

# Review of TACs

## Bering Sea Crab: 2021/22 Season

ADF&G presentation to BSAI crab industry, 19 Oct 2021

Join by ZOOM:

[https://us02web.zoom.us/j/87239667966?pwd=czV4dU  
p5a1hCenRoZmttM1FYZlFsUT09](https://us02web.zoom.us/j/87239667966?pwd=czV4dU<br/>p5a1hCenRoZmttM1FYZlFsUT09)

Meeting ID: 872 3966 7966

Passcode: 976908

# 2021/22 TAC Summary

<b>Fishery</b>	<b>OFL (mill lb)</b>	<b>ABC (mill lb)</b>	<b>TAC (mill lb)</b>
<b>Pribilof blue king crab</b>	<b>0.0026</b> (total catch)	<b>0.0020</b> (total catch)	<b>0</b> (directed fishery closed)
<b>Pribilof red king crab</b>	<b>1.90</b> (total catch)	<b>1.43</b> (total catch)	<b>0</b> (directed fishery closed)
<b>St. Matthew blue king</b>	<b>0.11</b> catch)	<b>0.08</b> (total male catch)	<b>0</b> (directed fishery closed)
<b>Bristol Bay red king crab</b>	<b>4.91</b> (total catch)	<b>3.68</b> (total catch)	<b>0.00</b> (retained catch)
<b>Bering Sea Tanner crab</b>	<b>59.89</b> (total catch)	<b>47.91</b> (total catch)	<b>0 (EBT), 1.10 (WBT)</b> (retained catch)
<b>Bering Sea snow crab</b>	<b>16.53</b> (total catch)	<b>12.35</b> (total catch)	<b>5.60</b> (retained catch)

# BSAI Crab Management Process

## May

- Fisheries conclude
- NPFMC Crab Plan Team meets to discuss model scenarios to review in September with new fishery and survey data

## June/July

- NOAA EBS bottom trawl survey

## August

- Survey data disseminated to assessment authors

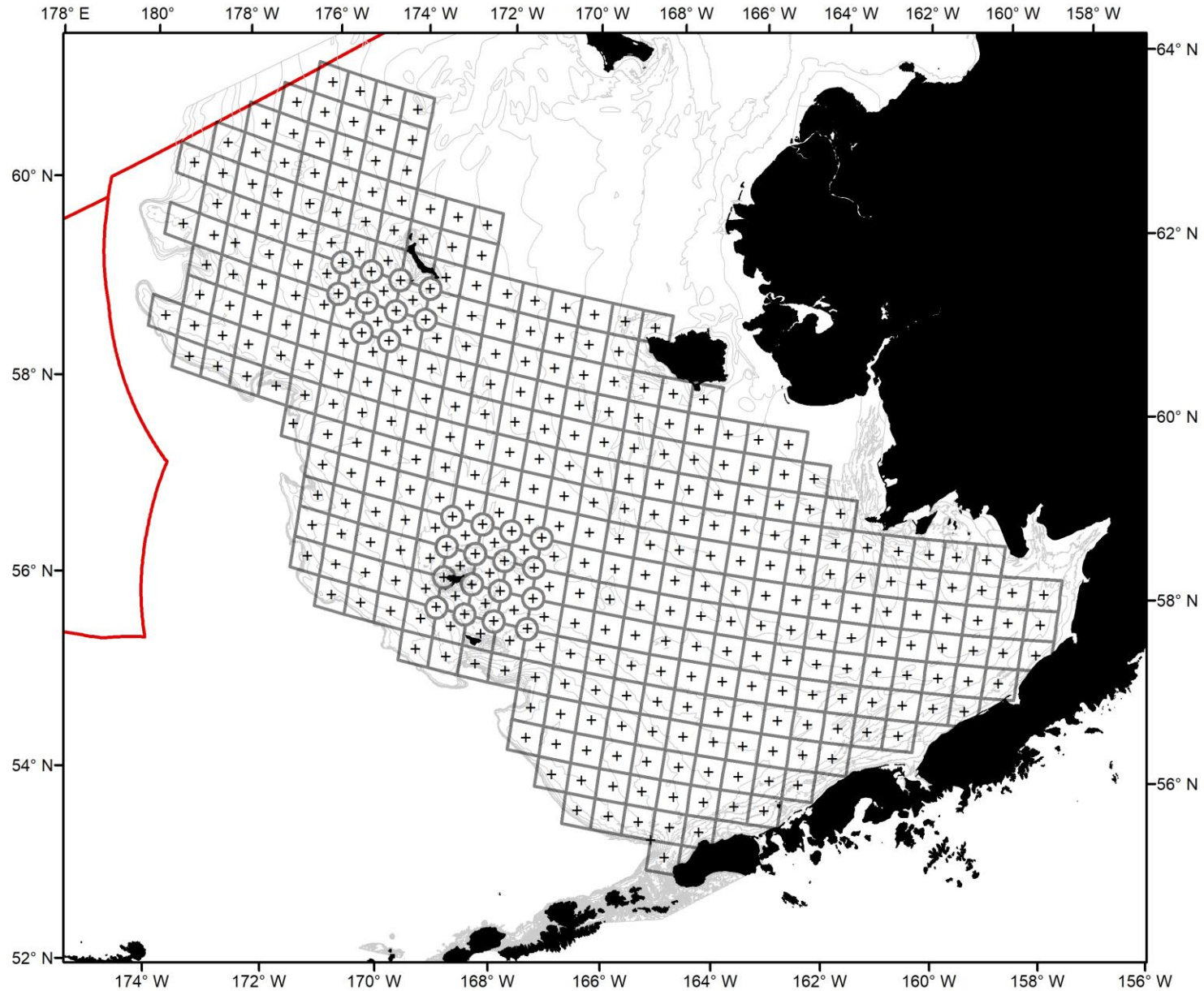
## September/October

- NPFMC Crab Plan Team meet to discuss model performance and recommend OFL/ABC
- NPFMC Scientific and Statistical Committee reviews CPT recommendations and advises Council action
- ADF&G reviews all survey, assessment, fishery, environmental information,..... sets TAC

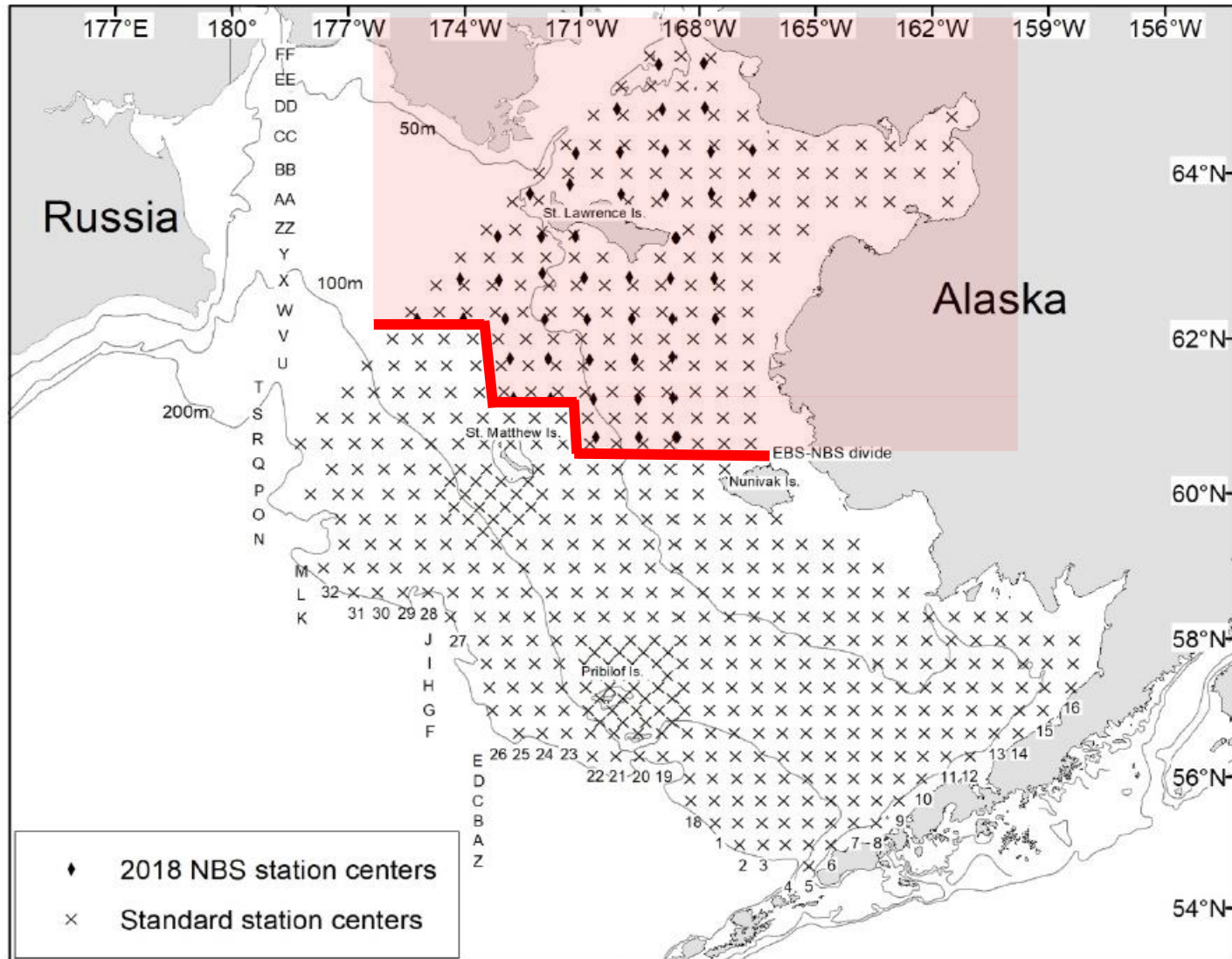
# NOAA EBS bottom trawl survey

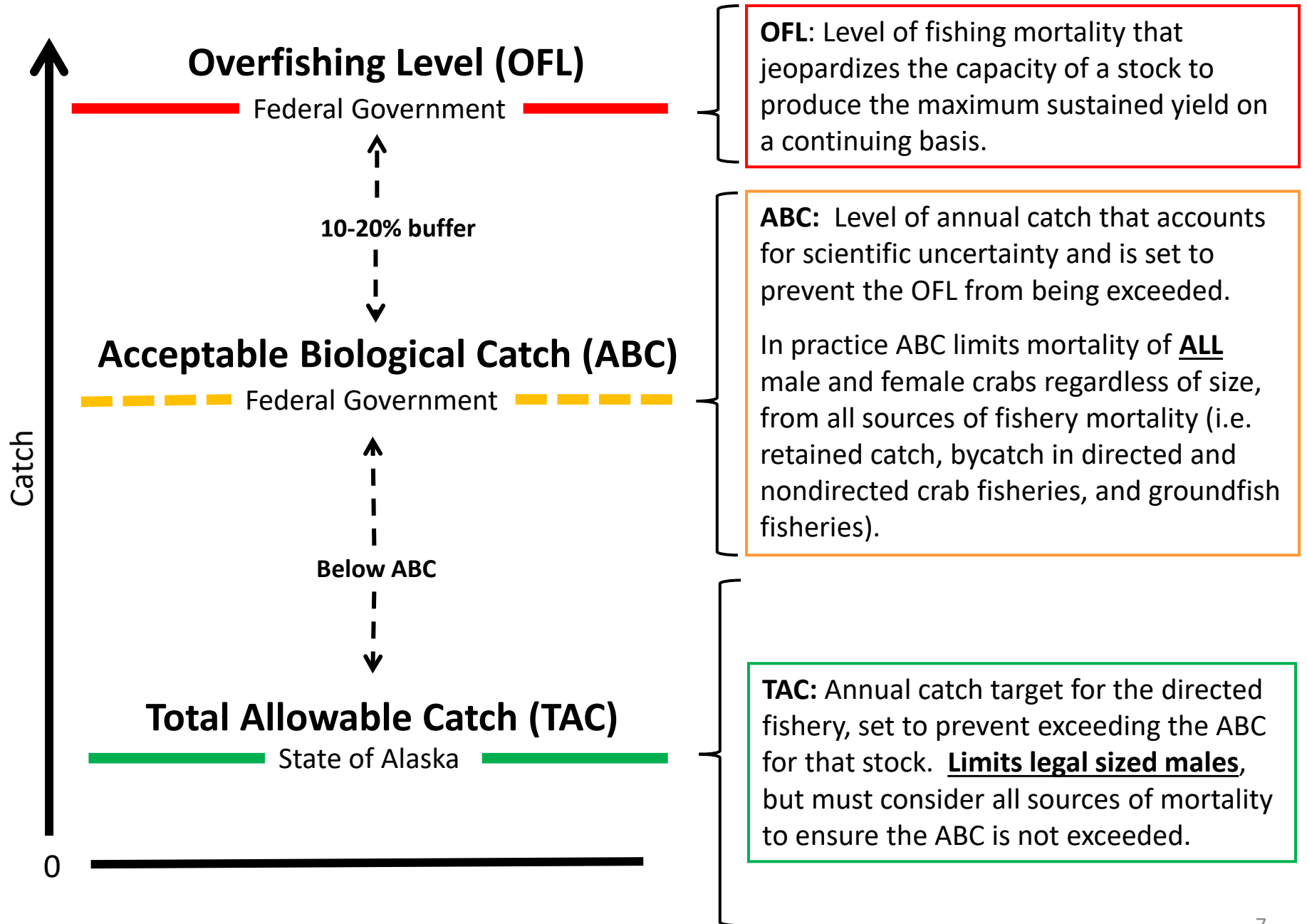
- 375 stations in standardized grid
  - 20 x 20 nmi grid + corner stations (high-density strata)
- Multi-species: crab + groundfish
- 83-112 Eastern otter trawl (83 ft head rope, 112 ft footrope)
  - Same gear since 1982
- Net mensuration gear
  - Bottom contact sensor
  - Net height + *width* sensors
  - GPS used for tow distance
  - Distance fished x net width data yield area-swept estimates for each haul

# NOAA EBS bottom trawl survey



# NOAA EBS + NBS bottom trawl surveys





Snow crab



# 2021 Assessment: scenario 21.2

- SSC + Council adopted CPT recommendations
- Stock status: 33% of  $B_{MSY}$ 
  - **“Overfished”**: Below MSST (50% of  $B_{MSY}$ )
  - Above federal threshold (25%  $B_{MSY}$ ) for fishery closure
- OFL: 16.53 million lbs
- **ABC: 12.35 million lbs**
  - including bycatch mortality of males and females in all fisheries
  - based on a 25% buffer on OFL

# Management Reference Points

**$B_{MSY}$** : Biomass that enables a stock to deliver maximum sustainable yield (i.e., the largest catches that can be taken over the long-term without causing population collapse)

- $B_{35\%}$ : is proxy for  $B_{MSY}$  typically when S-R relationships are unreliable
  - biomass at which spawning biomass per recruit is 35% of unfished levels
- $F_{MSY}$ : Fishing rate that allows for  $B_{MSY}$
- $F_{35\%}$  is proxy for  $F_{MSY}$

**MSST** (minimum stock size threshold): 50% of  $B_{MSY}$

- MMB threshold for a stock to be declared “overfished”

