Snow crab rebuilding projections

Cody Szuwalski et al.

CPT audible

- 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
- 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

Rebuilding specifications

- Updated data, MLE, sampled productivity

Rebuilding projections

- 4 productivity scenarios + 5 fishing scenarios

Unobserved mortality

- 5x and 100x scenarios

Projection selection

- What happened + Recruitment projection papers + unobserved mortality

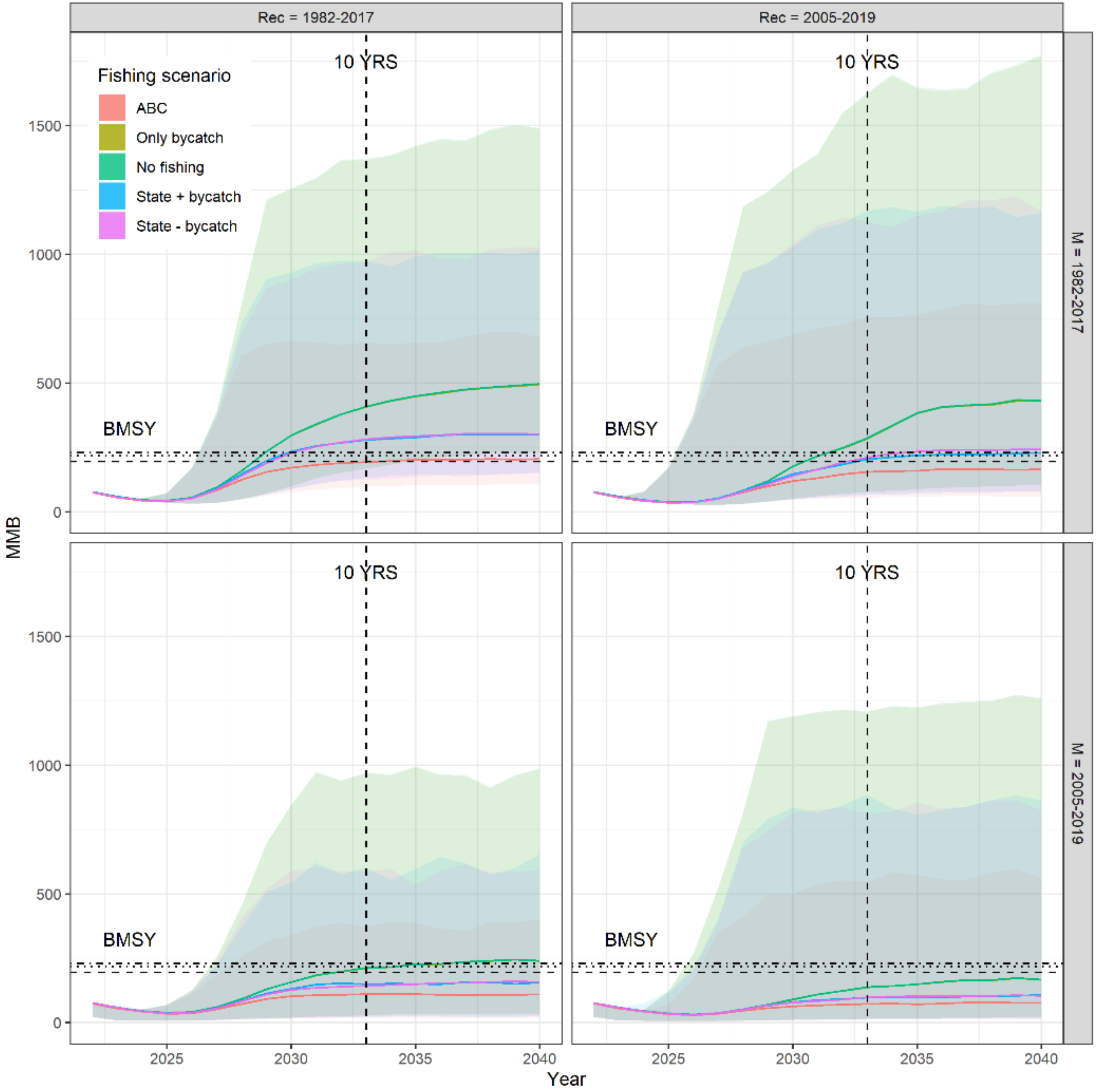
Projection specifications

- Projection
  - 2000 iterations per scenario
  - Started from the local minimum of 22.1ab
  - Sample natural mortality and recruitment from a range of years
  - No stochasticity in initial status or parameter values

Projection scenarios

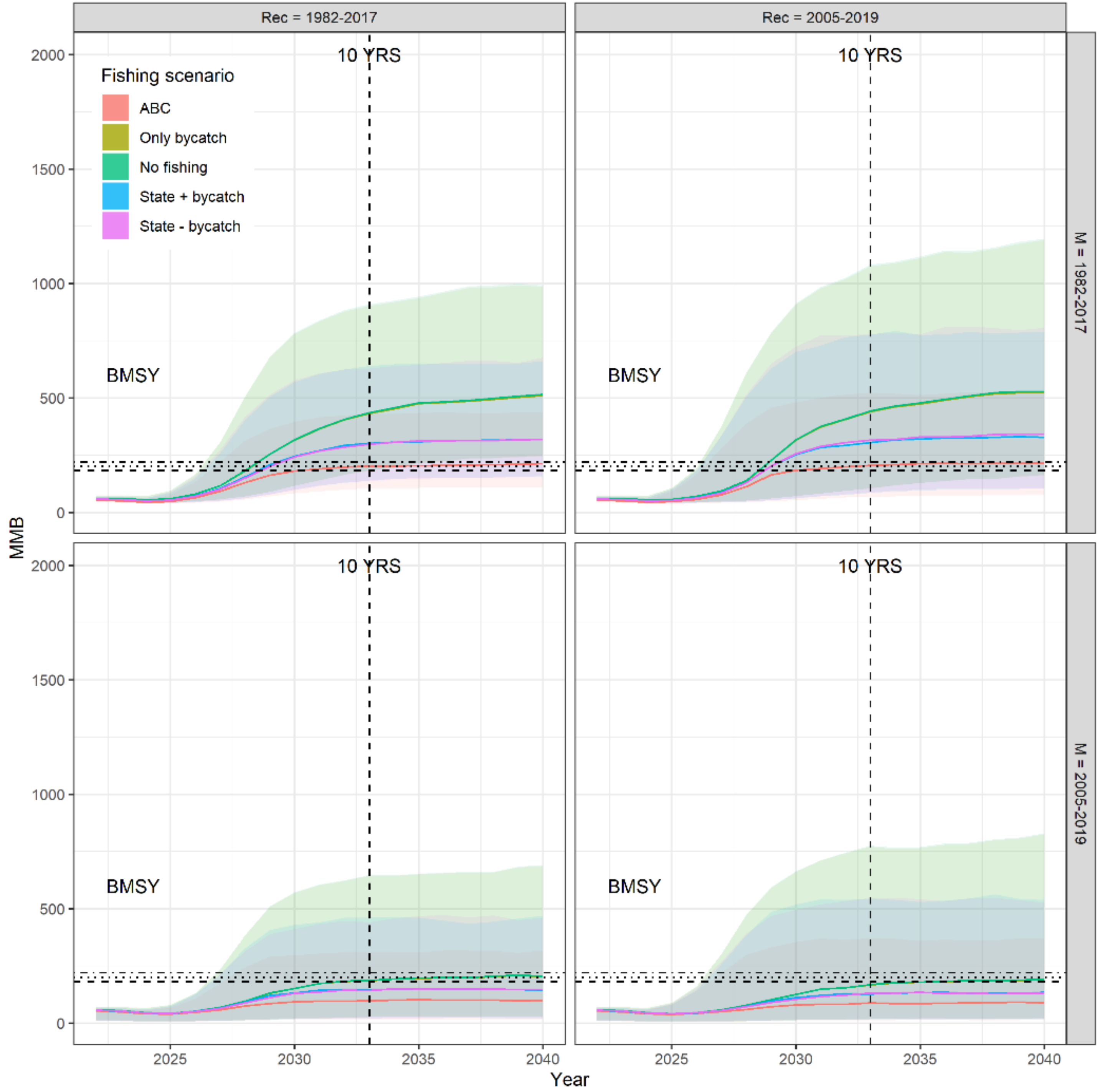
- Productivity
  - Sample M and recruitment from two time periods
  - 1982-2017: More optimistic case; no mortality events.
  - 2005-2019: Most recent period of alternating warm/cool with 1 in 7 chance of mortality event.
  - Three target biomasses presented
    - 1982-2021 (status quo)
    - 1982-2017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

