT recommends this as the most realistic scenario given the data that are available to model the stock post-collapse (i.e., only with survey data from 2021 and 2022)