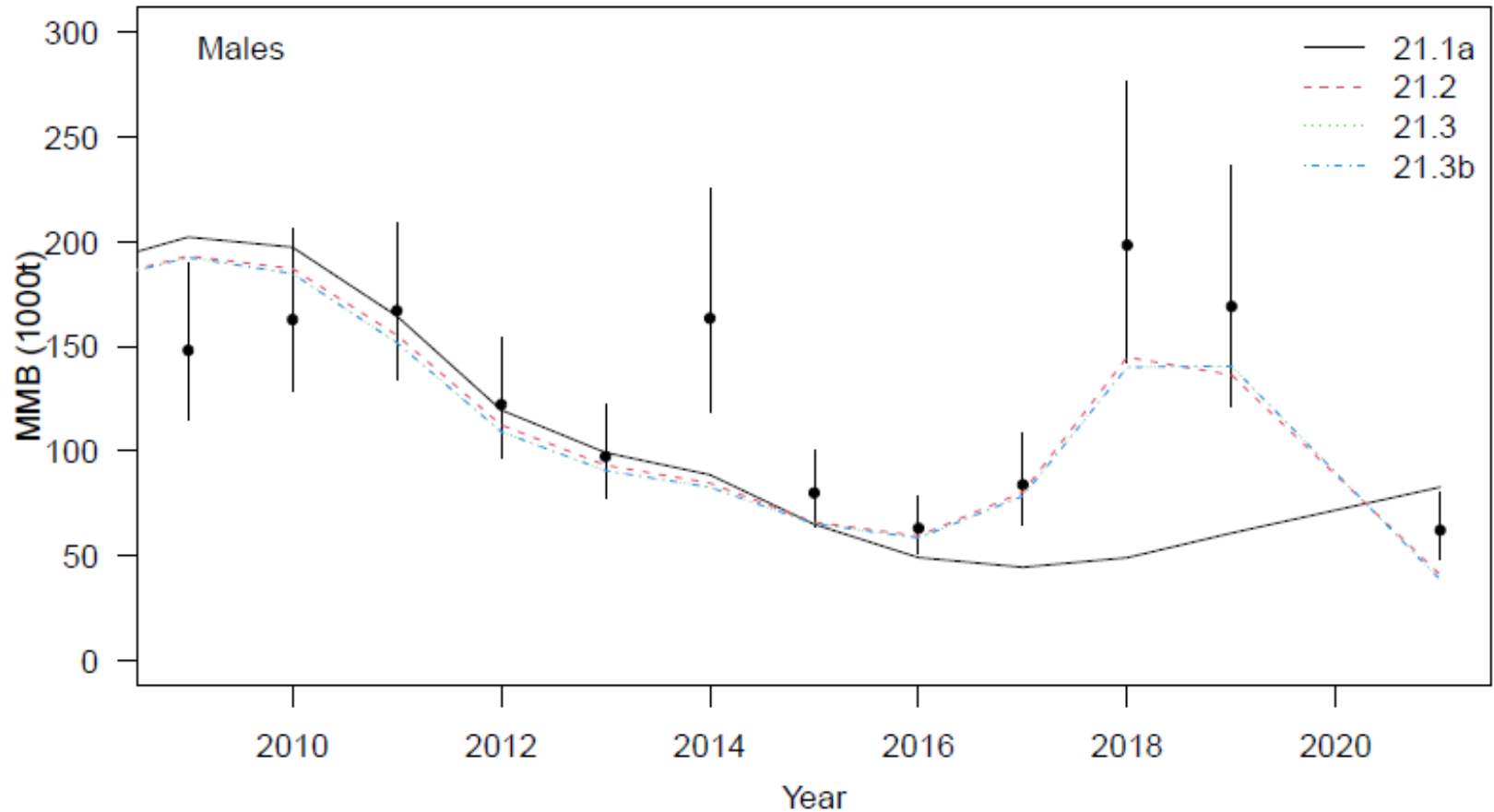
**MMB**: mature male biomass

- Considered “currency” of the stock
- MMB projected to Feb 15, 2022 (proxy time for mating) assuming OFL level removals and  $M$  (natural mortality)
- $MMB/B_{MSY}$  is stock status

# 2021 Assessment

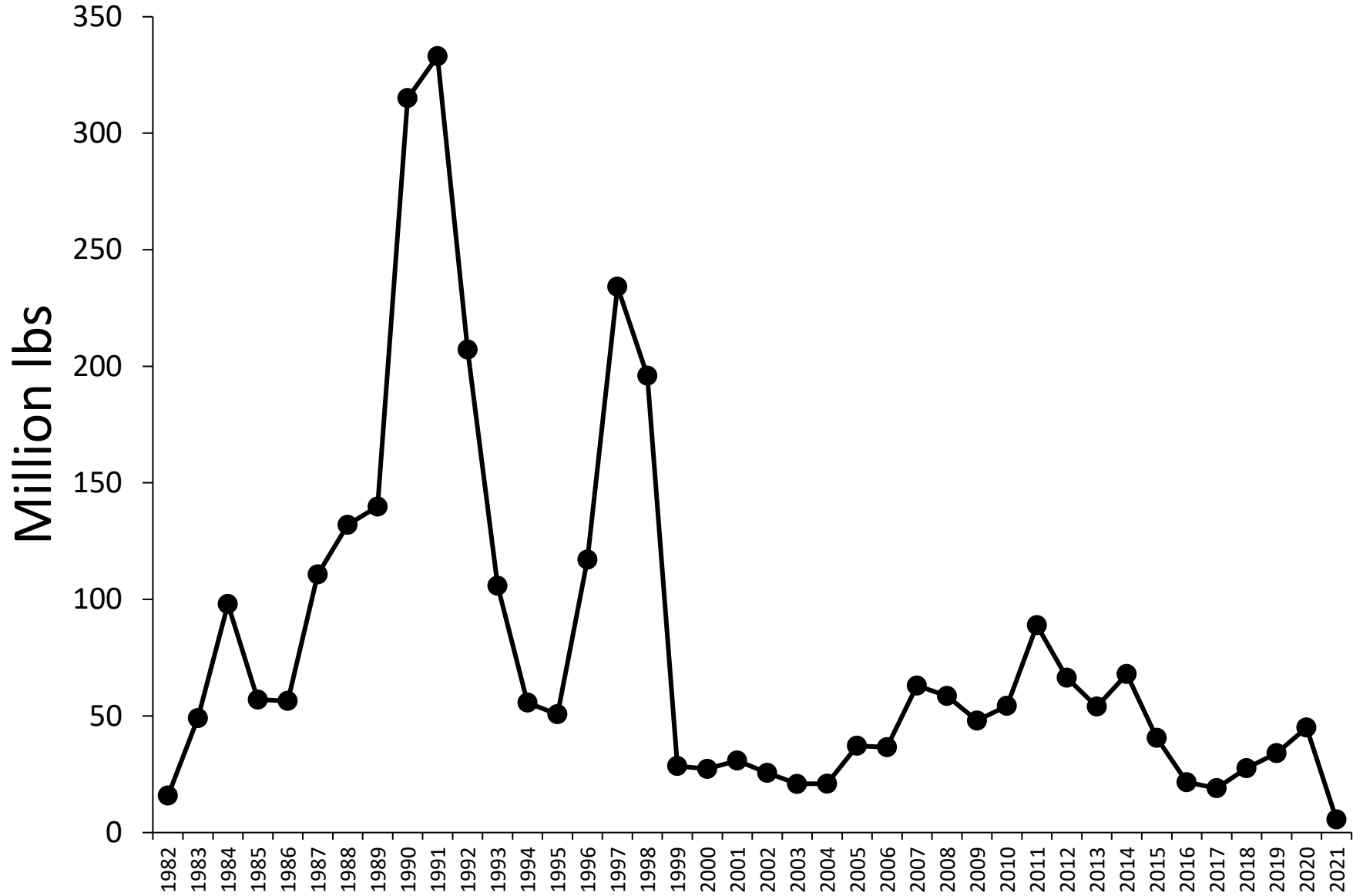
- Cancelled 2020 survey
- Extreme 2021 survey result
- Model convergence issues: status quo model with updated data did not converge
- Author had to get creative in order to get the model to converge
  - Include high mortality events in 2018 + 2019
  - M in recent years most plausible cause of decline: predation, bitter crab, warm bottom temps

# Model fit to terminal year

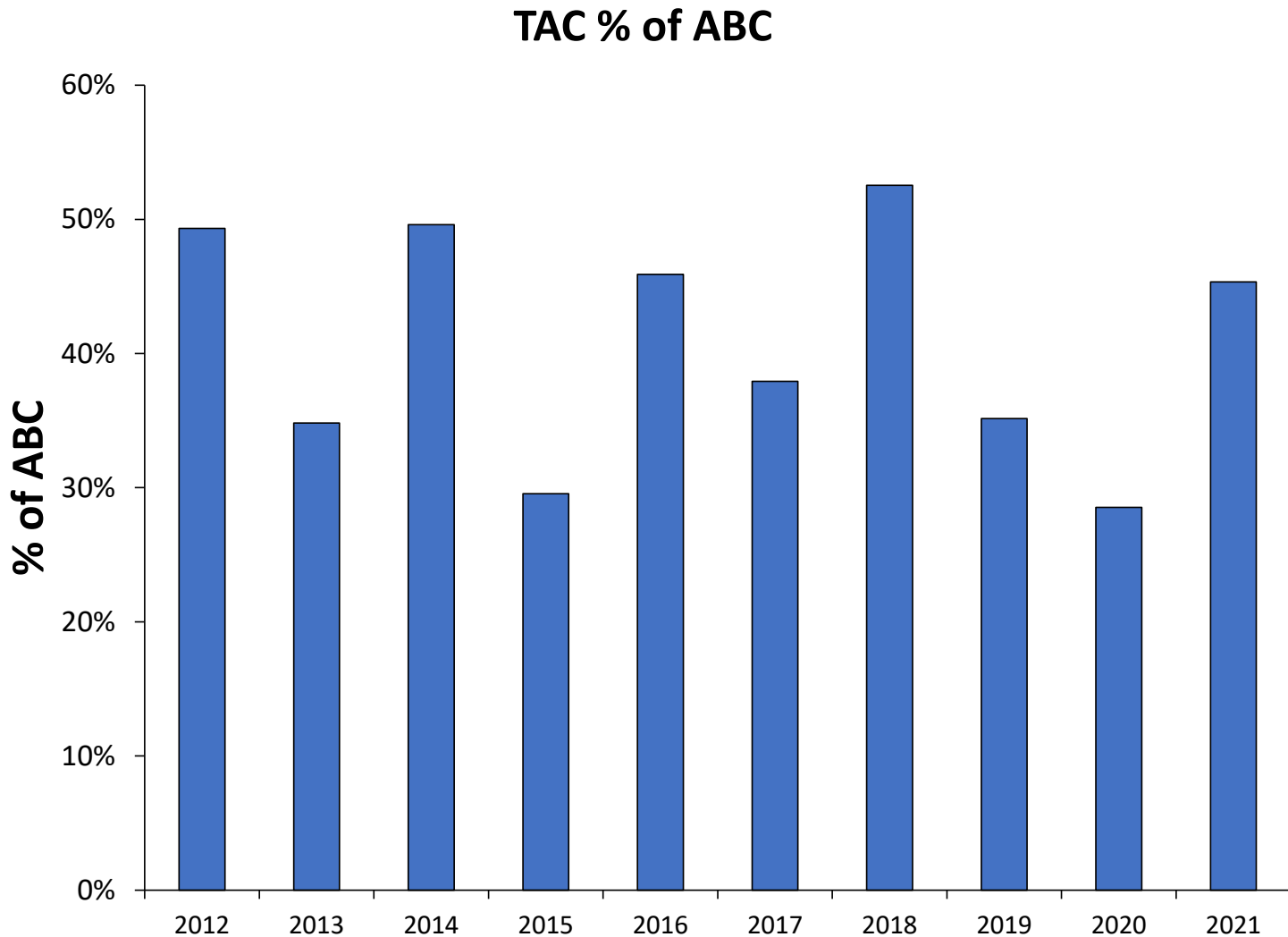


From C. Szuwalski presentation to CPT Sept 2021

# Historical TACs



# Snow crab TAC = 5.6 million lbs



# FMP 8.2.2. Total Allowable Catch and Guideline Harvest Level

The FMP authorizes the State to set preseason TACs and GHs under State regulations.....

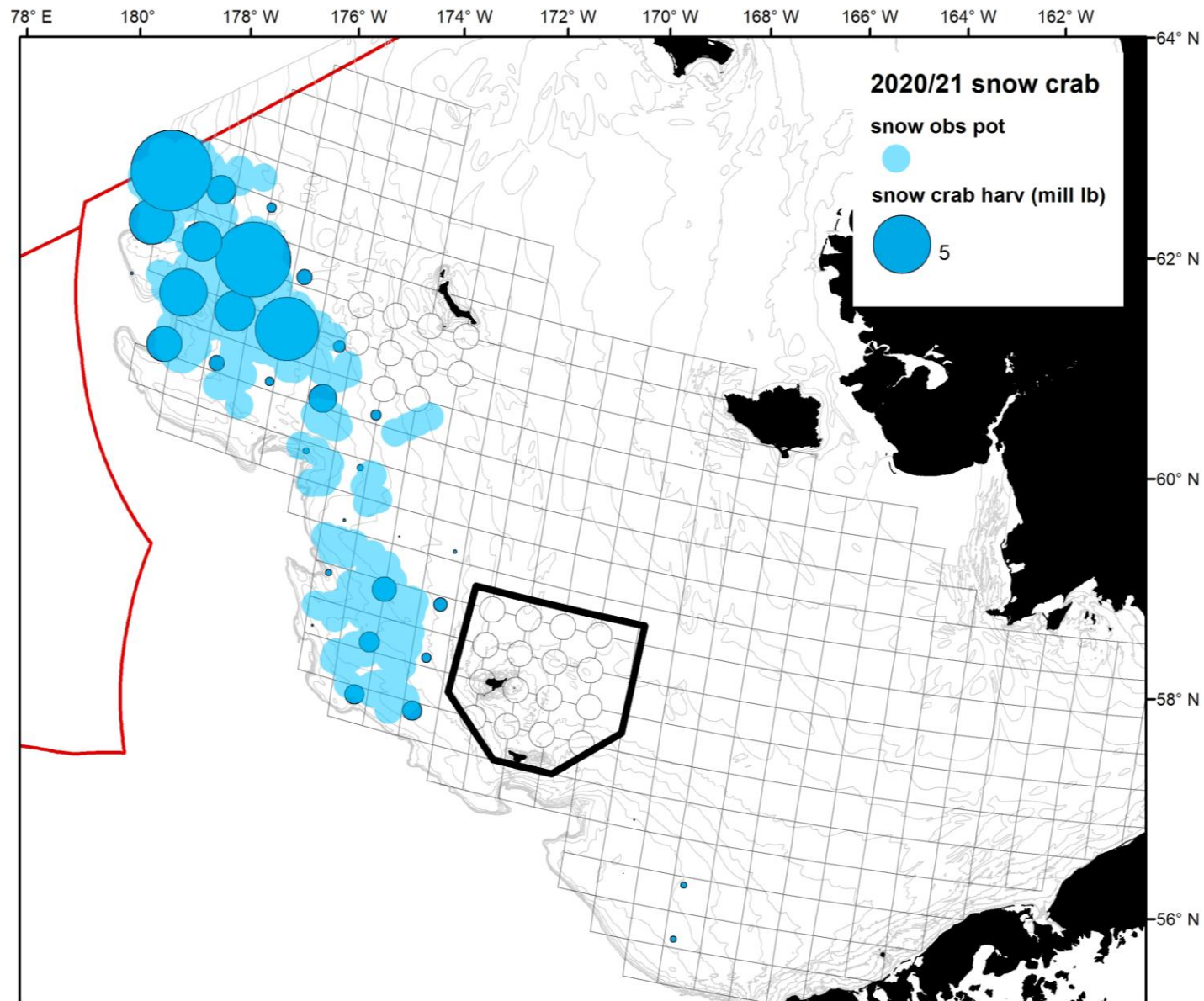
The State will take into account the following factors, to the extent information is available, in developing harvest strategies or setting TACs and GHs:

- (1) whether the (Annual Catch Limit) ACL for that stock was exceeded in the previous year;
- (2) stock status relative to the OFL and ACL;
- (3) estimates of exploitable biomass;
- (4) estimates of recruitment;
- (5) estimates of thresholds;
- (6) market and other economic considerations;
- (7) additional uncertainty; and**
- (8) any additional factors pertaining to the health and status of the stock or the marine ecosystem.**

Additional uncertainty includes:

- (1) management uncertainty (i.e., uncertainty in the ability of managers to constrain catch so the ACL is not exceeded, and uncertainty in quantifying the true catch amount) and
- (2) scientific uncertainty identified and not already accounted for in the ABC** (i.e., uncertainty in bycatch mortality, estimates of trends and absolute estimates of size composition, shell condition, molt status, reproductive condition, spatial distribution, bycatch of non-target crab stocks, environmental conditions, fishery performance, fleet behavior, and the quality and amount of data available for these variables).