- 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



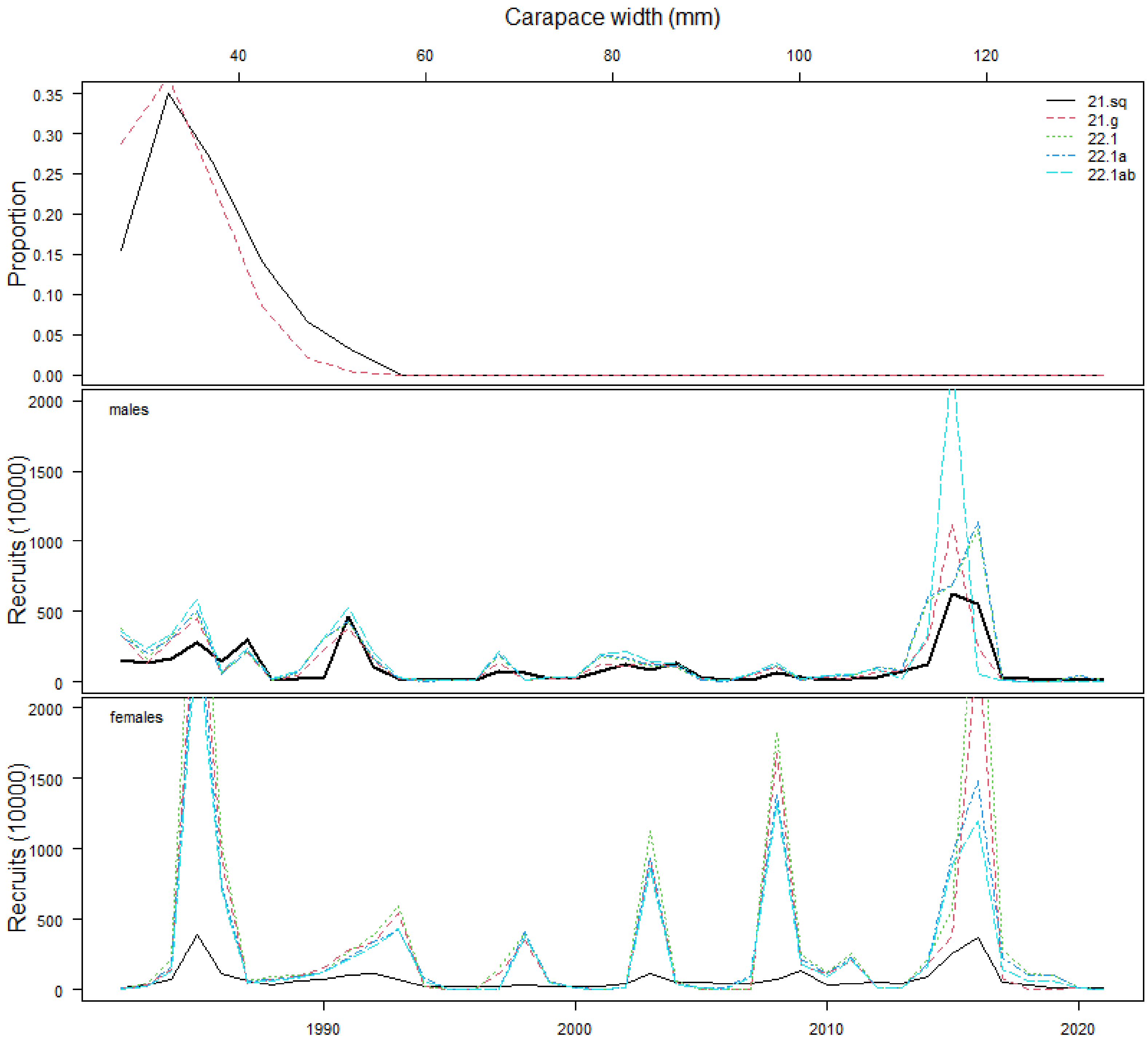
Base projections (22.1ab)

- 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



Base projections (22.1a)

- Smaller scale than 22.1ab because of the magnitude of the 2015 estimated recruitment
- Average recruitment from both periods are similar
- Mortality events resulted in slower (or no) rebuilding)
- Tmin ranged from 2029 to never depending on scenario



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

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

Base projections (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	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

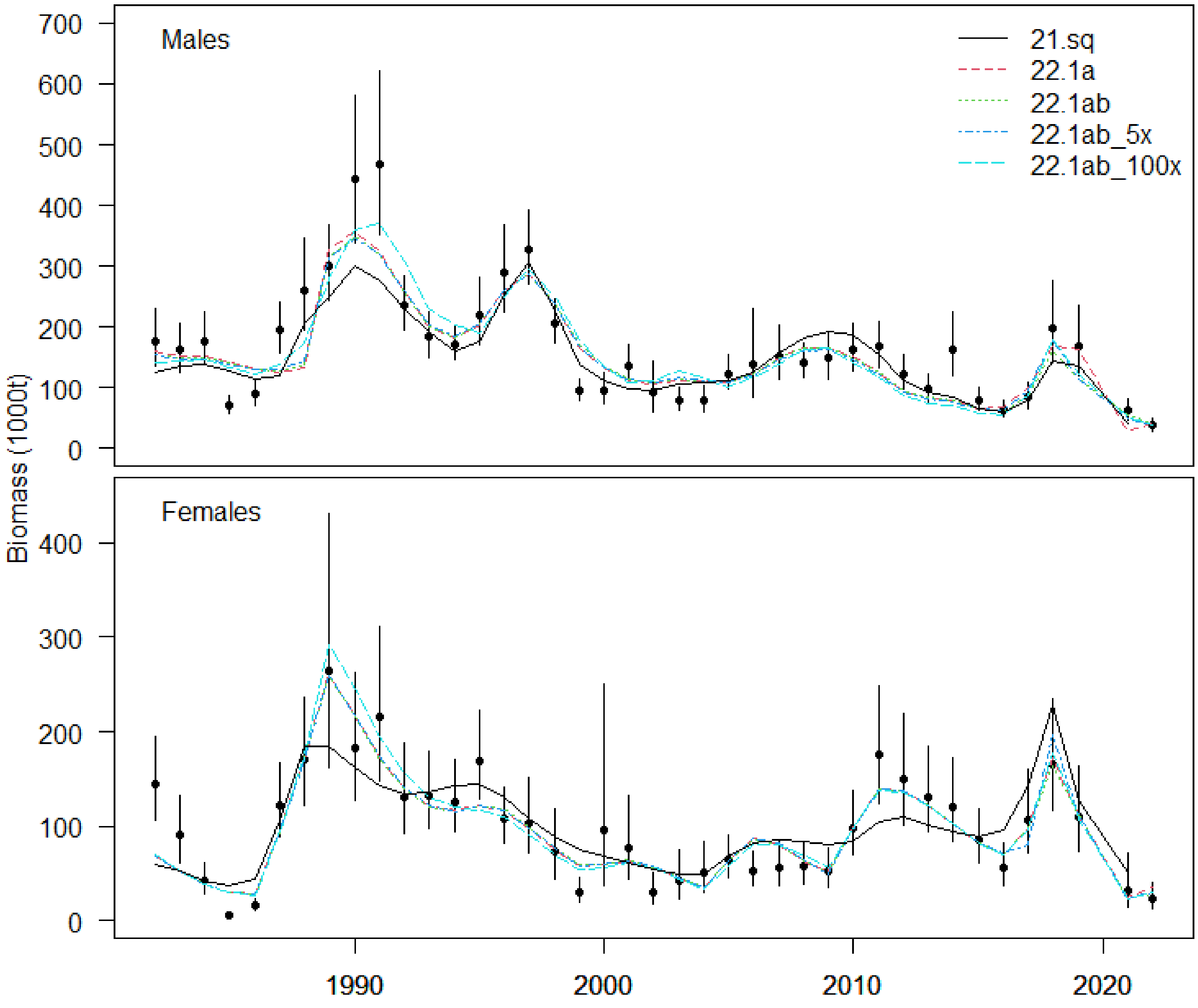
Base projections (22.1a)

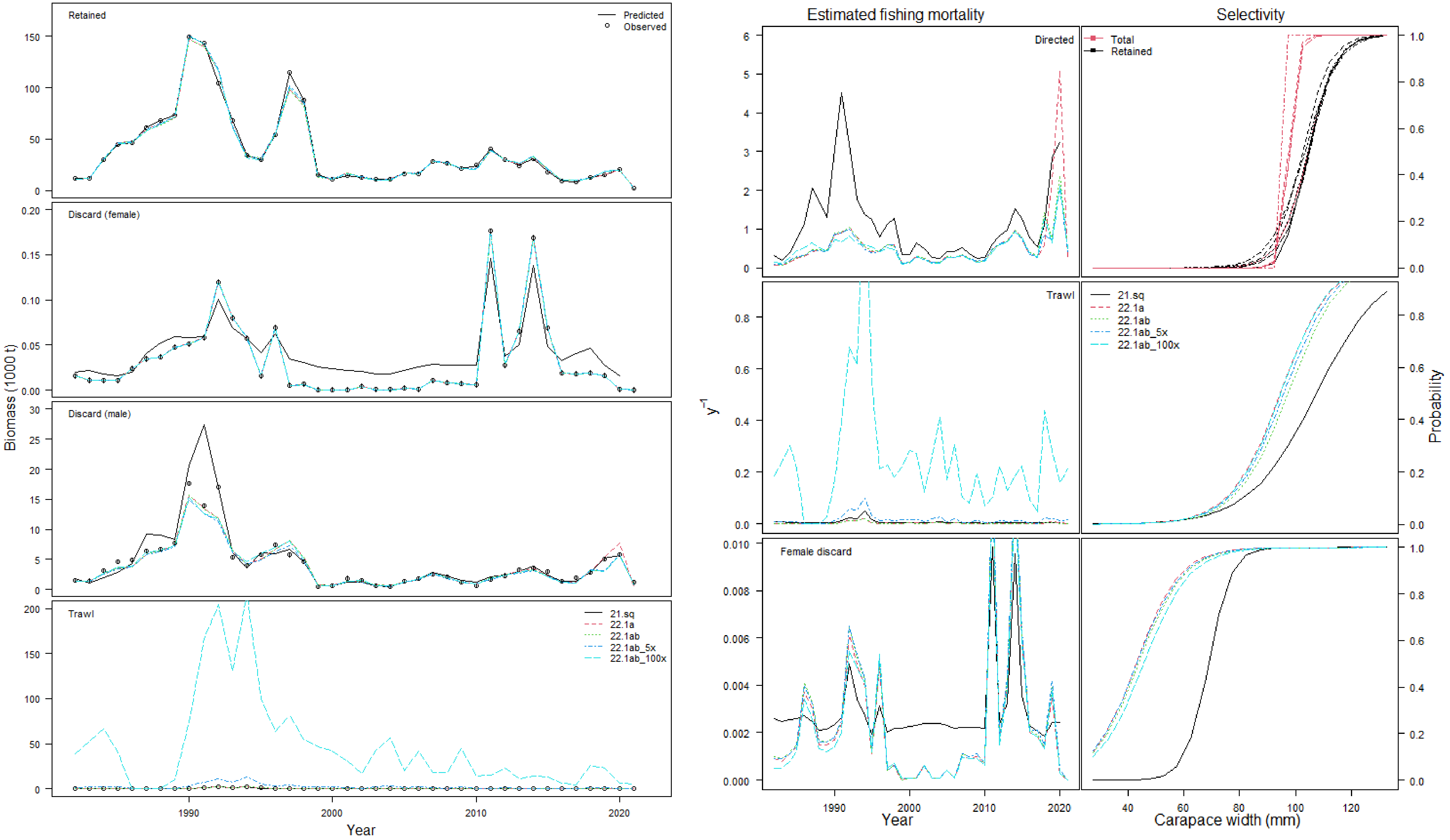
Unobserved mortality

- It’s clear that there must be unobserved mortality (see Dr. Rose’s ppt)

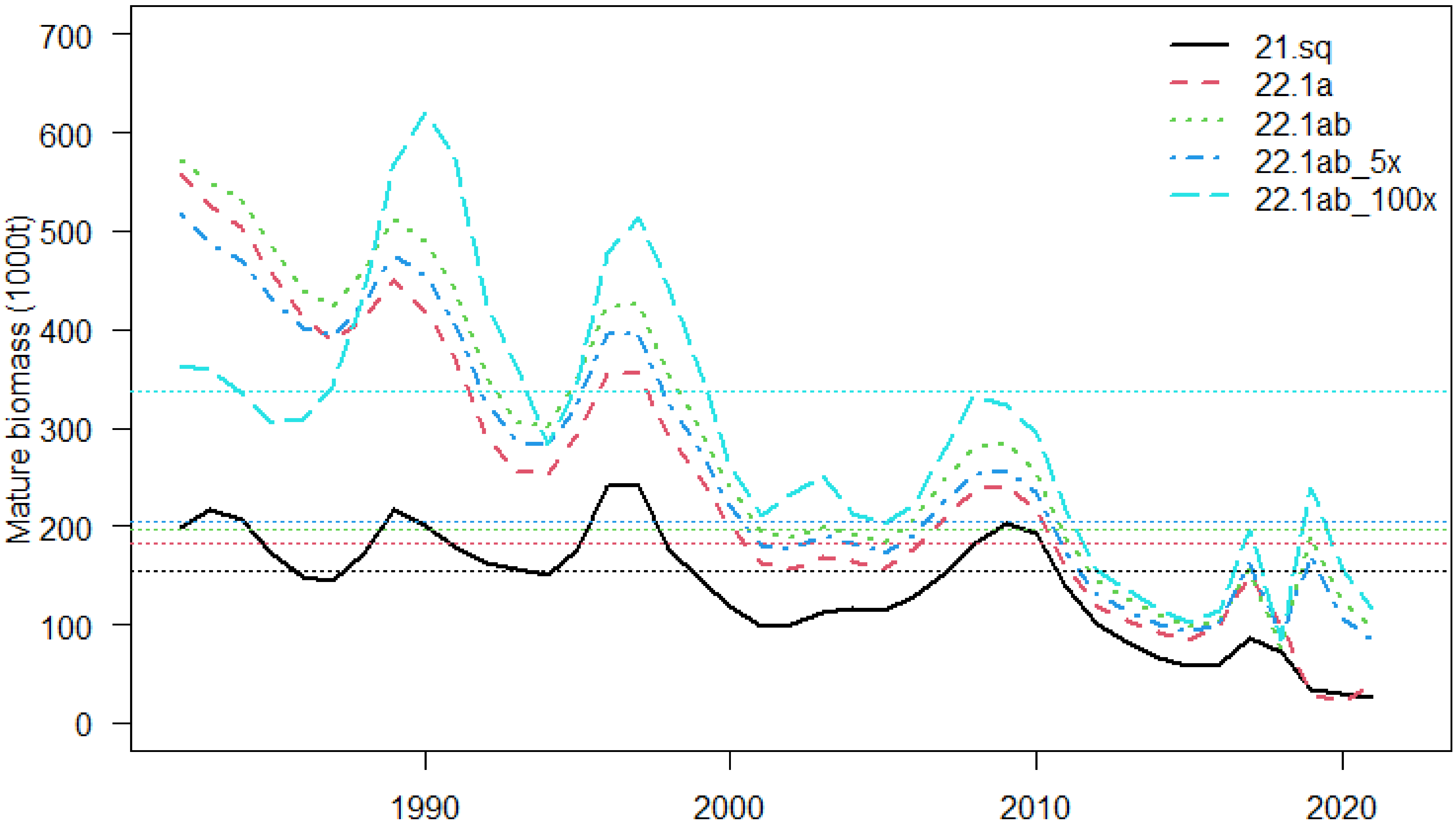
- It’s hard to make a case that unobserved mortality is a large driver of recent population dynamics given we just saw the largest cohort ever establish in the Bering Sea.

- Still, our only management levers are modifying fishing mortality in the directed and non-directed fisheries, so this deserves attention.