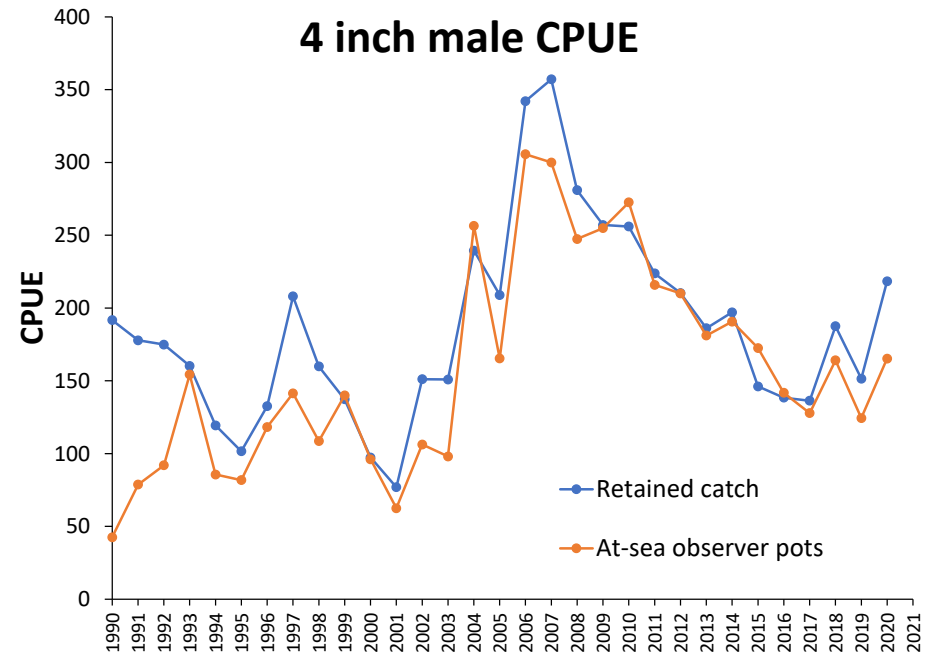
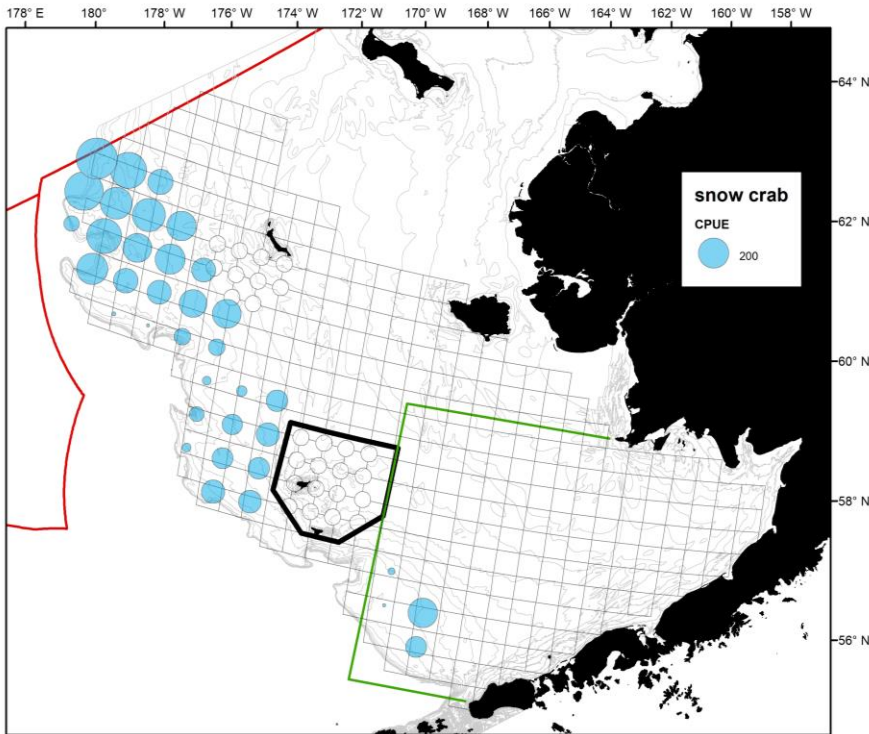
# 2020/21 snow crab retained catch



\* Excludes stat areas with <3 vessels

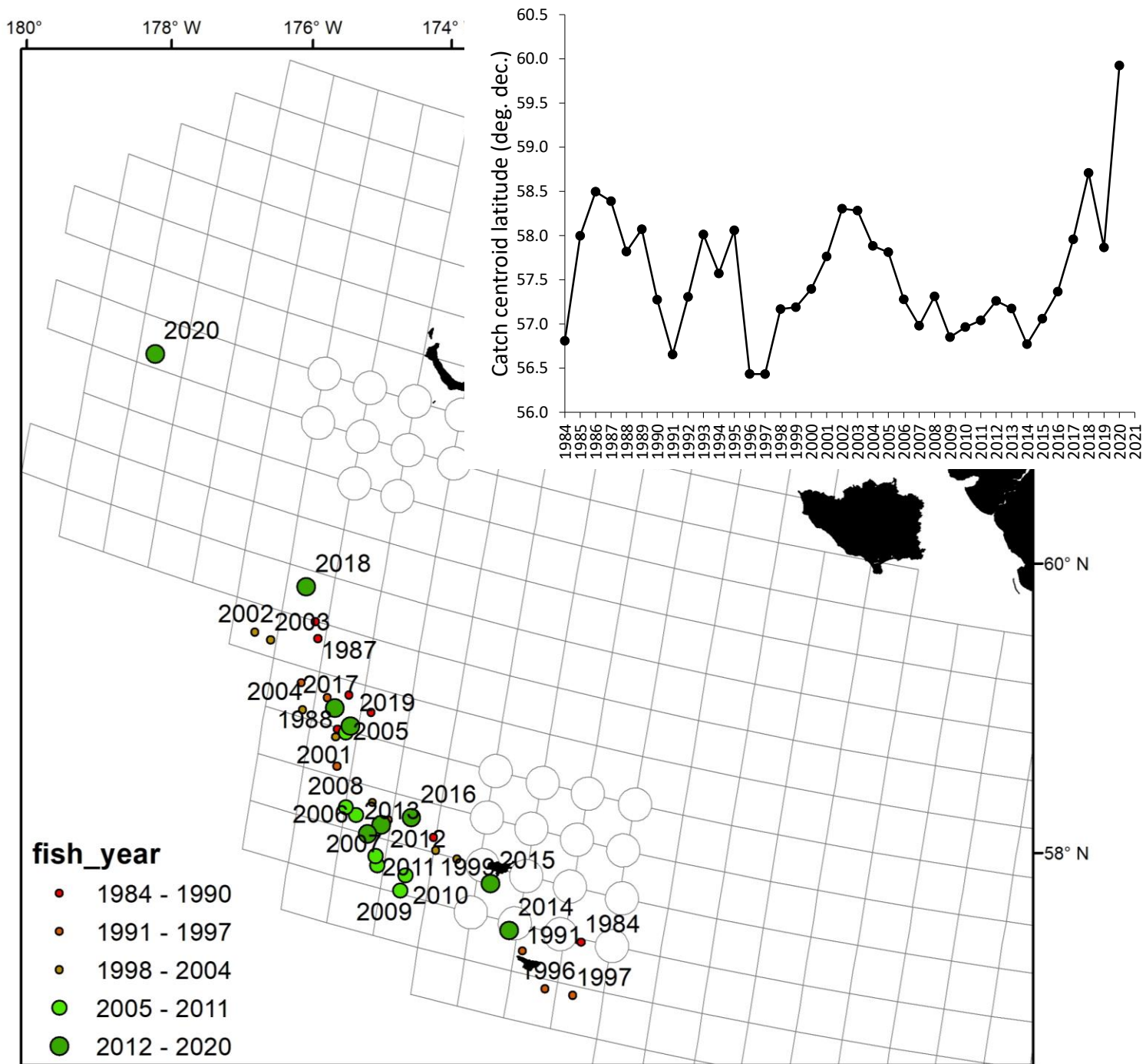


# 2020/21 snow crab fishery CPUE



\* Excludes stat areas with <3 vessels

# Snow crab weighted mean centers of catch

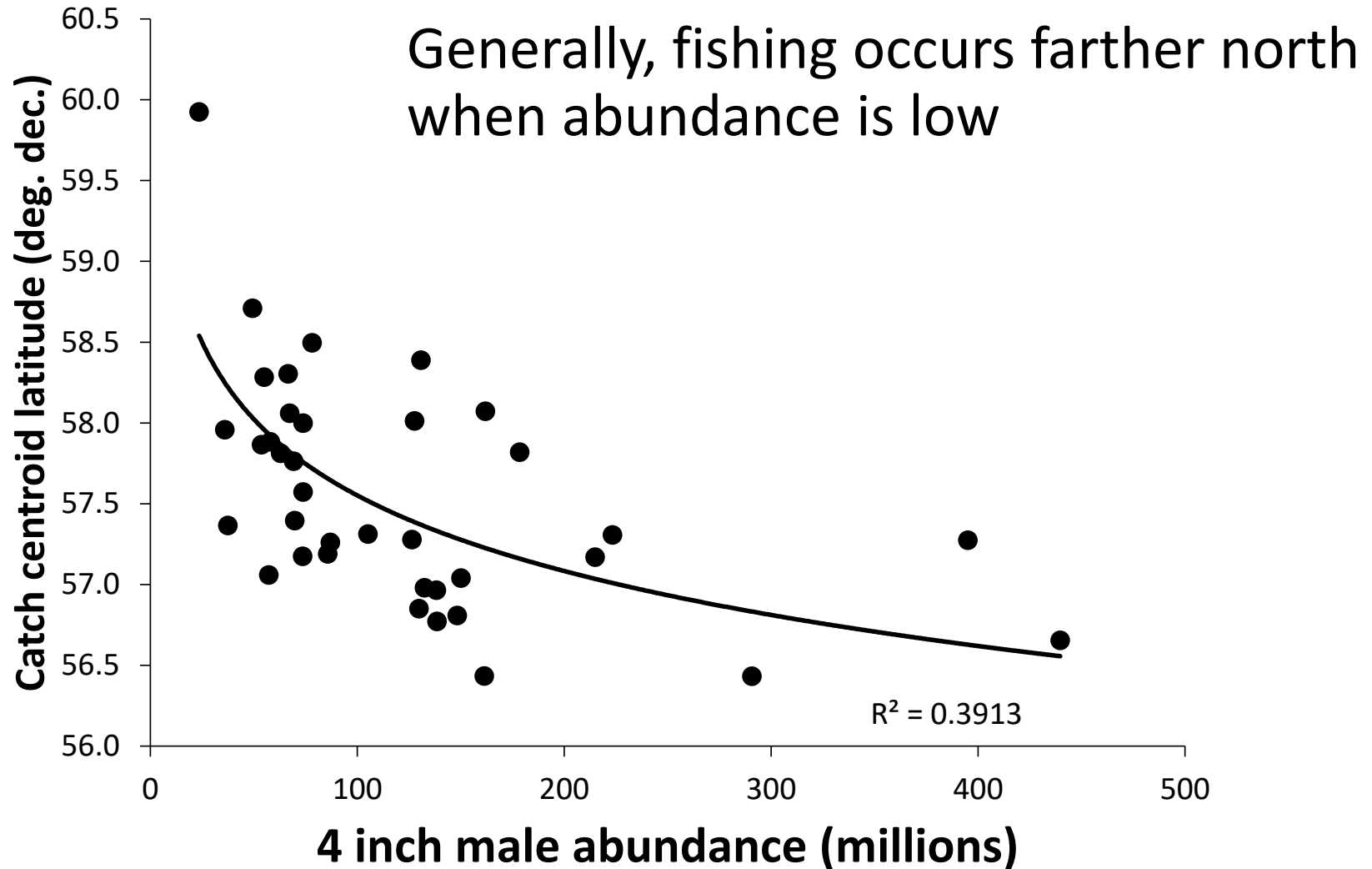


# Historical Accounts (AMRs): 1985/86 period of low abundance

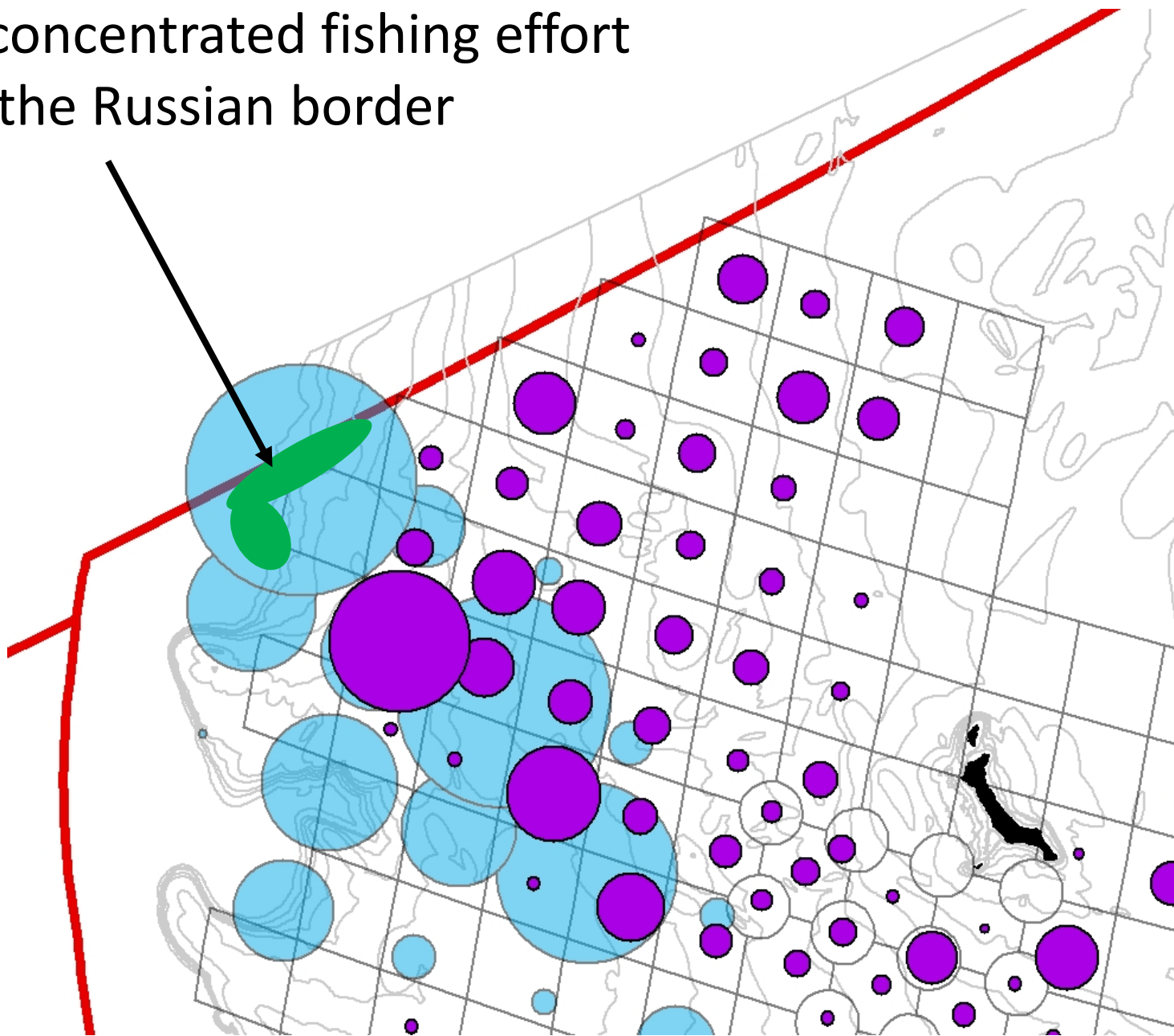
The C. opilio catch of 66.0 million is the largest catch recorded in the eight year history of the fishery and over 13.0 million pounds greater than the previous historic high of 52.7 million pounds taken in 1981 (Table 6). The 8.8 million pounds reported from the Northern sub-district is also the largest catch ever taken from the area. Since this area produced very large, clean shelled crab, more effort can be expected to occur here in 1986. Average catch per pot varied greatly by sub-district during various months but averaged 120 crab per pot for the entire season (Tables 6, 7 and 9).

After the June closure, fishing and processing vessels moved north of 58°N. latitude. With a greater fishing effort and the ability to deliver crab to a floater processor at St. Matthew Island, new grounds were quickly exploited. Fishing occurred as far west as 179° W. longitude and north to 60° N. latitude. Much of the new grounds produced very high catches per pot and average weights (Table 8). Some catcher/processors were able to take a 4½ to 4½ inch crab, averaging 1.5 pounds or greater. The average width for all districts was 109.5 mm, 4 & 5/16 inches (Figures 5 & 6).