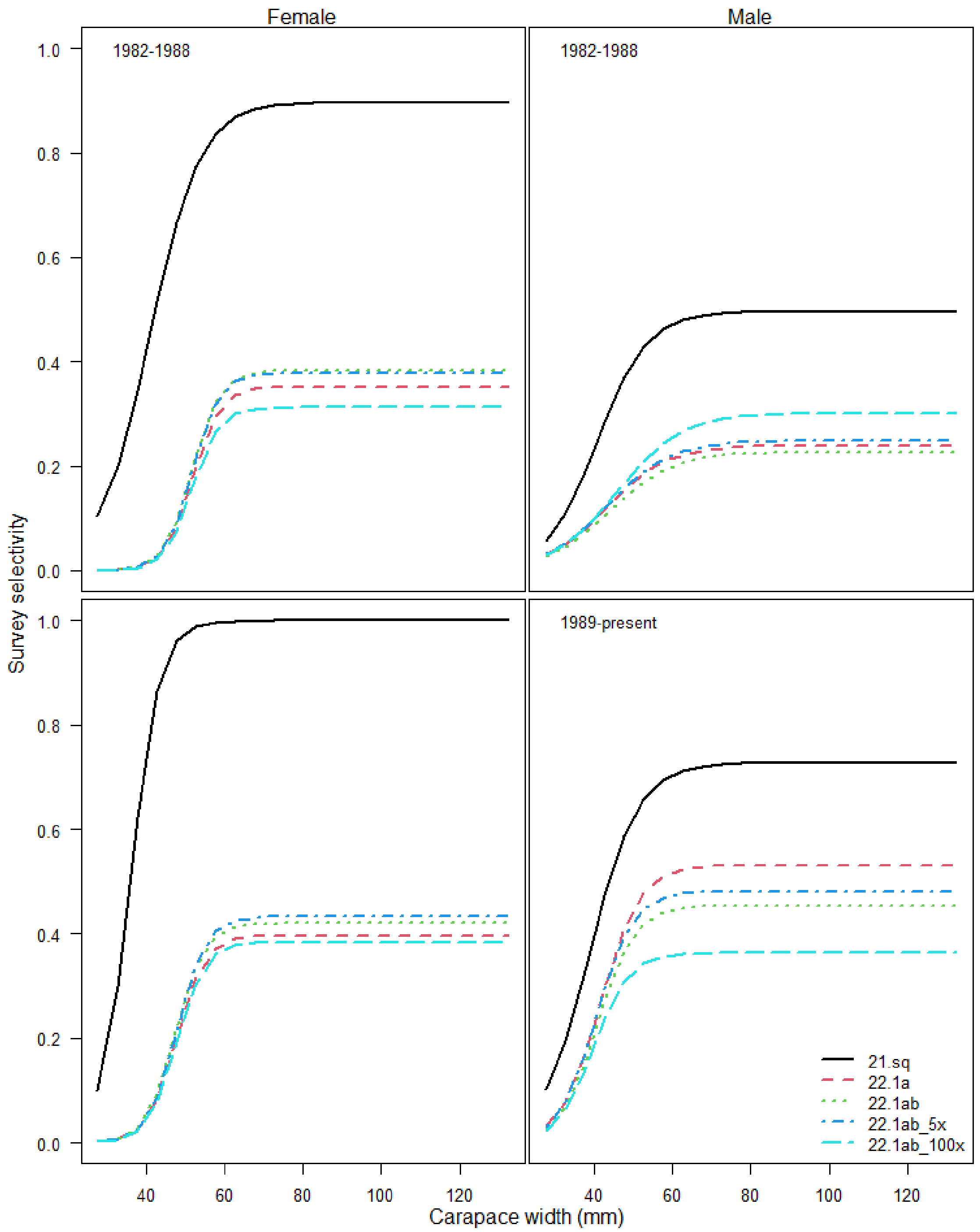

Males
21.sq
22.1a
22.1ab
22.1ab_5x
22.1ab_100x
Females
Biomass (1000t)
0
100
200
300
400
500
600
700
1990
2000
2010
2020

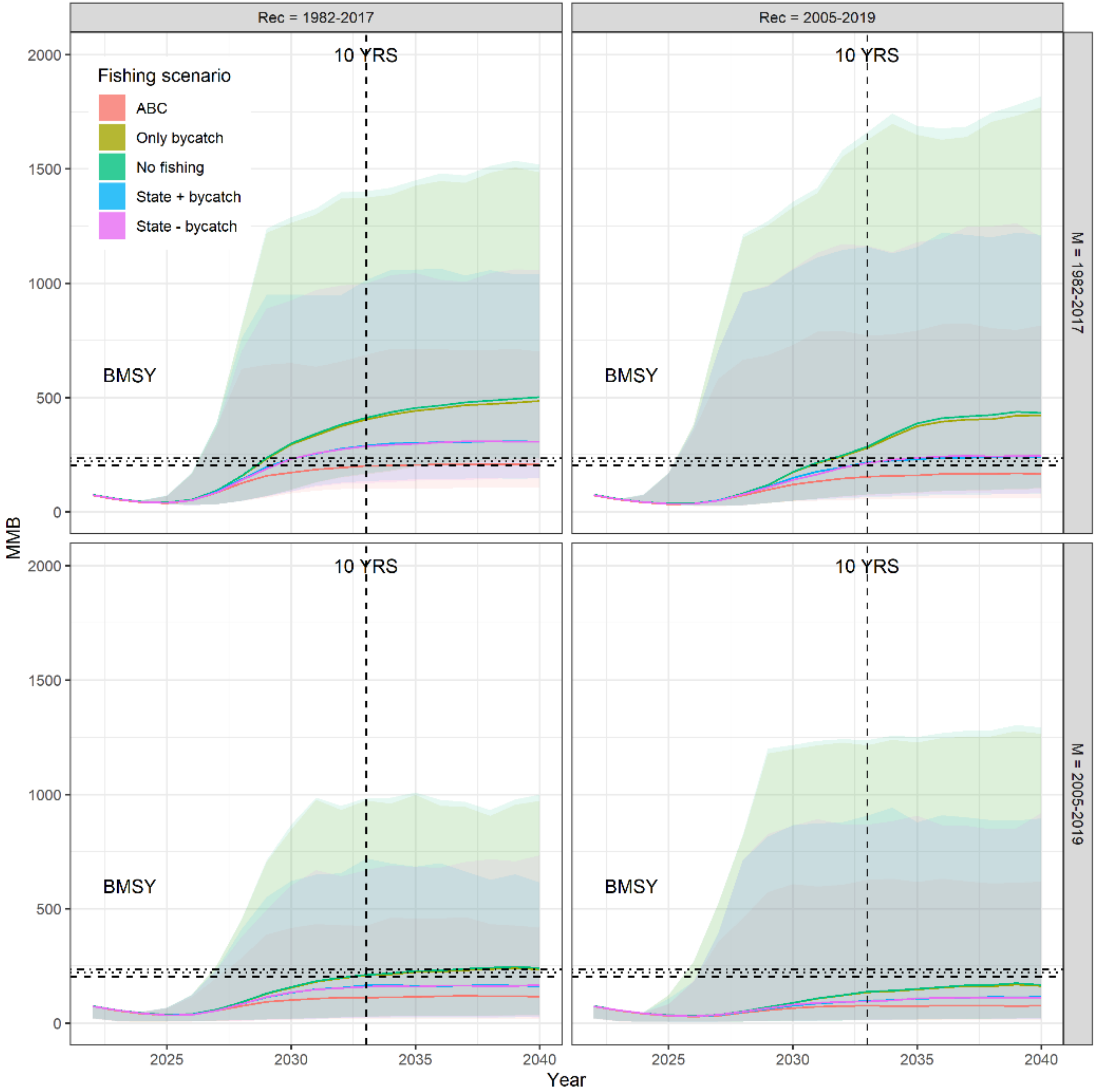


Retained
Predicted
Observed
Discard (female)
Discard (male)
Trawl
21.sq
22.1a
22.1ab
22.1ab_5x
22.1ab_100x
Biomass (1000 t)
Year
Estimated fishing mortality
Selectivity
Directed
Total
Retained
Trawl
Female discard
y^{-1}
Probability
Carapace width (mm)



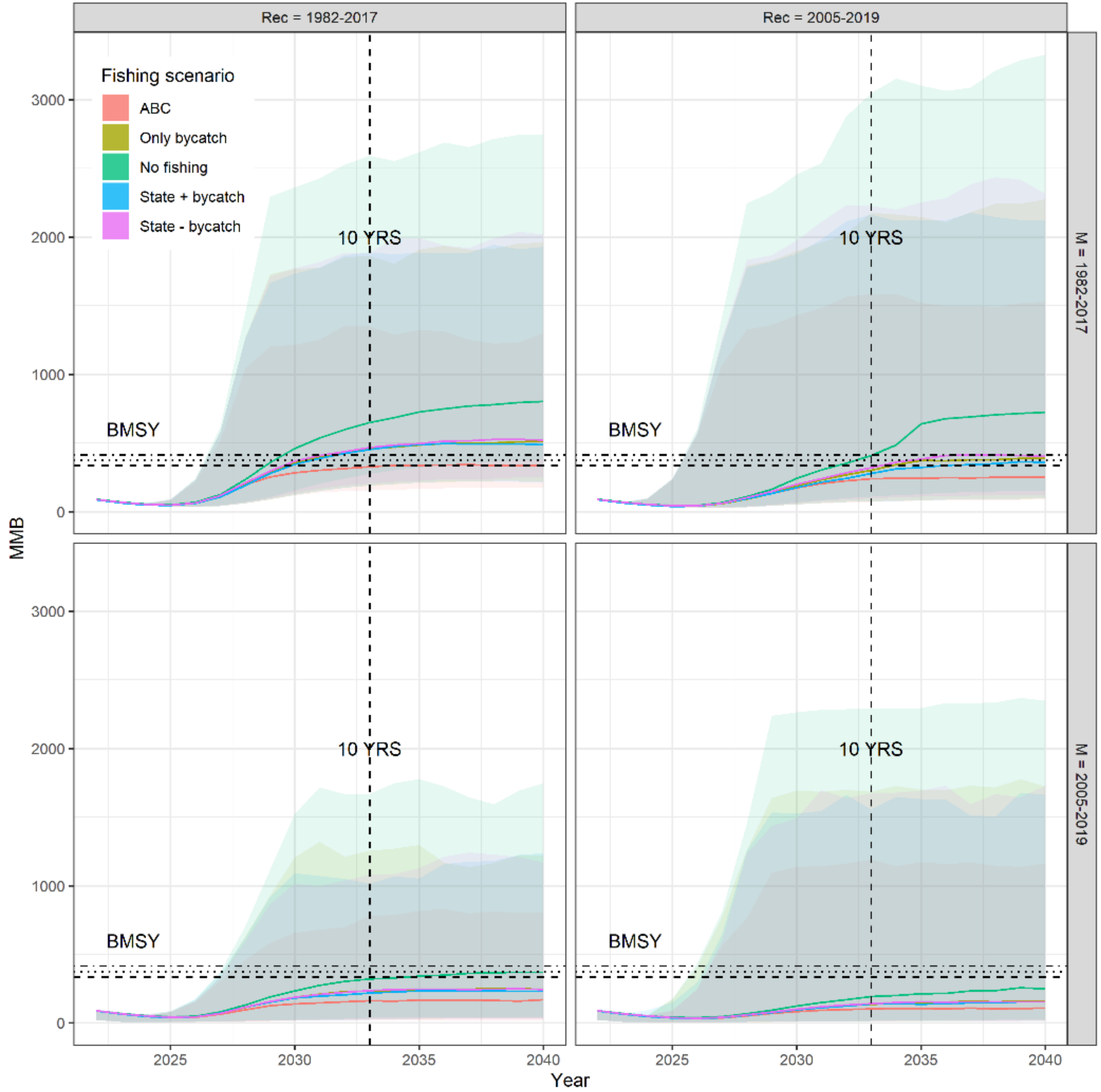
Mature biomass (1000t)
700
600
500
400
300
200
100
0
1990
2000
2010
2020
21.sq
22.1a
22.1ab
22.1ab_5x
22.1ab_100x