# Historical fishing behavior



Lots of concentrated fishing effort  
right at the Russian border

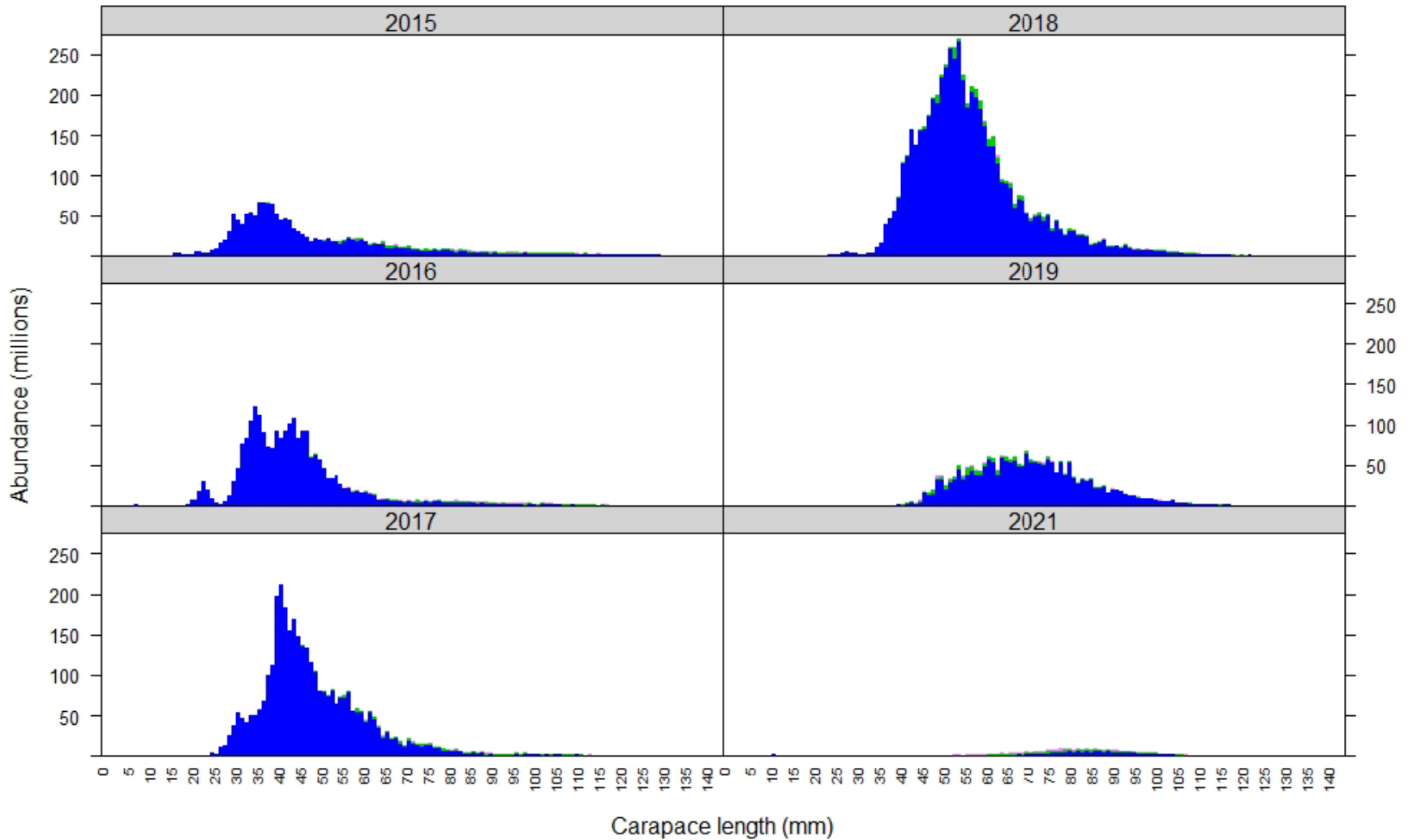


# NOAA survey

## Snow Crab (male)

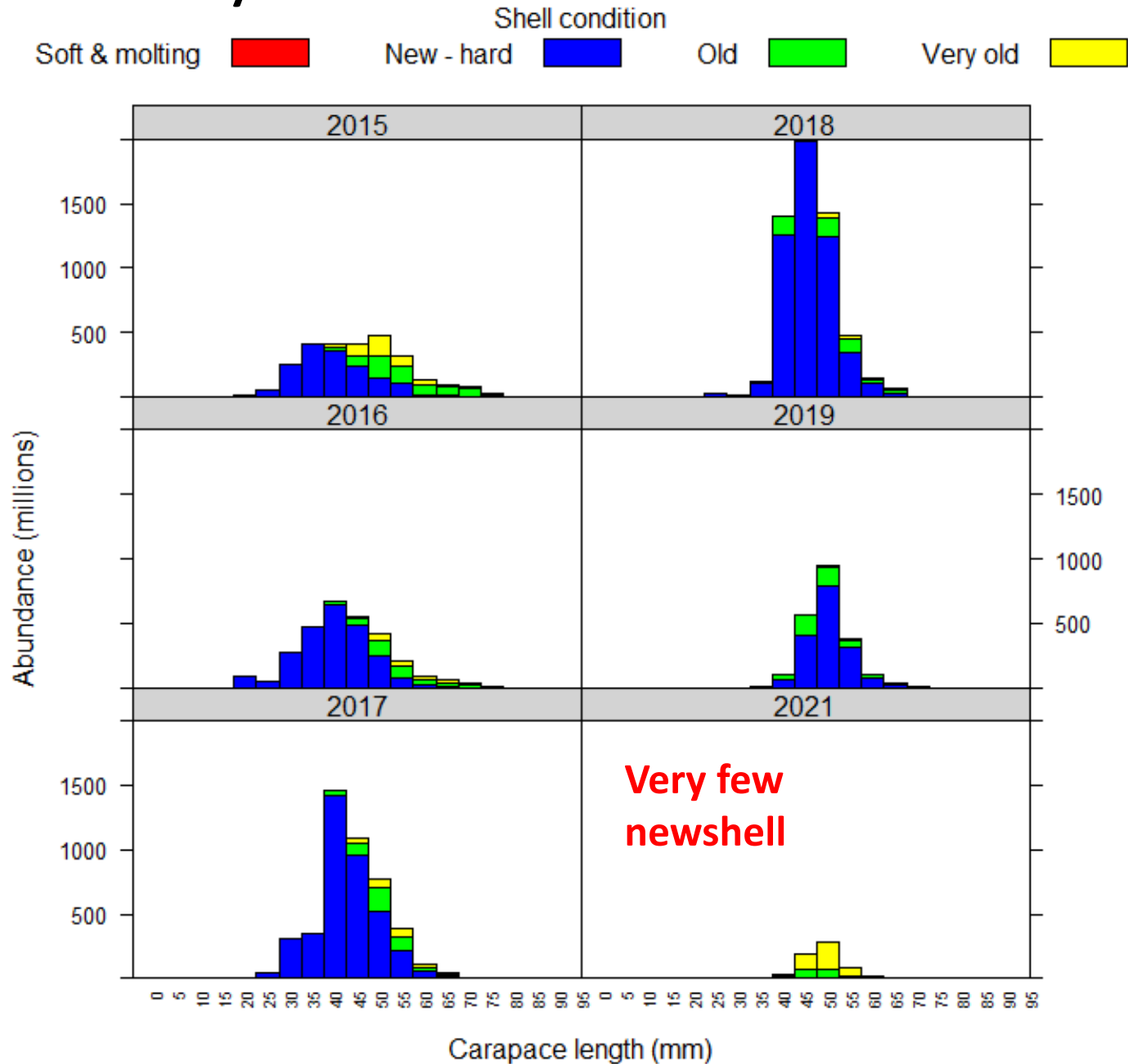
Shell condition

Molting & soft ■ New - hard ■ Old ■ Very old ■

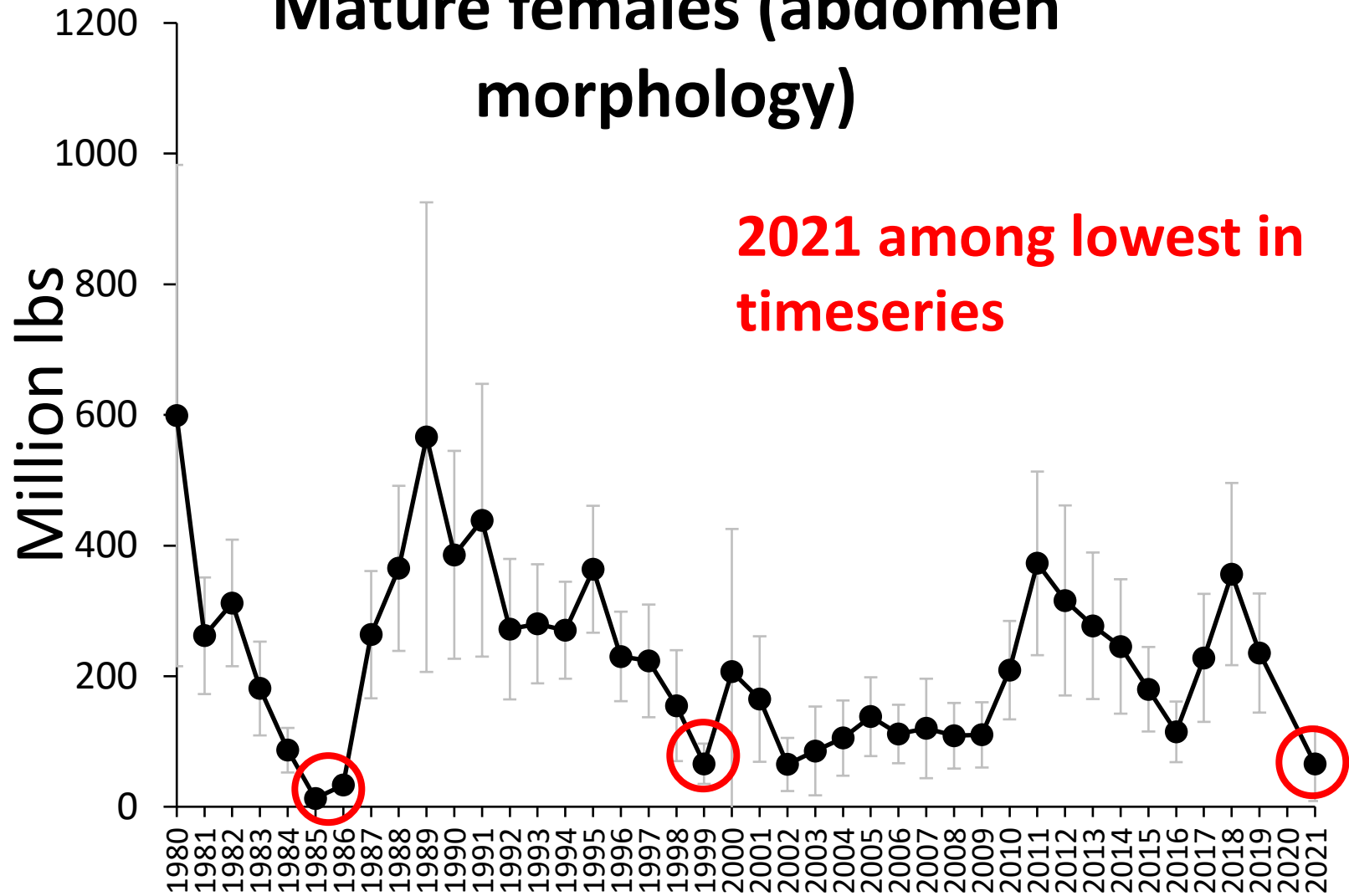


# NOAA survey

## Female snow crab

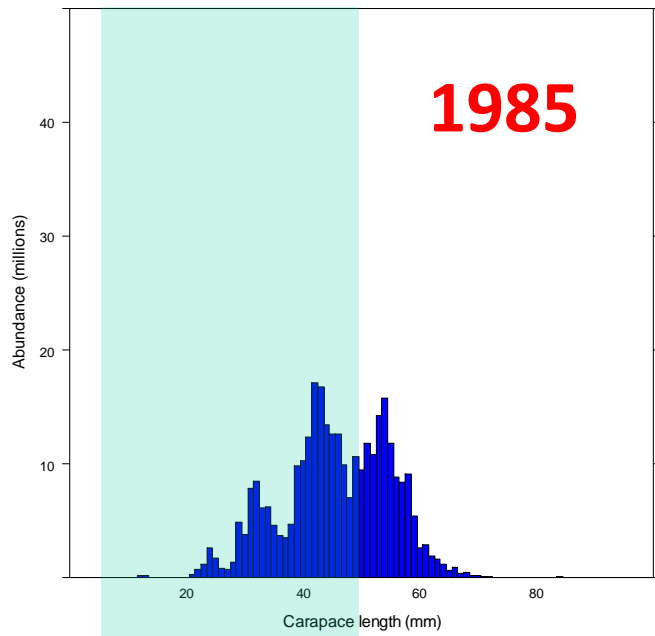


# Mature females (abdomen morphology)

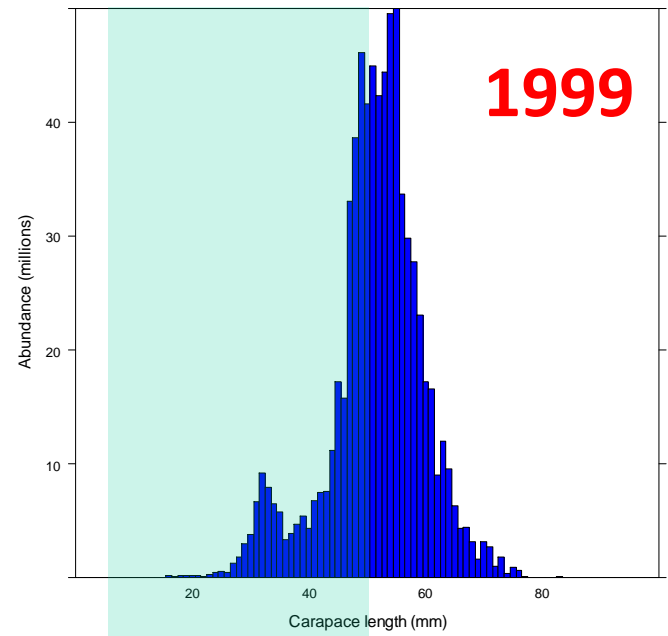