Female
Male
1982-1988
1982-1988
1989-present
Survey selectivity
Carapace width (mm)
0.0
0.2
0.4
0.6
0.8
1.0
40
60
80
100
120
21.sq
22.1a
22.1ab
22.1ab_5x
22.1ab_100x



5x projections (22.1ab)

- Scenarios with and without bycatch can now be discerned, but still very close
- Small difference in the t_mins or time to rebuilding under state strategies



100x projections (22.1ab)

- Scenarios with and without bycatch are very different (bycatch is now overlaid by the state strategies
- State strategy minus bycatch has an issue with the coding, the purple line should be close to the green line because in the way the OFL is calculated, a fixed fishing mortality is allocated to the non-directed fleet before calculating the F needed to

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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	2030
bycatch	Rec = 1982-2017	M = 2005-2019	2033	2035	2038
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bycatch	Rec = 2005-2019	M = 2005-2019	Inf	Inf	Inf
State + bycatch	Rec = 1982-2017	M = 1982-2017	2030	2030	2031
State + bycatch	Rec = 1982-2017	M = 2005-2019	Inf	Inf	Inf
State + bycatch	Rec = 2005-2019	M = 1982-2017	2033	2034	2036
State + bycatch	Rec = 2005-2019	M = 2005-2019	Inf	Inf	Inf
State - bycatch	Rec = 1982-2017	M = 1982-2017	2030	2030	2031
State - bycatch	Rec = 1982-2017	M = 2005-2019	Inf	Inf	Inf
State - bycatch	Rec = 2005-2019	M = 1982-2017	2033	2034	2035
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State - bycatch	Rec = 2005-2019	M = 2005-2019	Inf	Inf	Inf

	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

- 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 was unobserved mortality increases

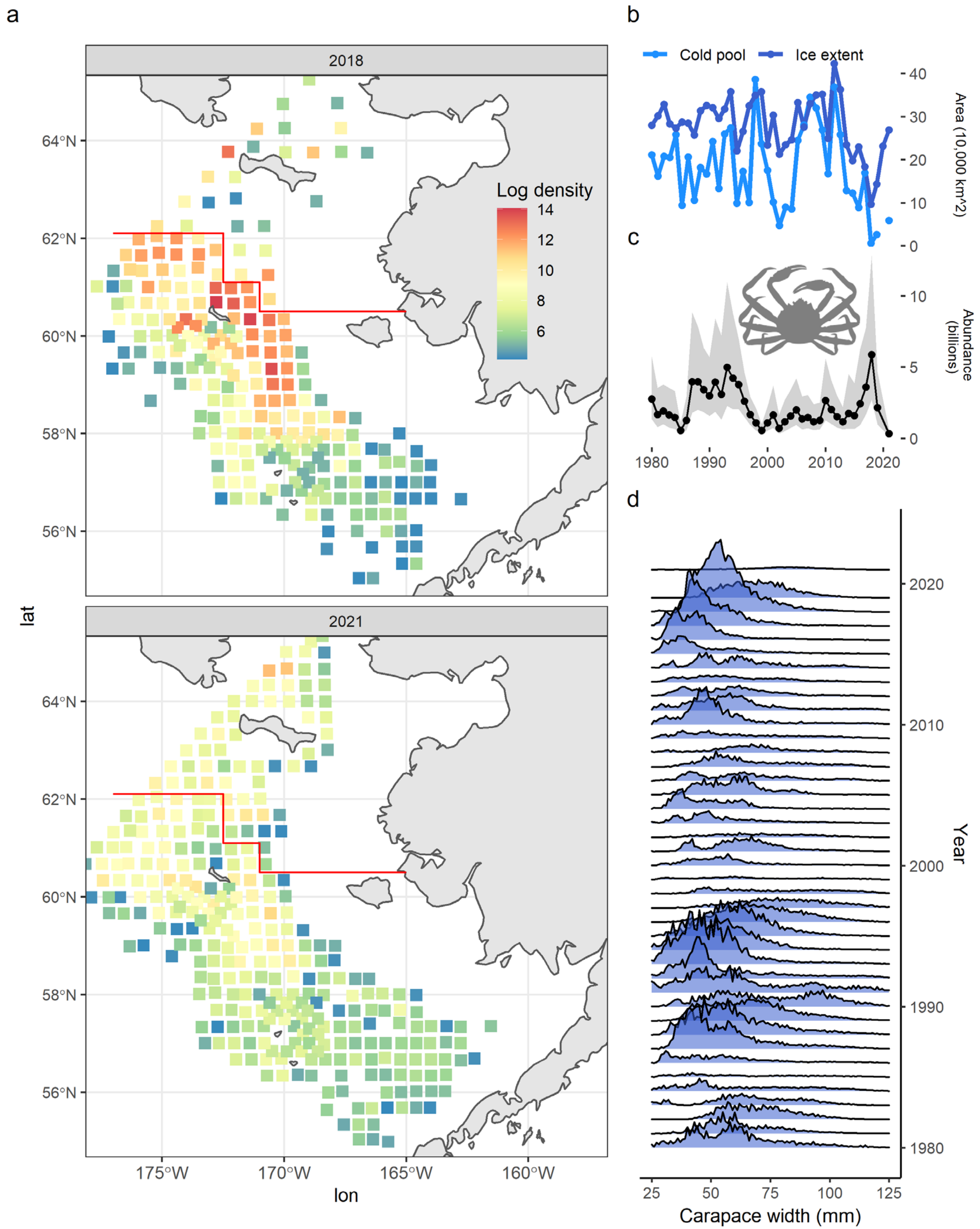
- If the OFL is similar for a given status adding unobserved mortality just decreases the amount of the OFL allocated to the directed fishery.
- Needs a retrospective analysis to understand potential impacts more fully

Projection selection

Natural mortality

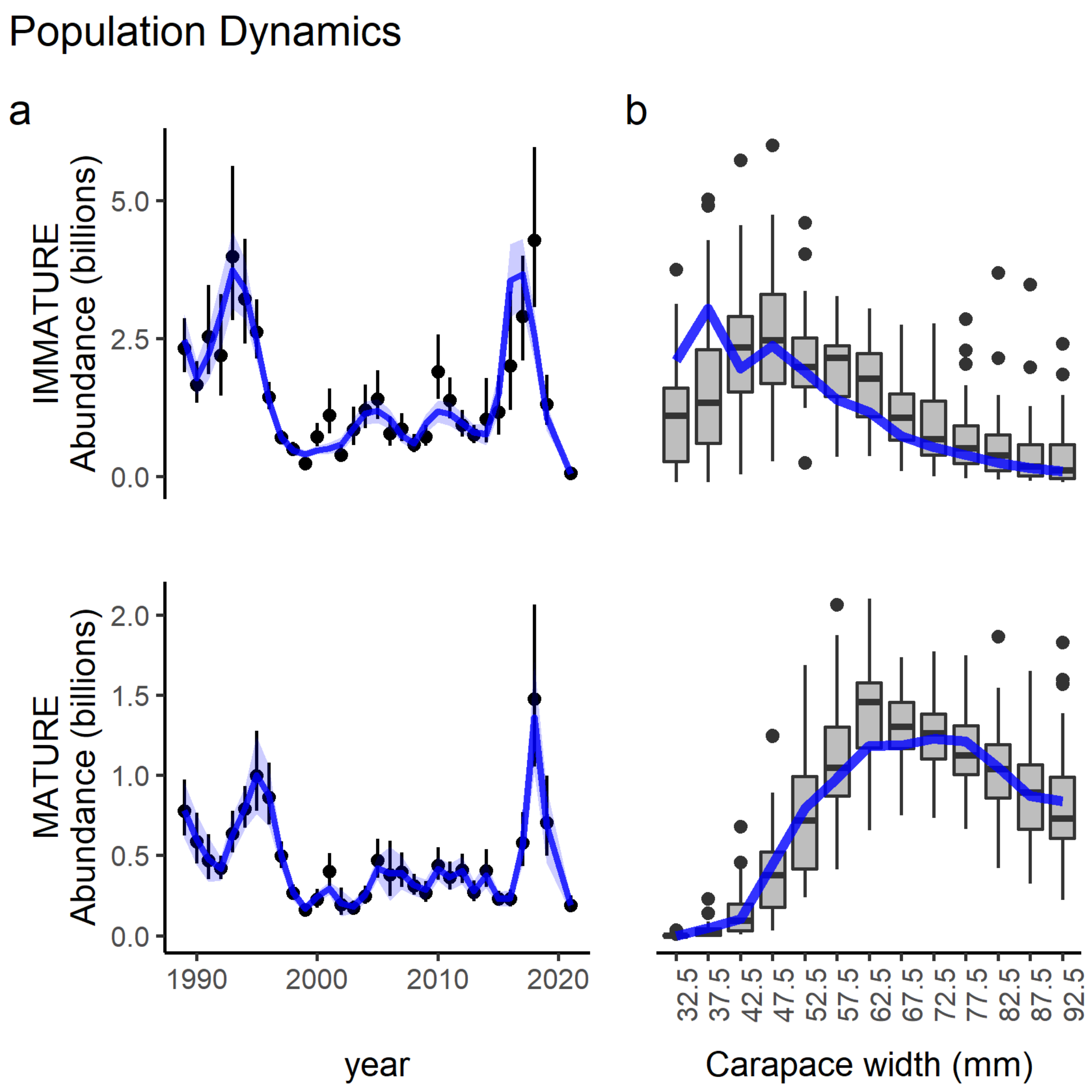
Recruitment

Unobserved mortality



Collapse of snow crab

- More crab than ever in 2018, fewer crab than ever in 2021 (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



Step 1: 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

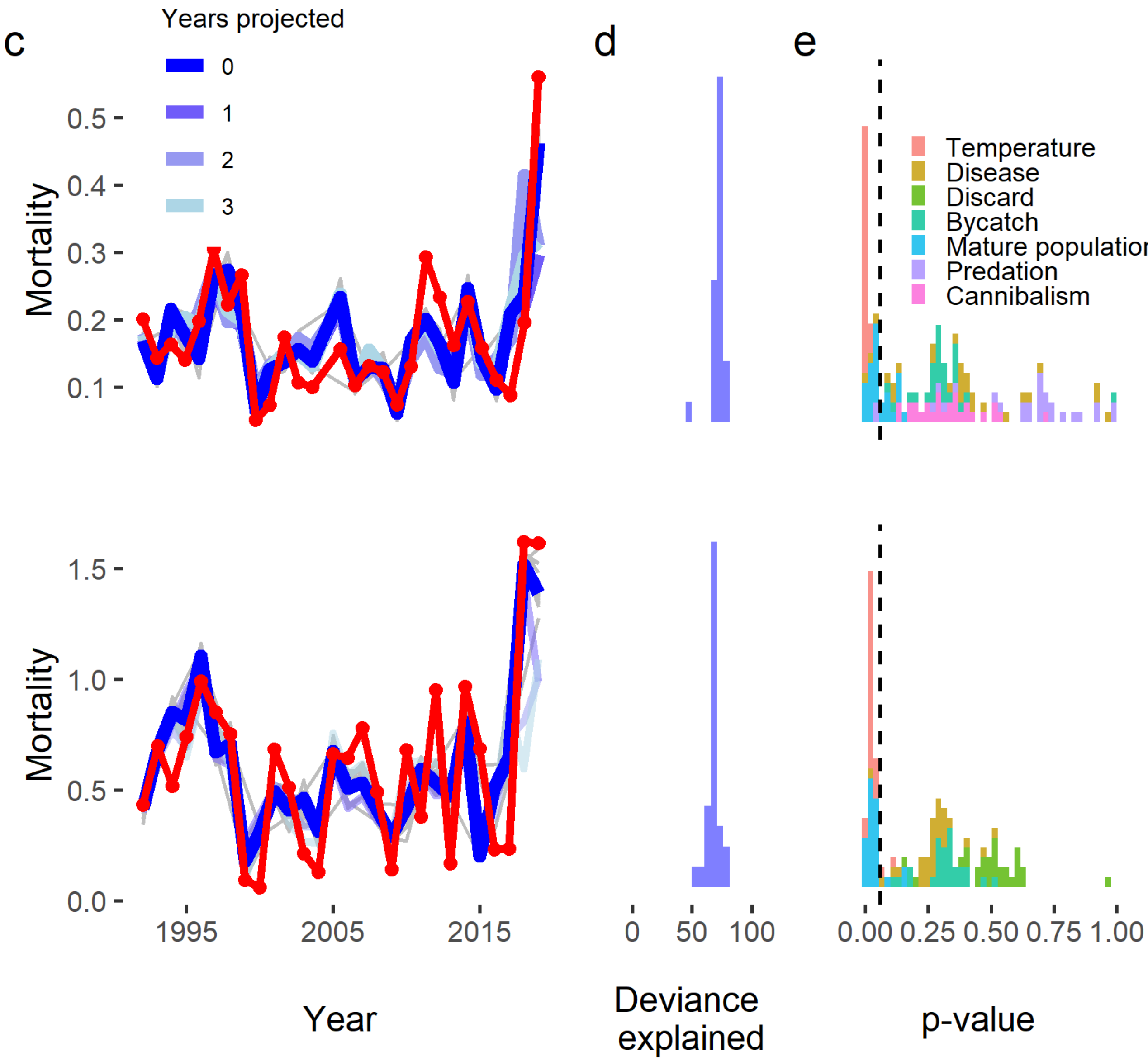
Estimated mortality from fits to the simulated data were highly correlated.

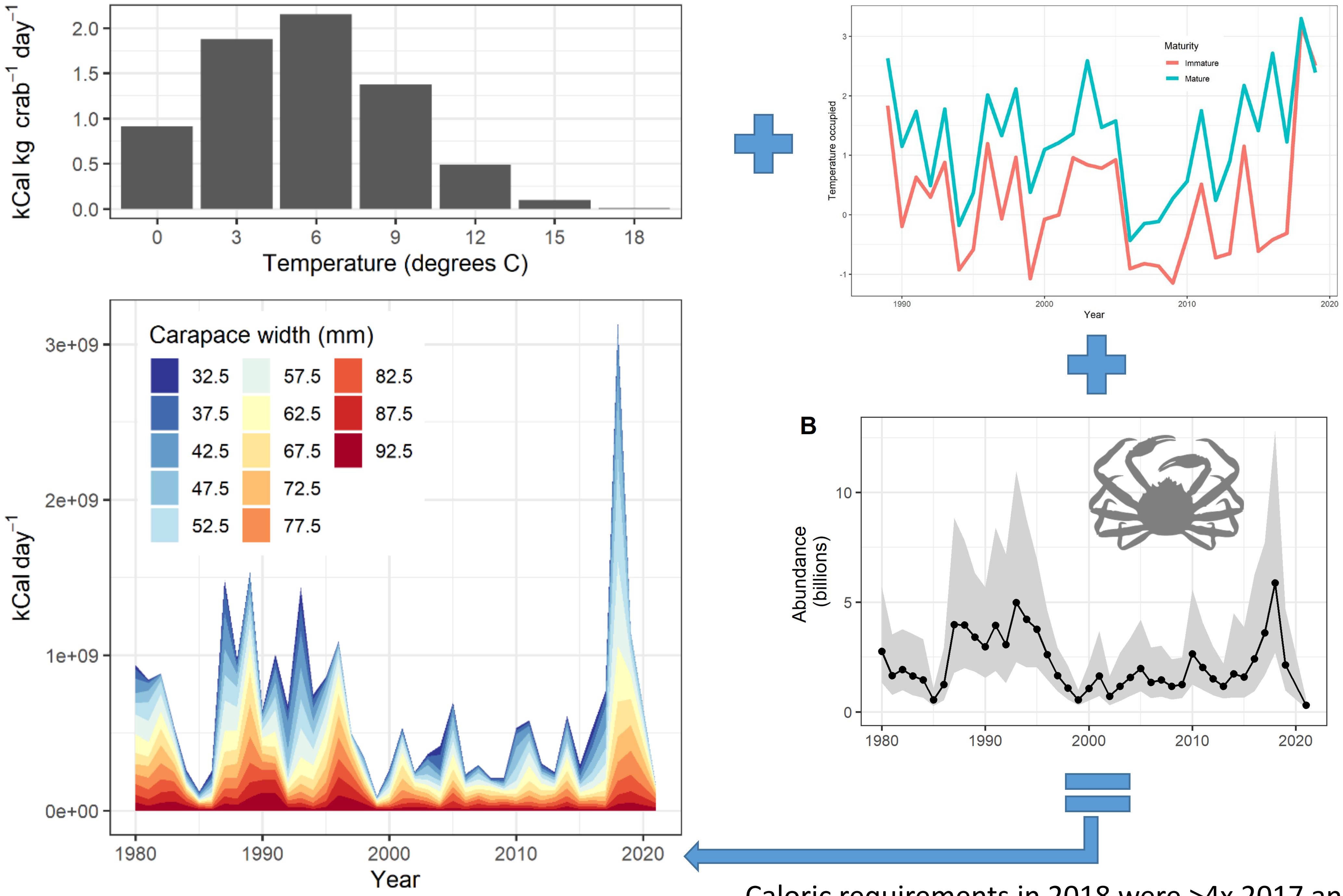
Step 2: Relate estimated mortality to environmental stressors