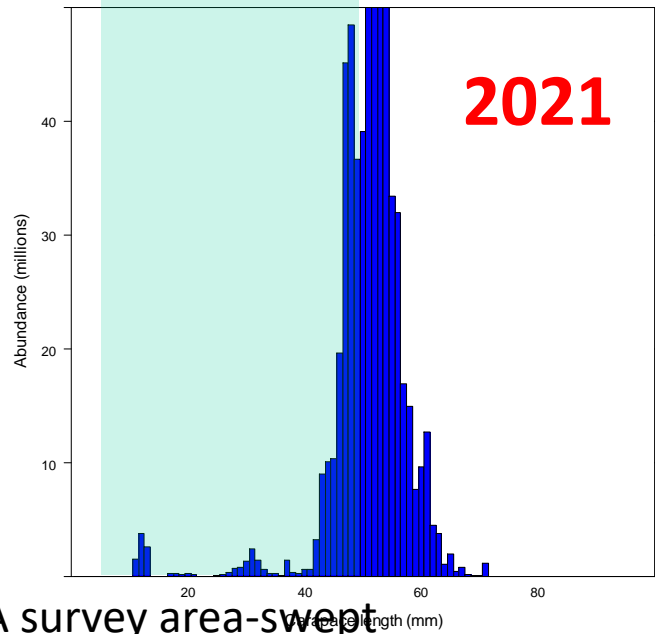
Female snow crab 1985



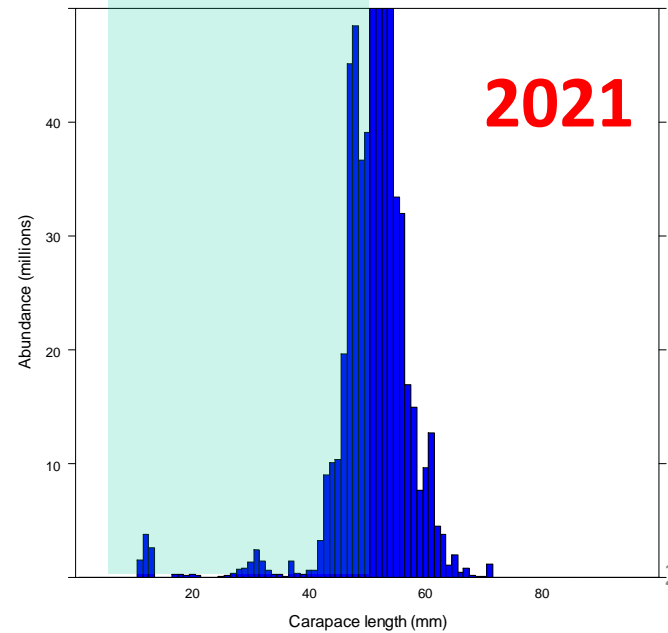
Female snow crab 1999



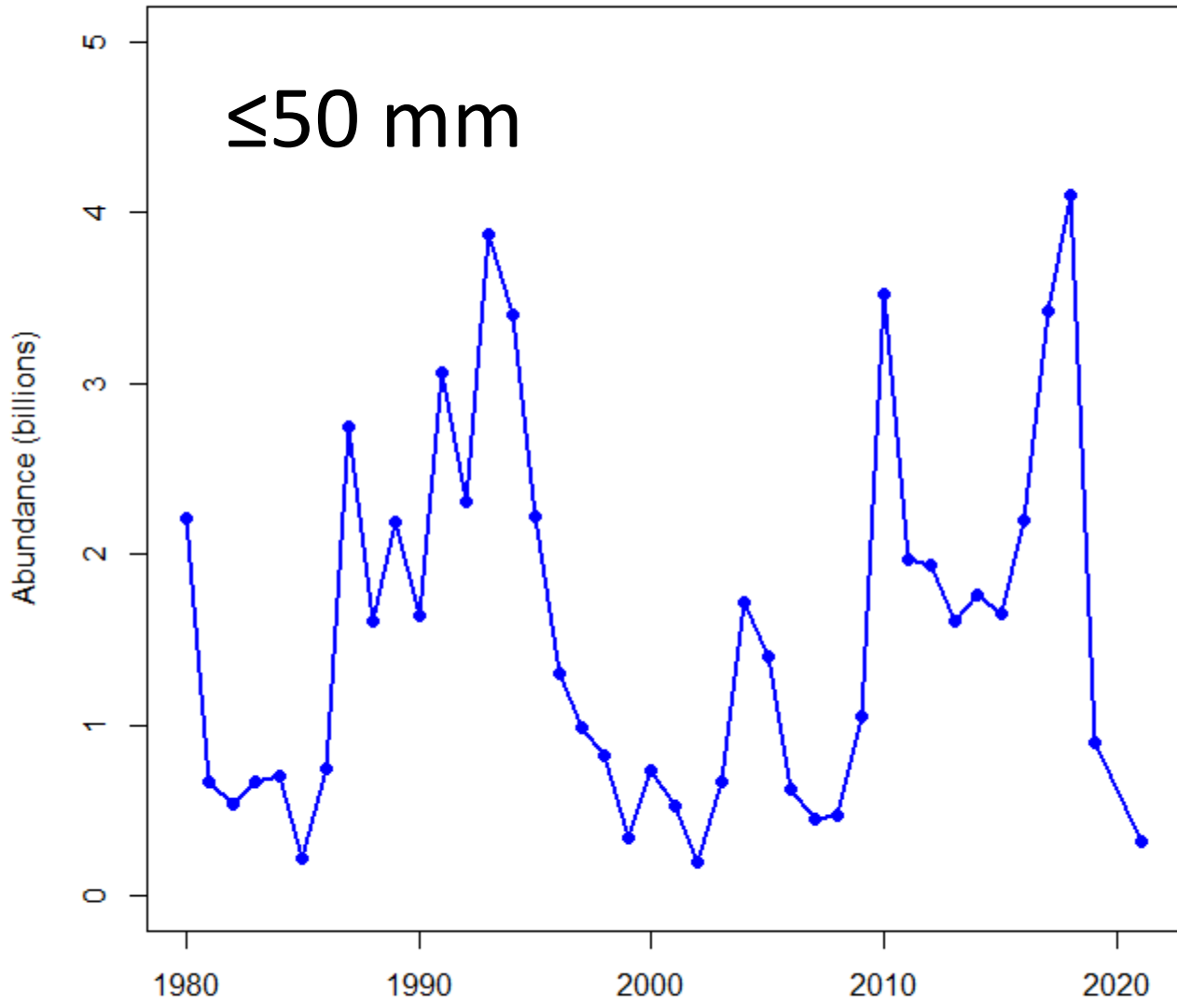
Female snow crab 2021



Female snow crab 2021

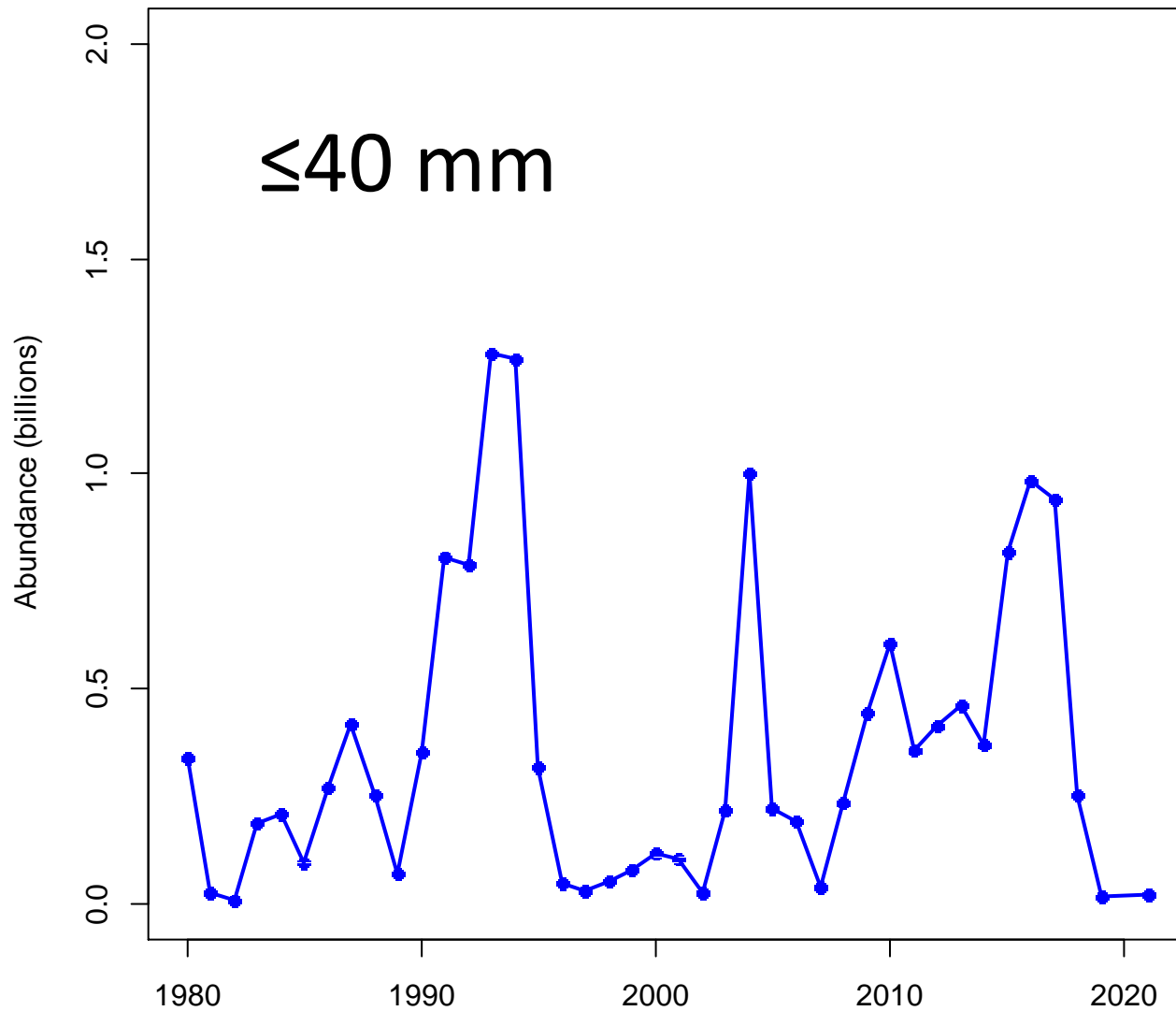


### FEMALE snow crab <50 (raw survey)



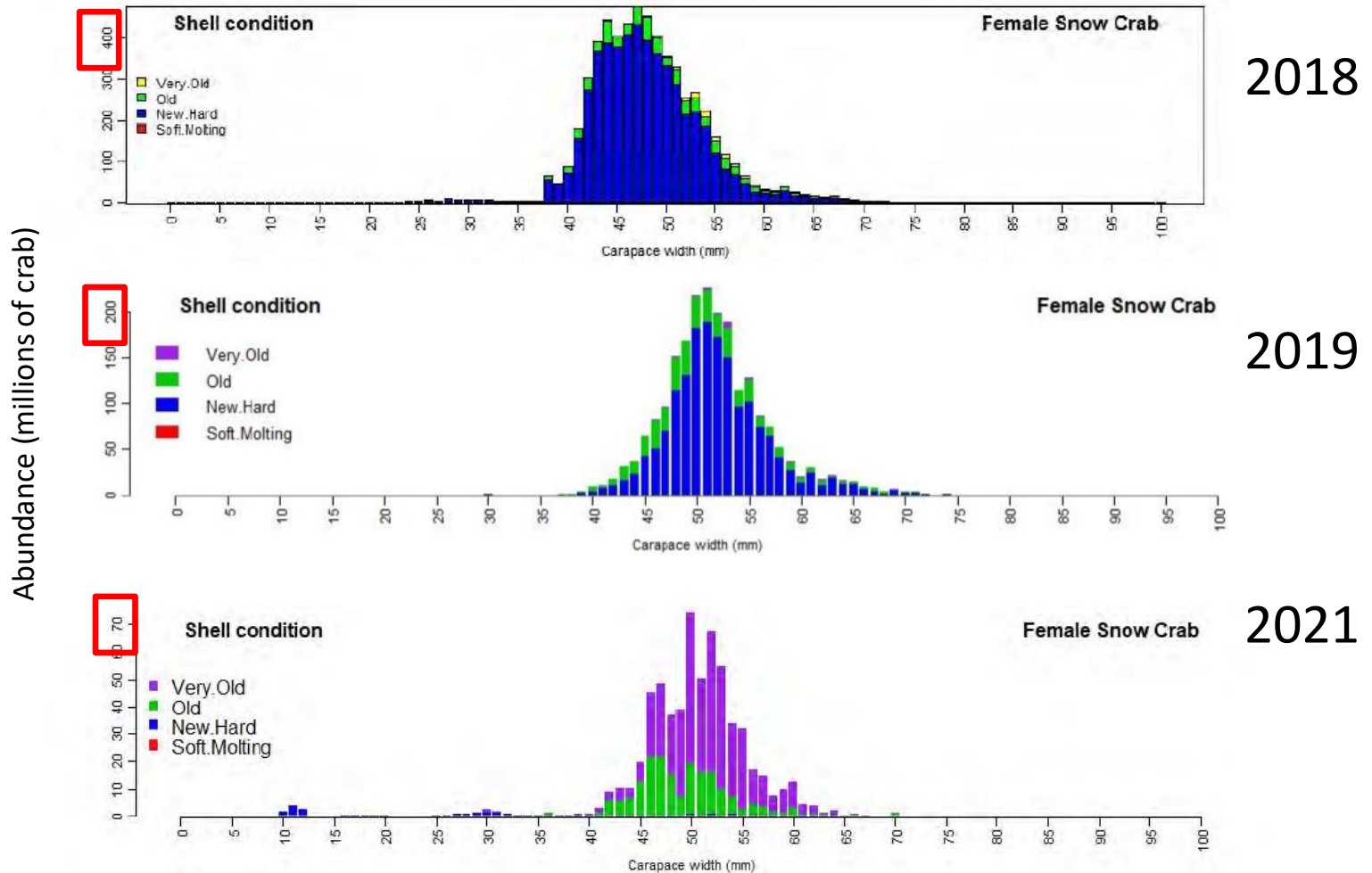
**2021 among the lowest we've seen**

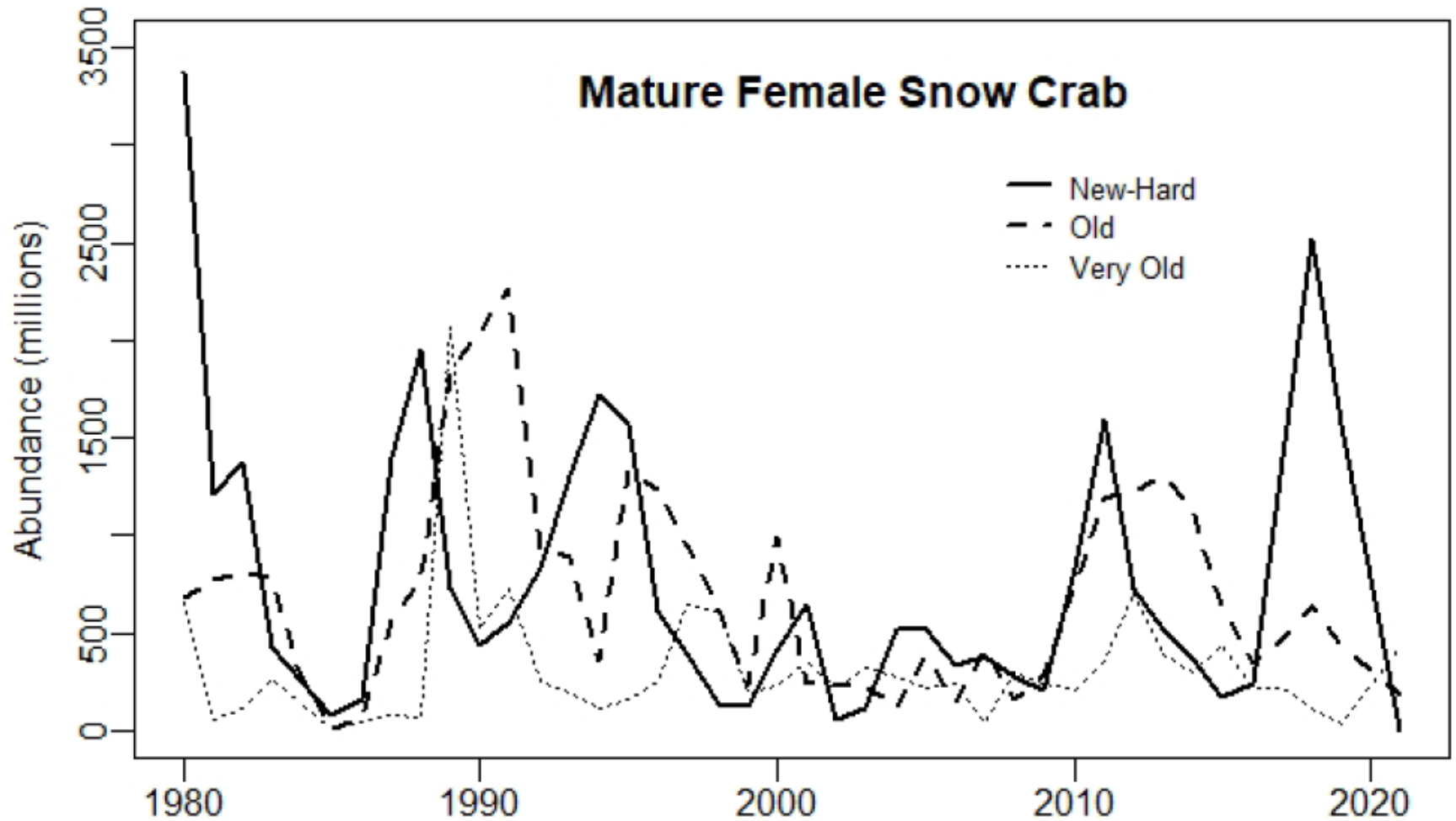
# FEMALE snow crab <40 (raw survey)