- 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

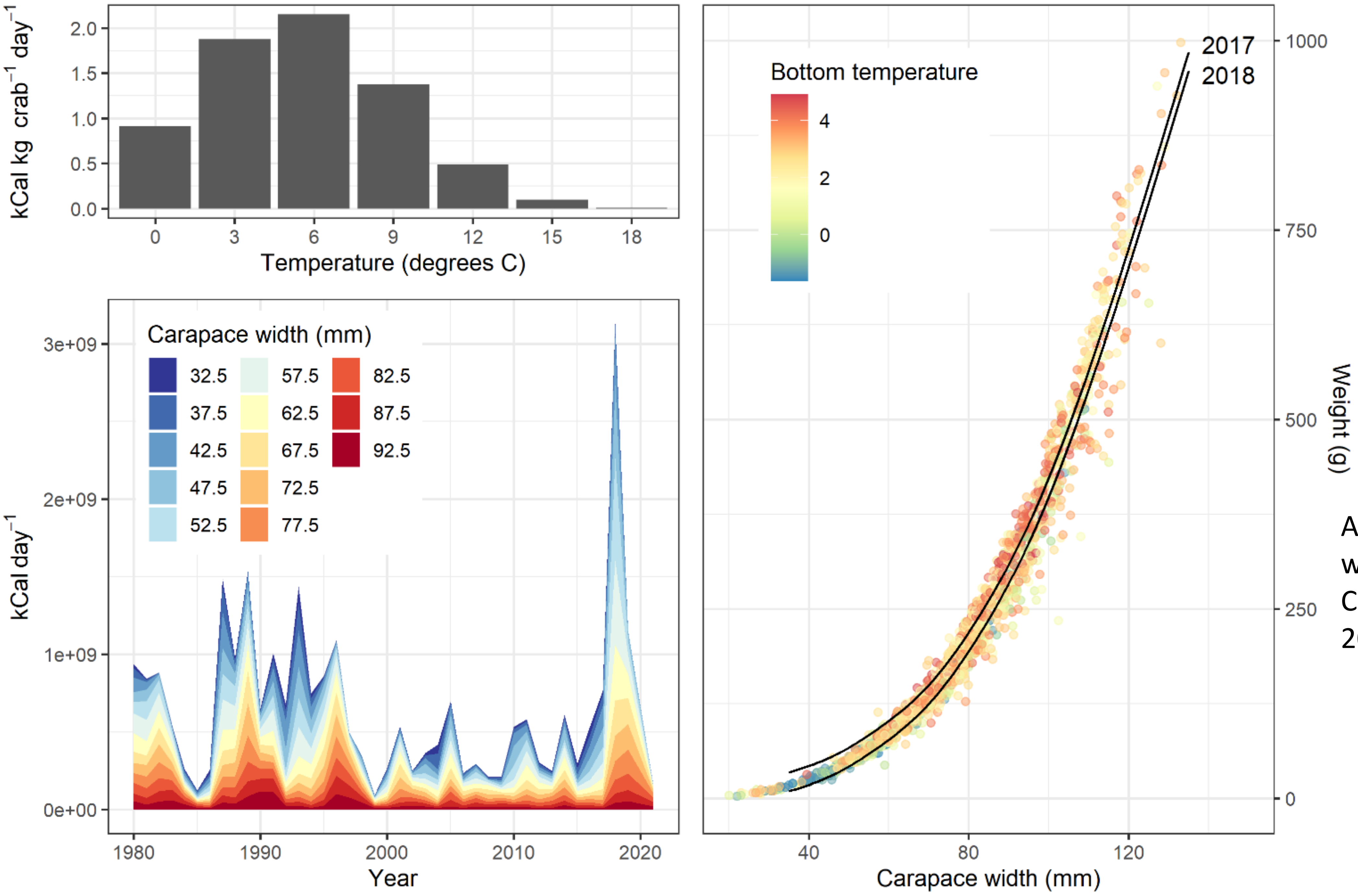
Temperature and **mature population density** were the consistently significant covariates.

Generalized Additive Models



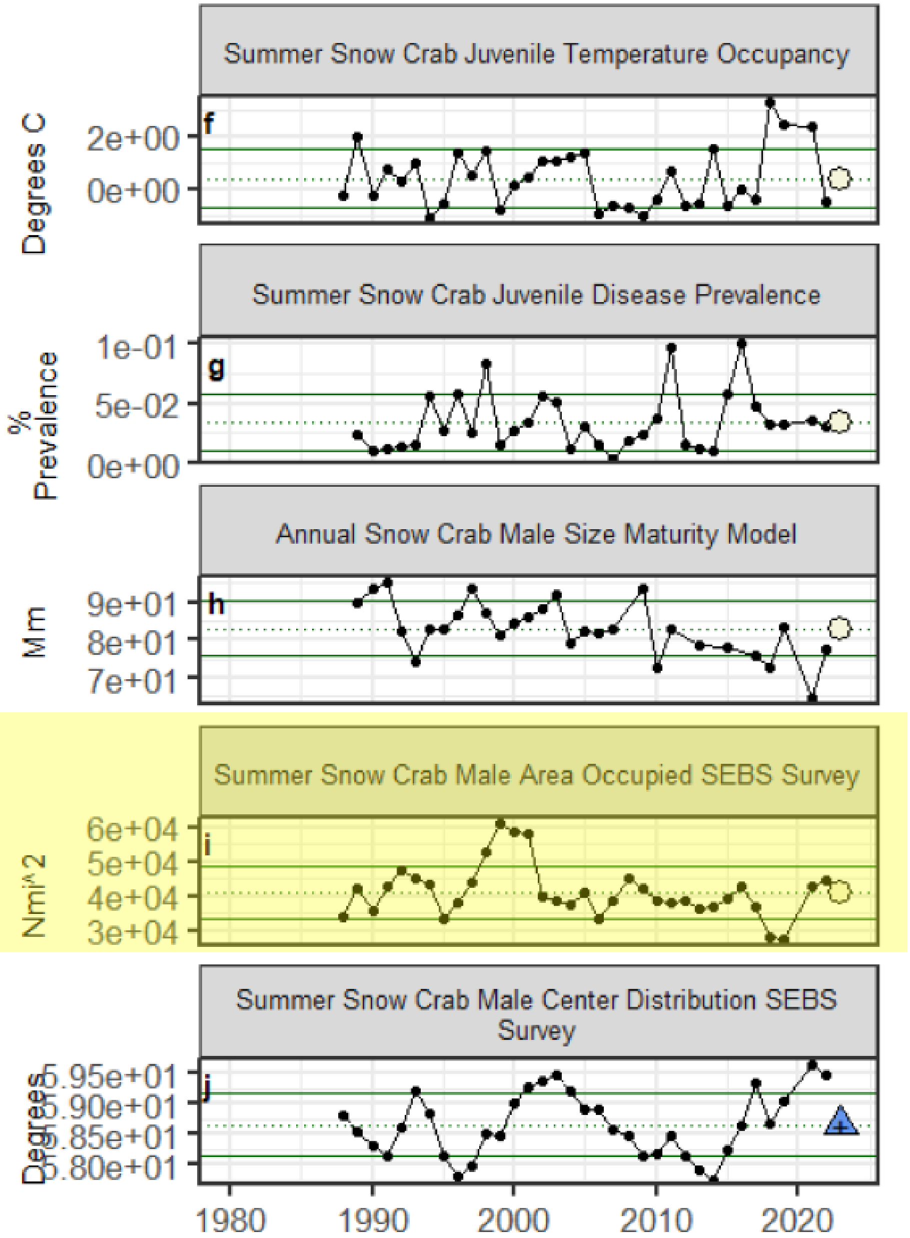


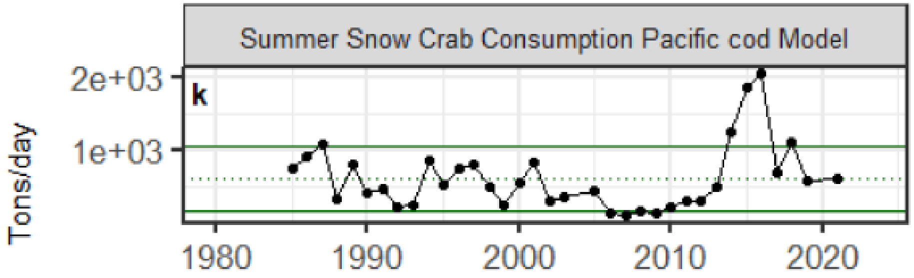
Caloric requirements in 2018 were >4x 2017 and >2x previous high



A 75 mm carapace width crab at 1 degree C was 15% lighter in 2018 than in 2017.