**2021 among  
the lowest  
we've seen**

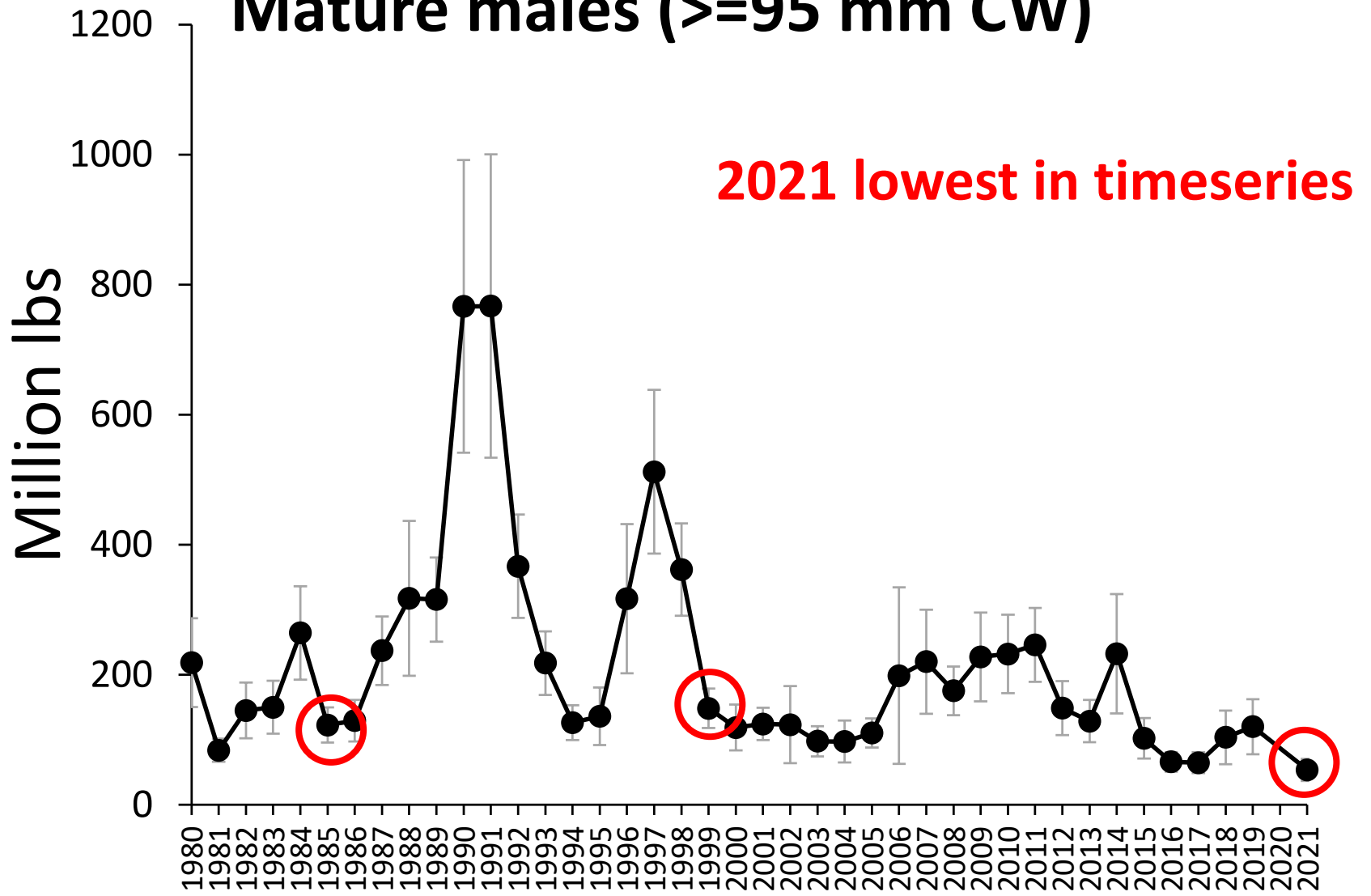
# Female abundance by shell condition



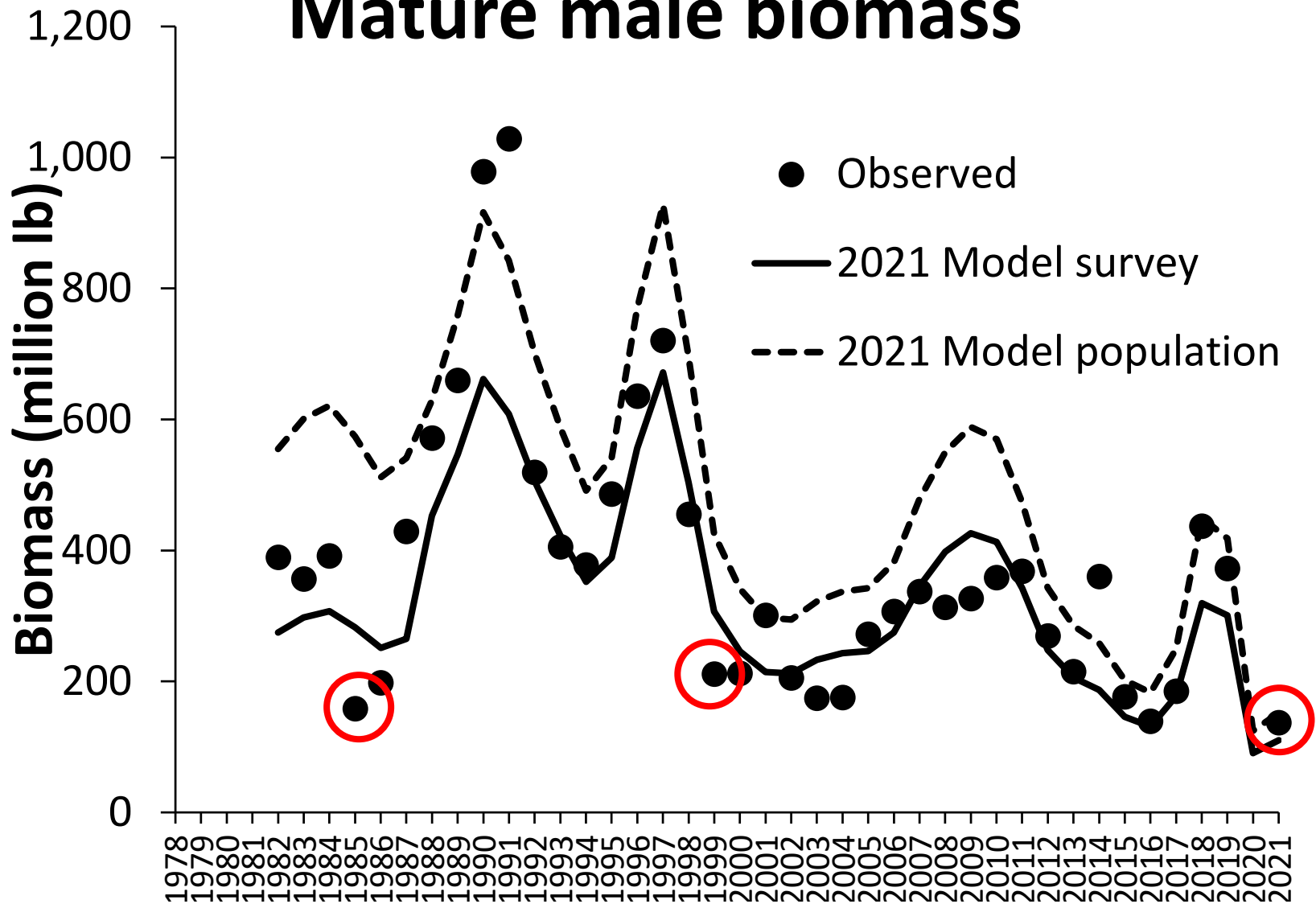


- No newshell mature females in 2021
- Decrease in oldshell
- Increase in very oldshell
- Oldshell females start cycling out of population in next few years

# Mature males ( $\geq 95$ mm CW)

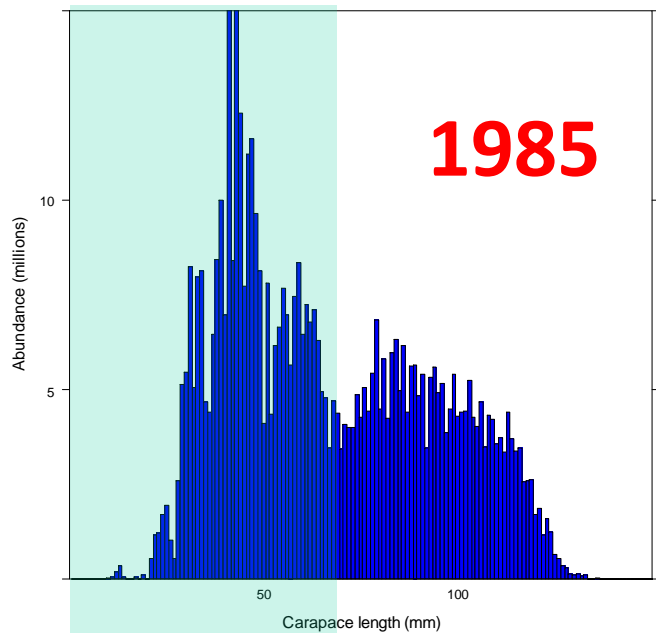


# Mature male biomass

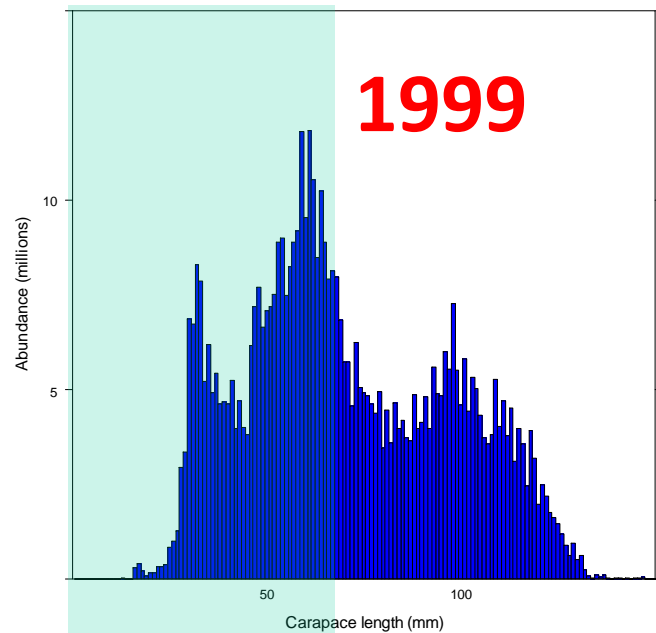


**2021 lowest in timeseries**

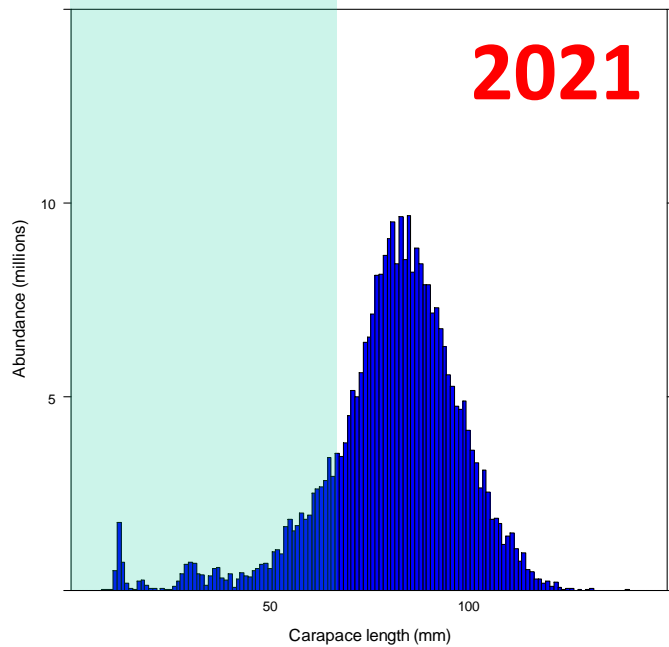
Male snow crab 1985



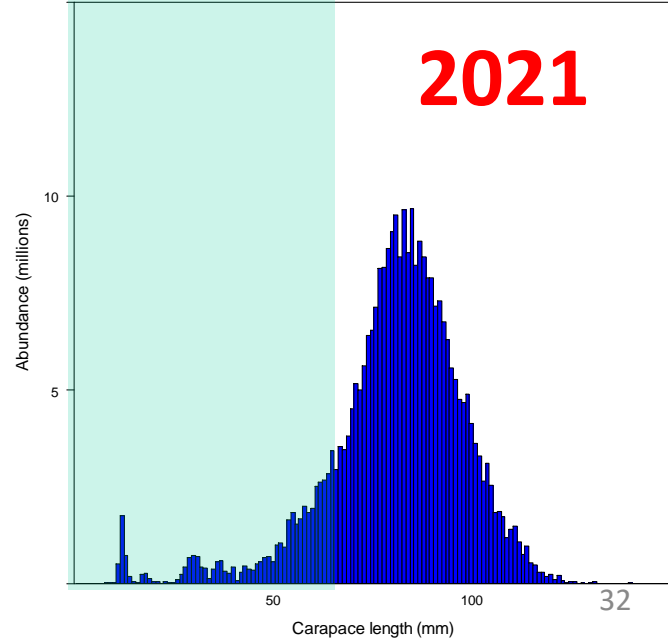
Male snow crab 1999



Male snow crab 2021

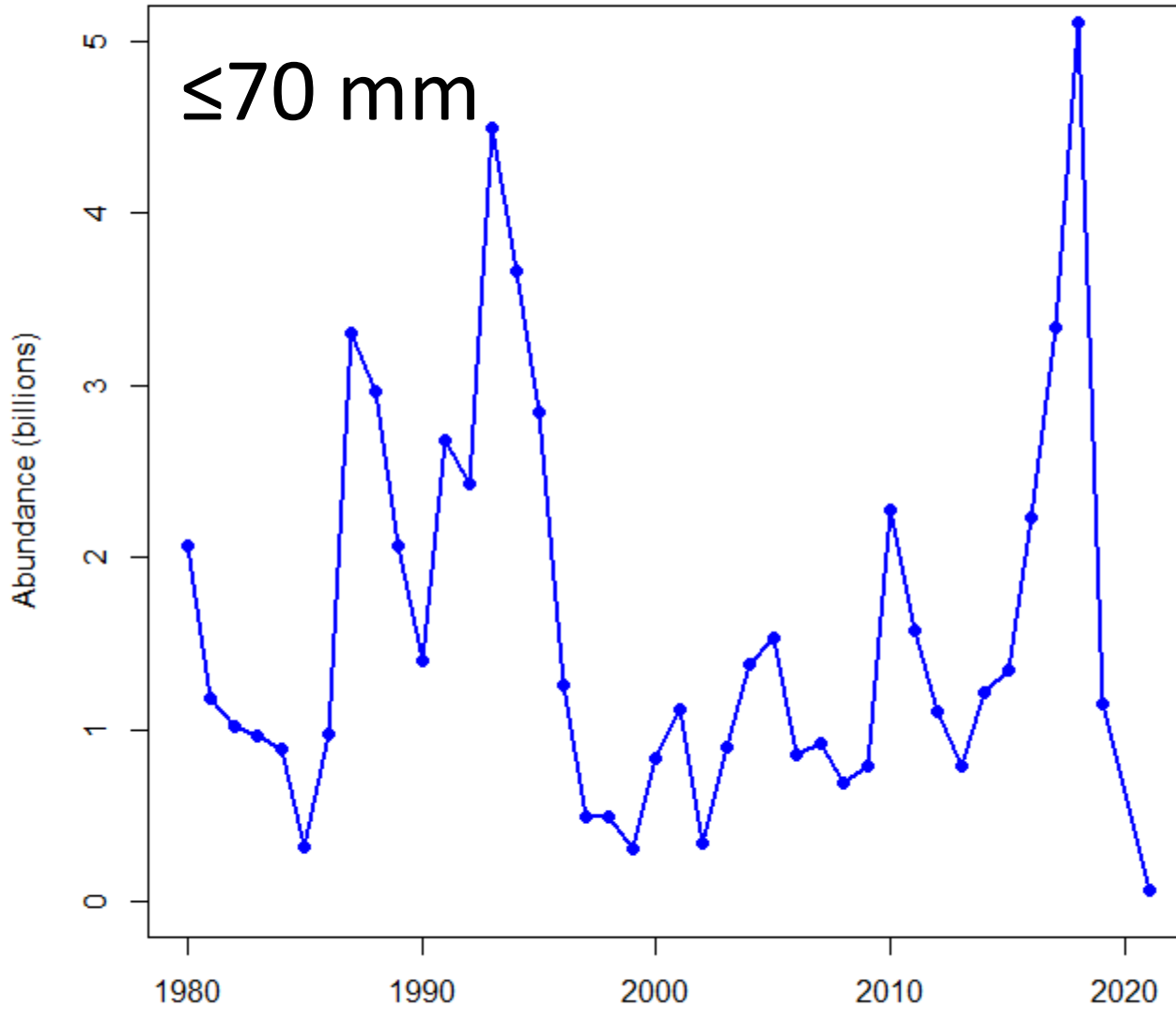


Male snow crab 2021



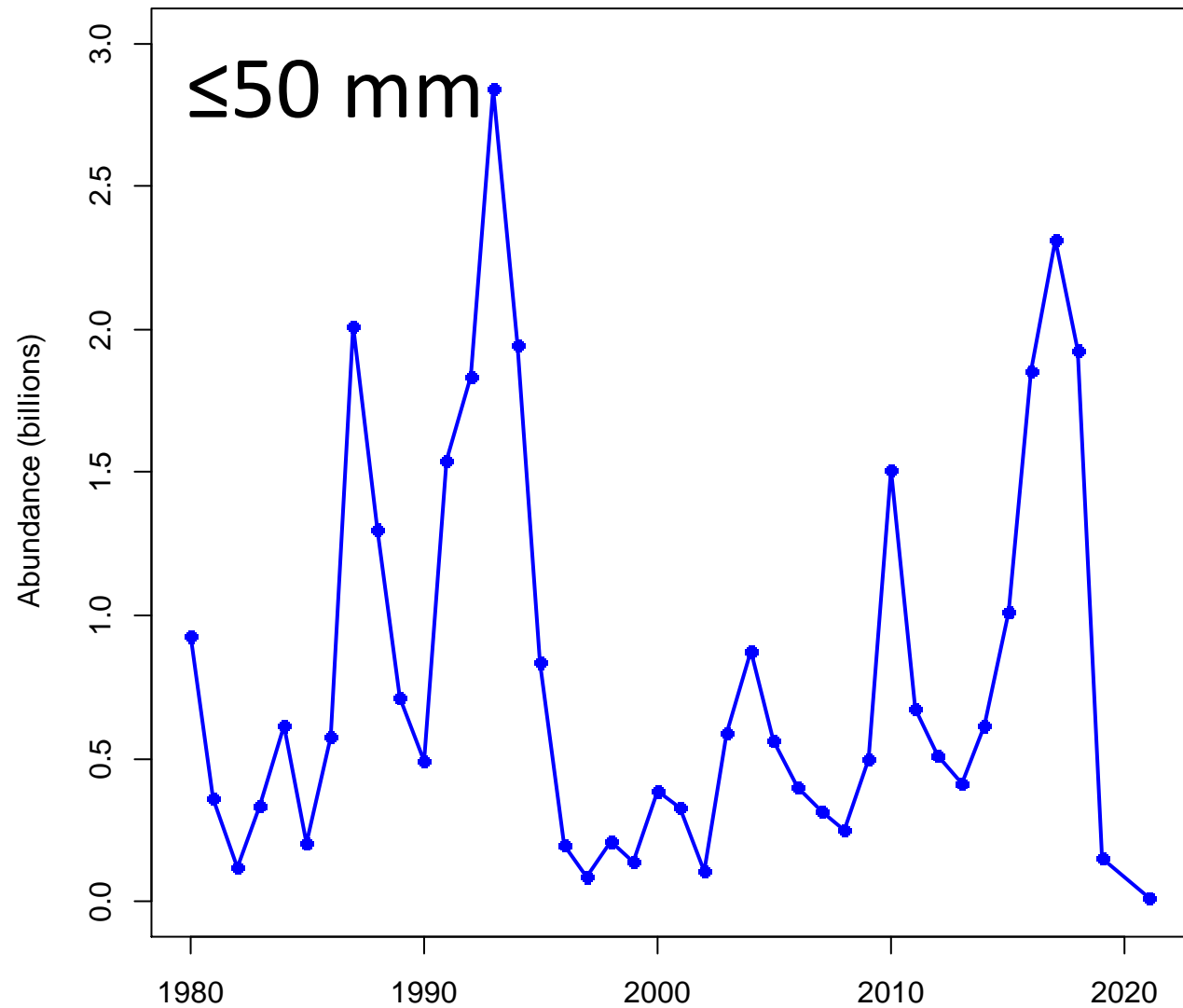


### MALE snow crab <70 (raw survey)



**2021 lowest  
in timeseries  
for male crab  
≤70 mm**

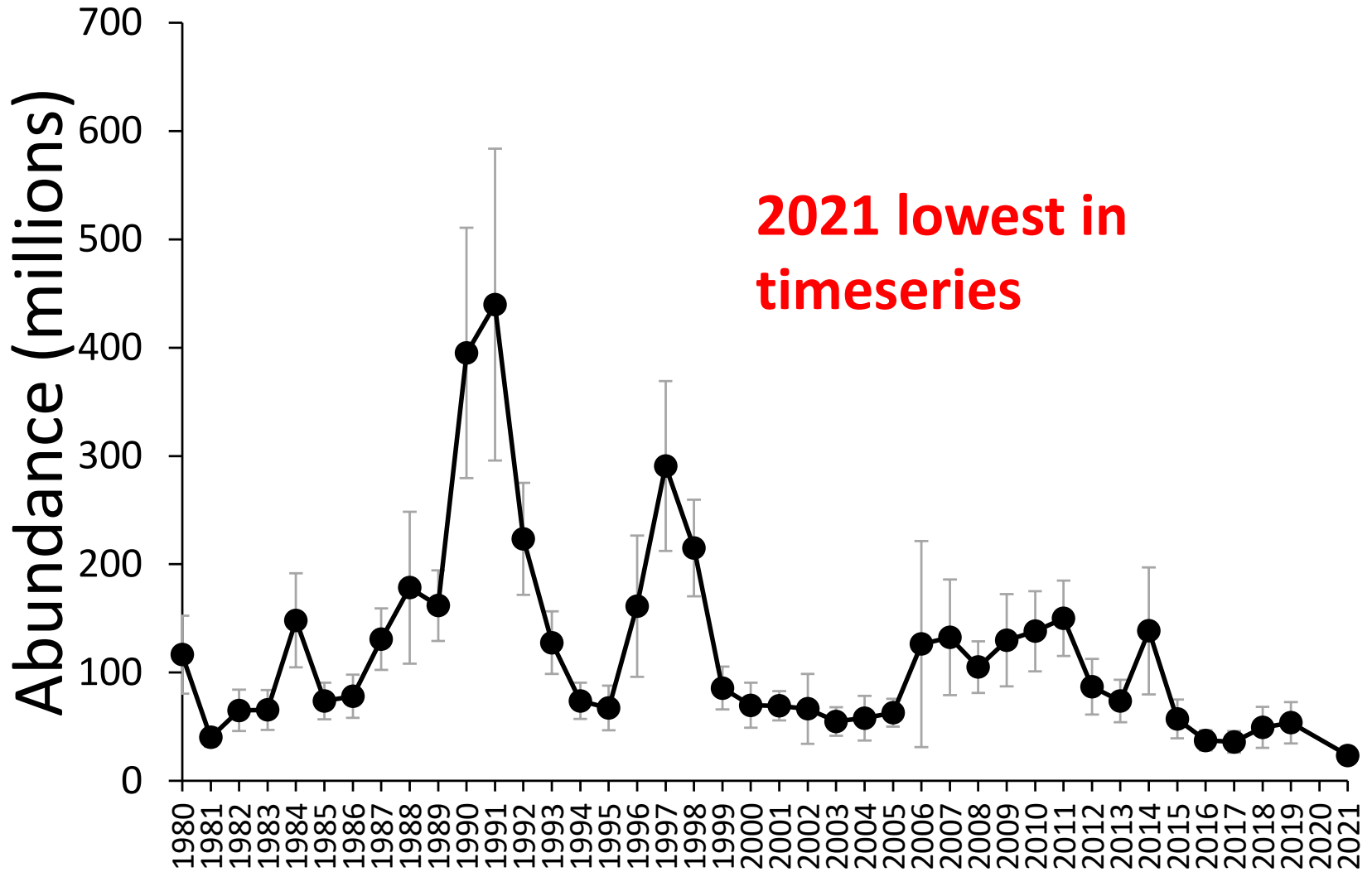
### MALE snow crab <50 (raw survey)



**2021 lowest  
in timeseries  
for male crab  
≤50 mm**

NOAA survey area-swept

# 4 inch males



**2021 lowest in timeseries**

# What happened?

## Theories:

1: They are still in the survey area, but the survey missed 'em

2: They moved outside of the survey area

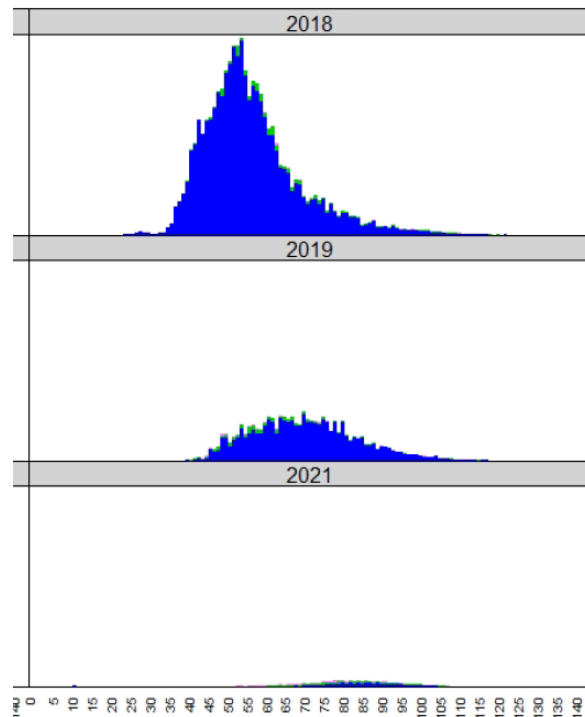
3: They died

# What happened?

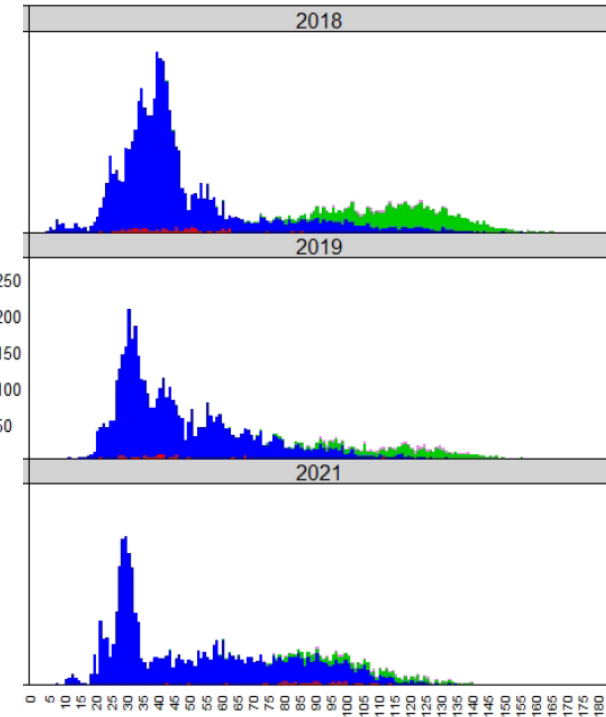
1: They are still in the survey area, but the survey missed 'em.

- No net performance problems
- Tanner crab did not undergo similar decline

## Snow crab



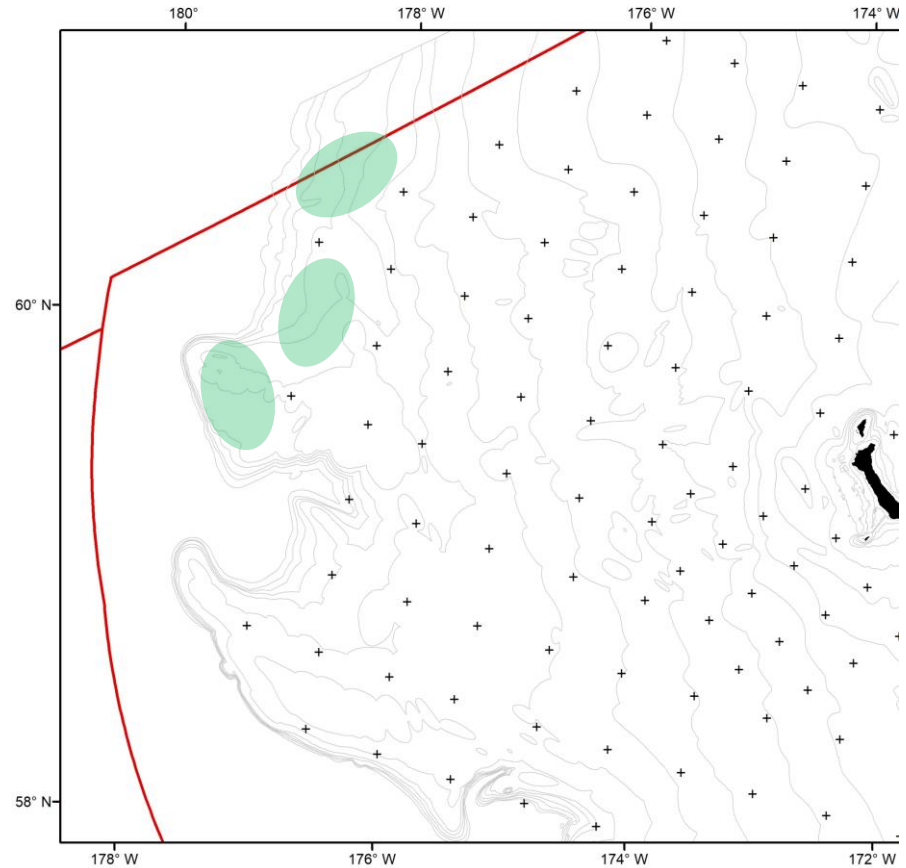
## Tanner W



# What happened?

1: They are still in the survey area, but the survey missed 'em.

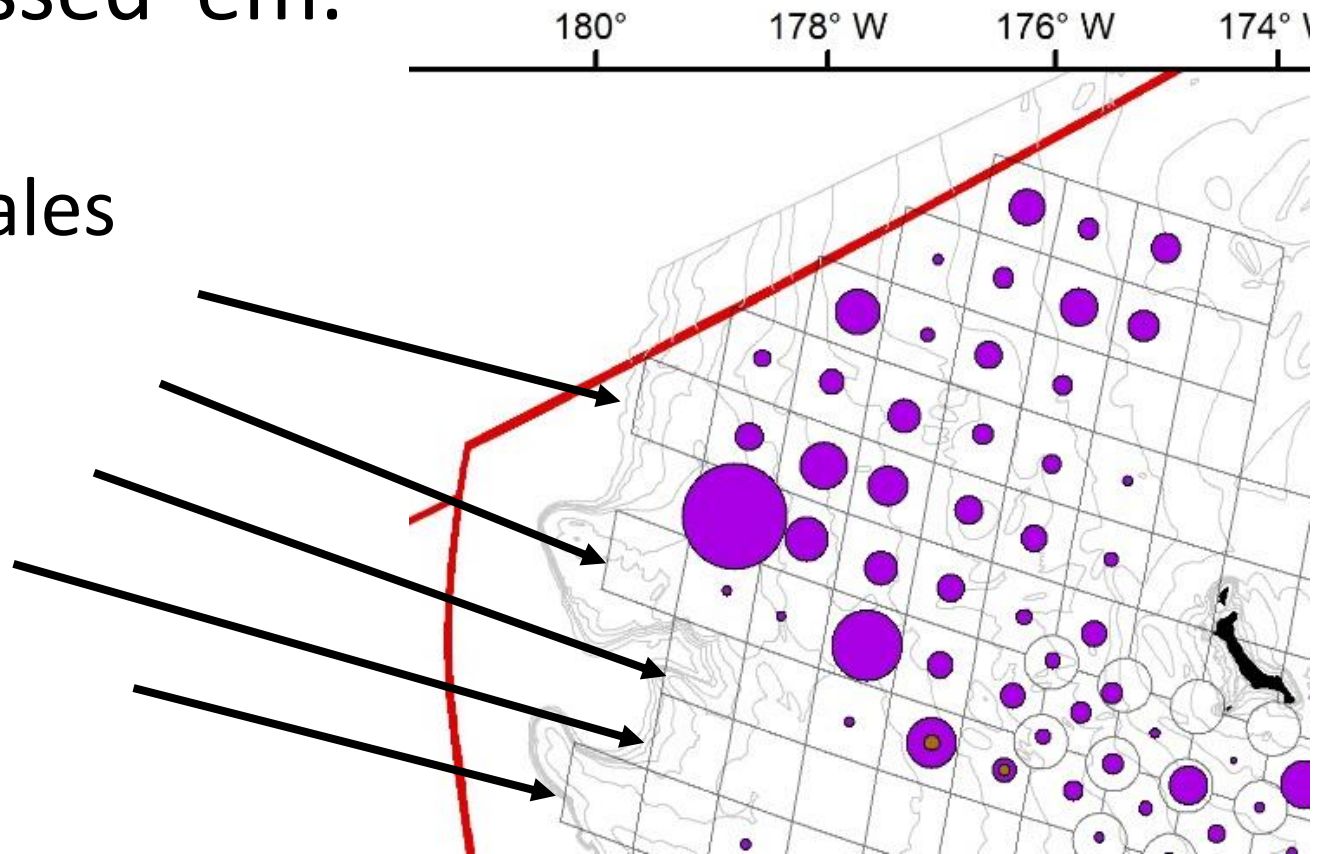
- Net touches very small portion (~0.004%) of survey area
- BUT, spacing is uniform, thus seems unlikely that large aggregations occurred in-between survey tows
- Some areas near shelf edge not covered by survey but areas not large enough to account for decline in numbers



# What happened?

1: They are still in the survey area, but the survey missed 'em.