Ecosystem Indicators





Sho

- Mature males have seen temperatures similar to 2018 and 2019 in the past, but no apparent mass mortality event
- The difference between now and then was density of crab and area occupied.

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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	-6.97	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	2.38	-0.25	7.92	0.93	-6.61	-5.92	0.55
Ice_cover + Cod + PDO	-3.50	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	4.85	7.50	8.40	2.16	2.20	6.93	-0.93	2.97	-8.32	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	-10.98	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	3.69	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	3.88	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	1.18	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	1.87	-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

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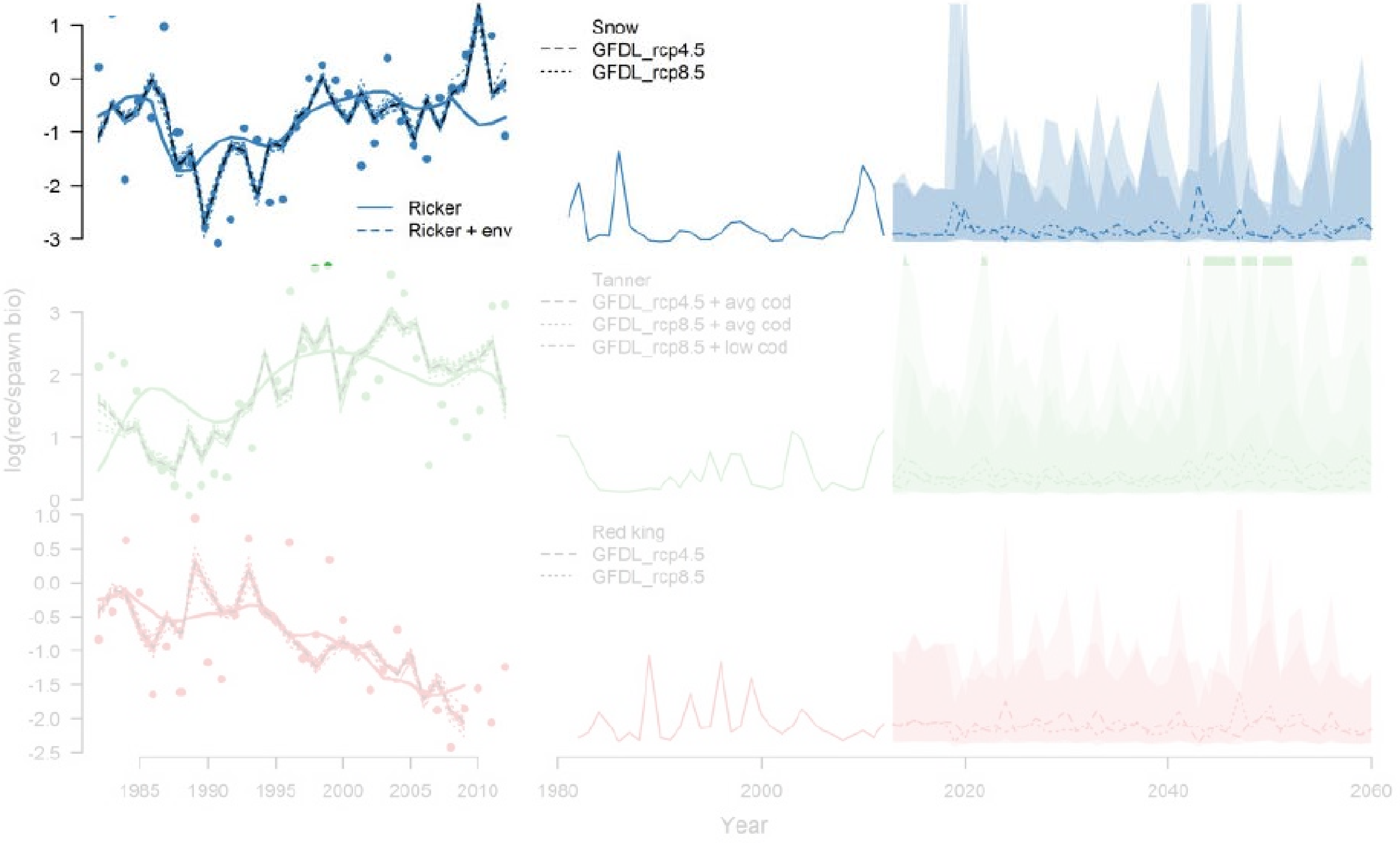
Climate change and the future productivity and distribution of crab in the Bering Sea

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]

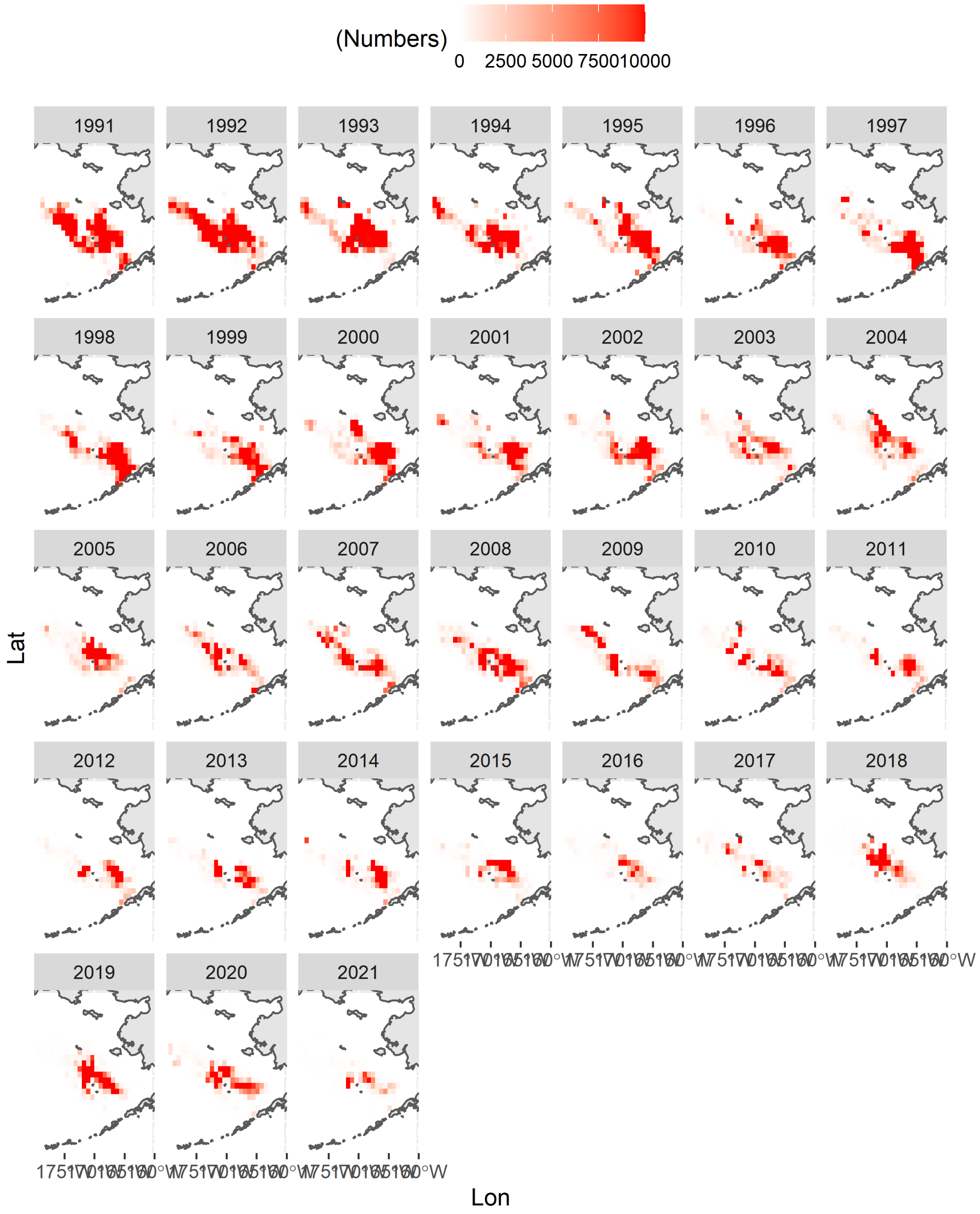
- Built models predicting recruitment based on environmental variables
- Ice and Arctic Oscillation related to snow crab recruits
- Lower recruitment when projected forward under linkages to global climate models



Author recommendations

- Lower projected recruitment
  - Szuwalski et al. 2020
  - However even the lowest scenario is probably optimistic
- Average natural mortality
  - SAFE appendix B & C
  - Temperatures may be high, but densities won’t be
- Status quo unobserved mortality

- Tmin = 2033
- Ttarget = 2030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