No 4 inch males  
on self edge  
stations



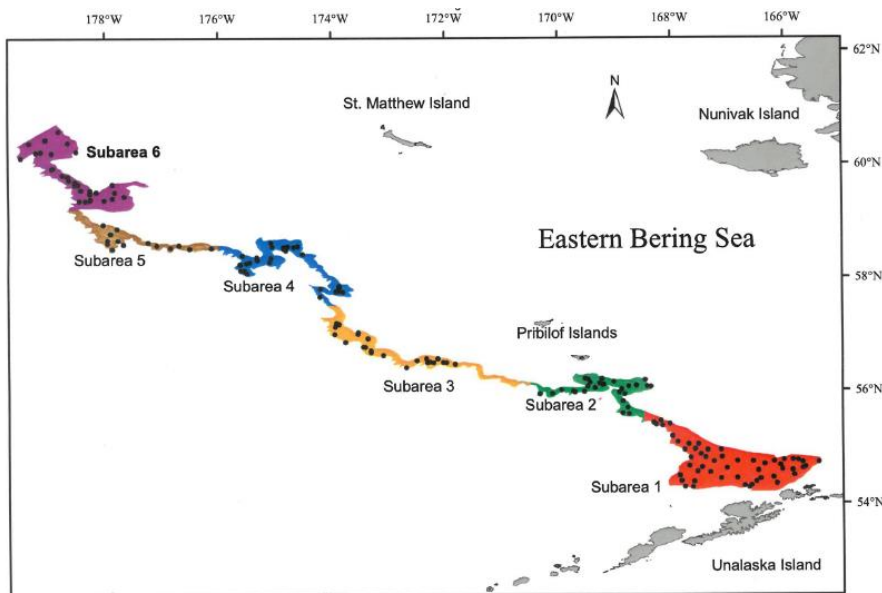
NOAA survey area-swept

Purple= survey 4-inch male abundance

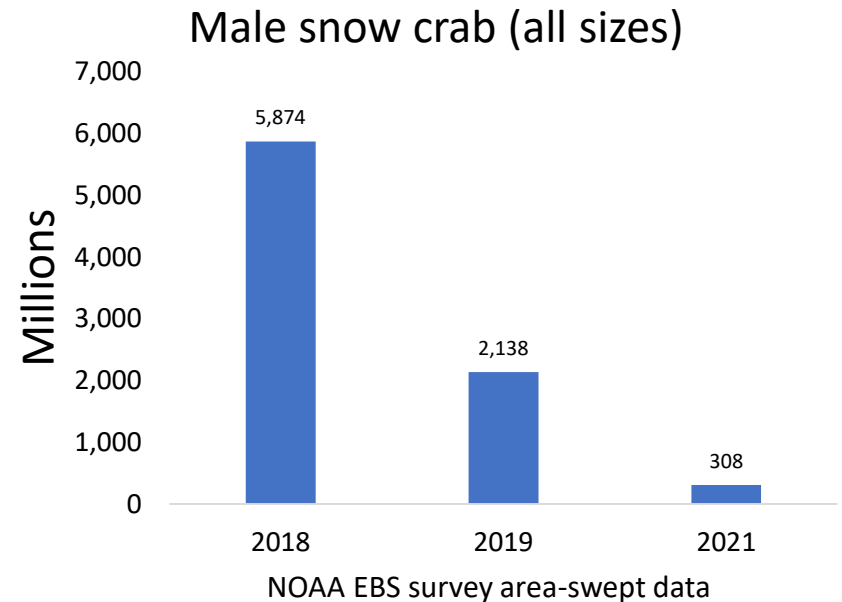
# What happened?

2: They moved outside of the survey area...onto slope?

Bering Sea slope survey area



< 10% of EBS shelf area



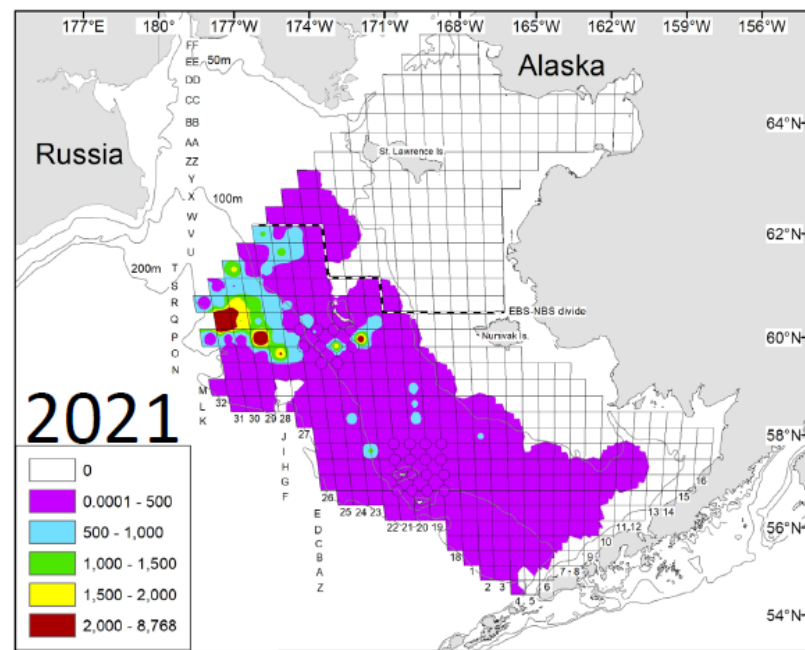
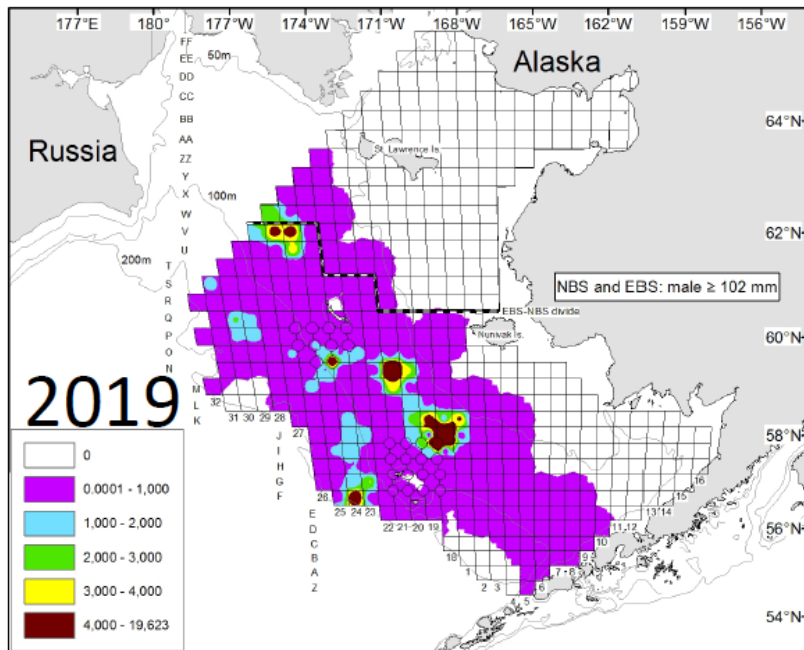
- Magnitude of change between 2019-2021 ~1.8 billion crab
- Is it plausible that many animals aggregated on the slope?



# What happened?

## 2: They moved outside of the survey area

- NBS survey does not explain the decline in the EBS

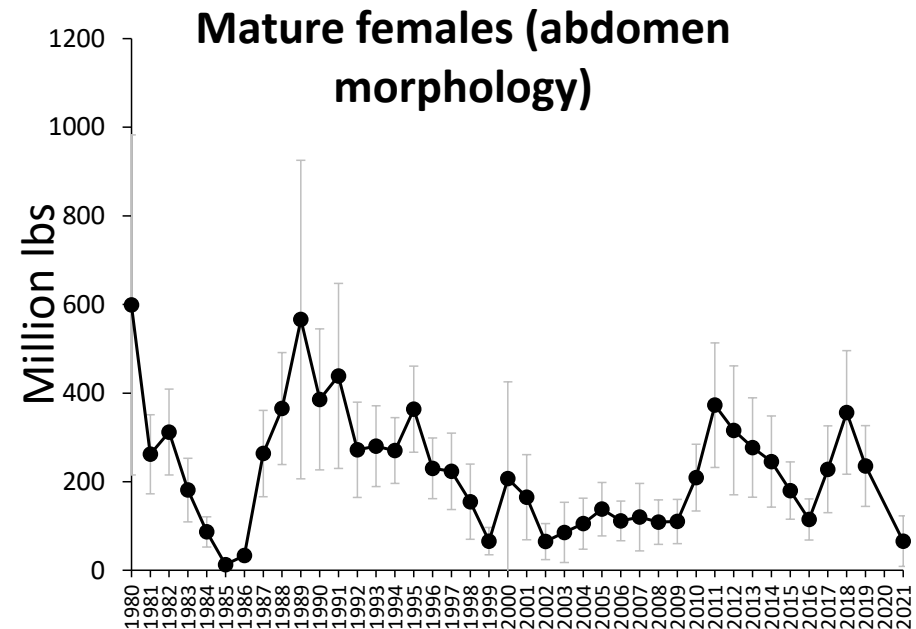
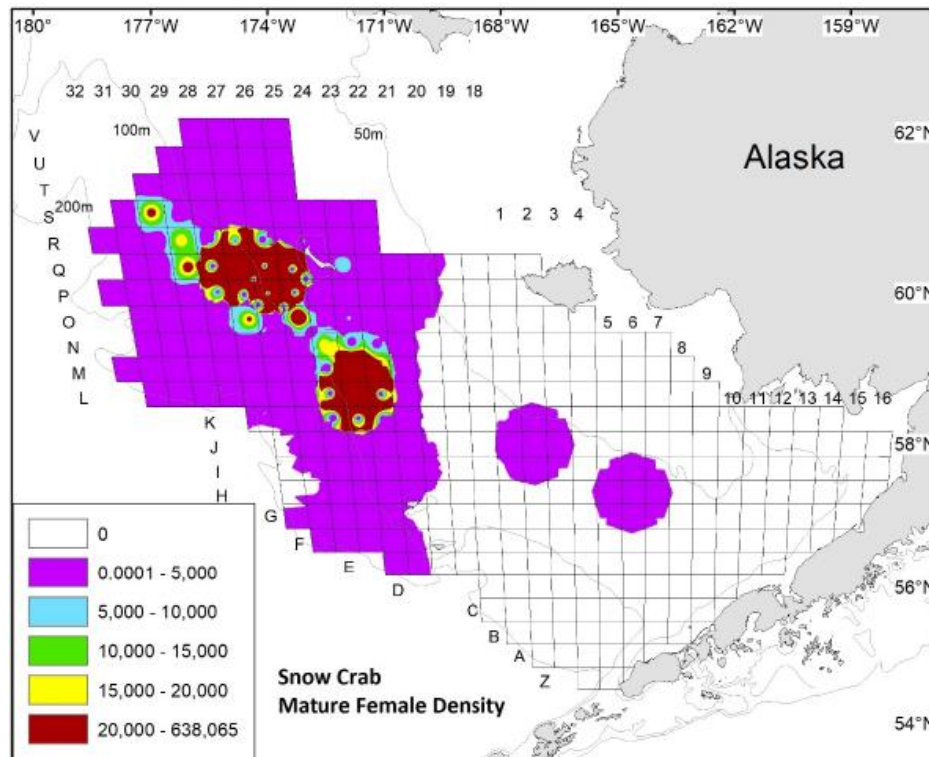


Note – Different scales each year

# What happened?

## 2: They moved outside of the survey area

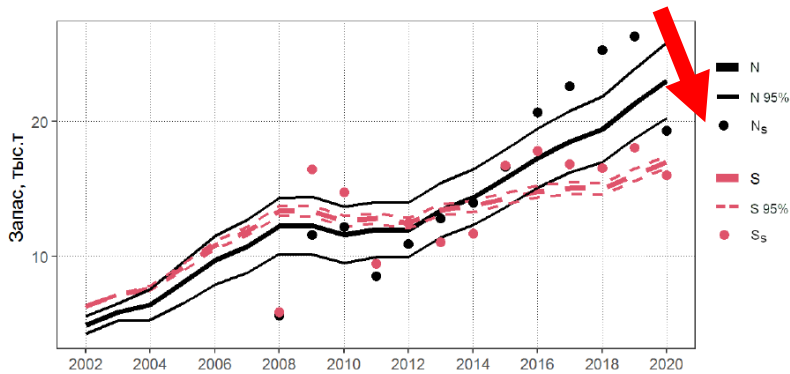
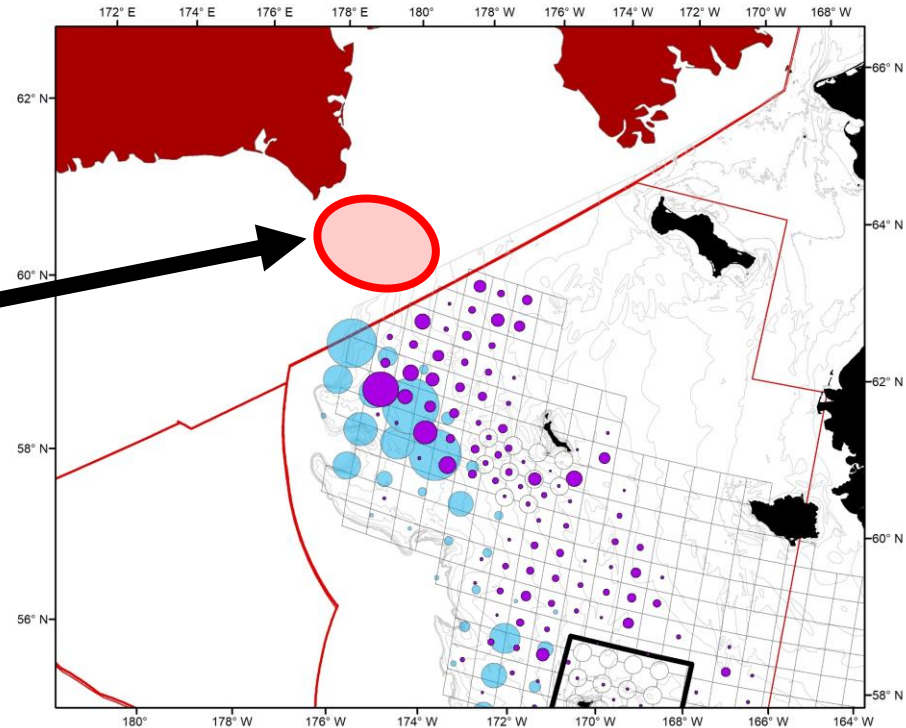
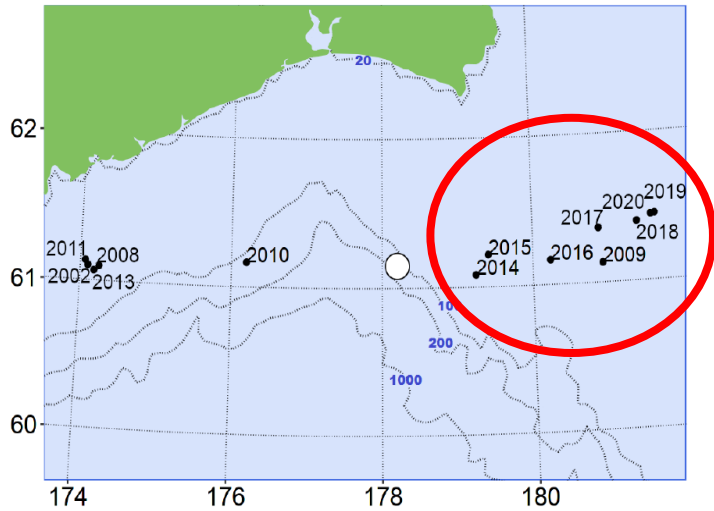
- Females not aggregated near survey boundary, but also experienced dramatic decline



# What happened?

2: They moved outside of the survey area....into Russia?

Centriods of Russian snow crab fishery



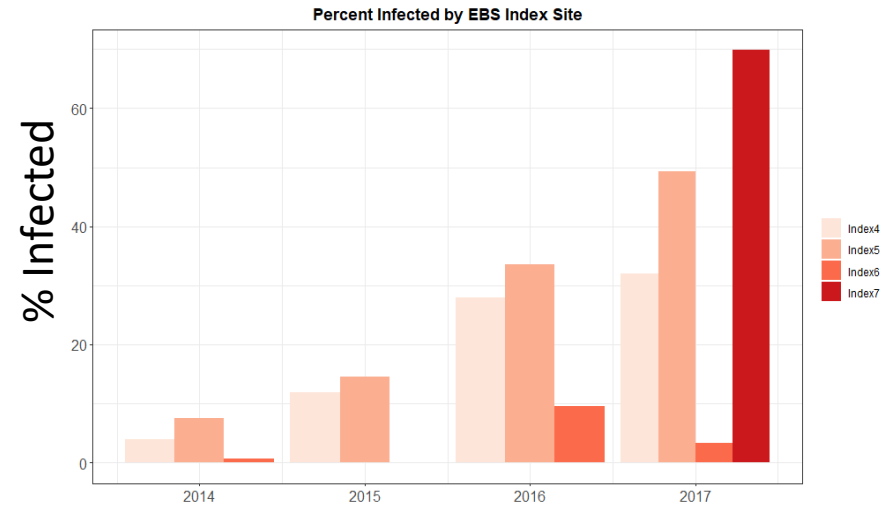
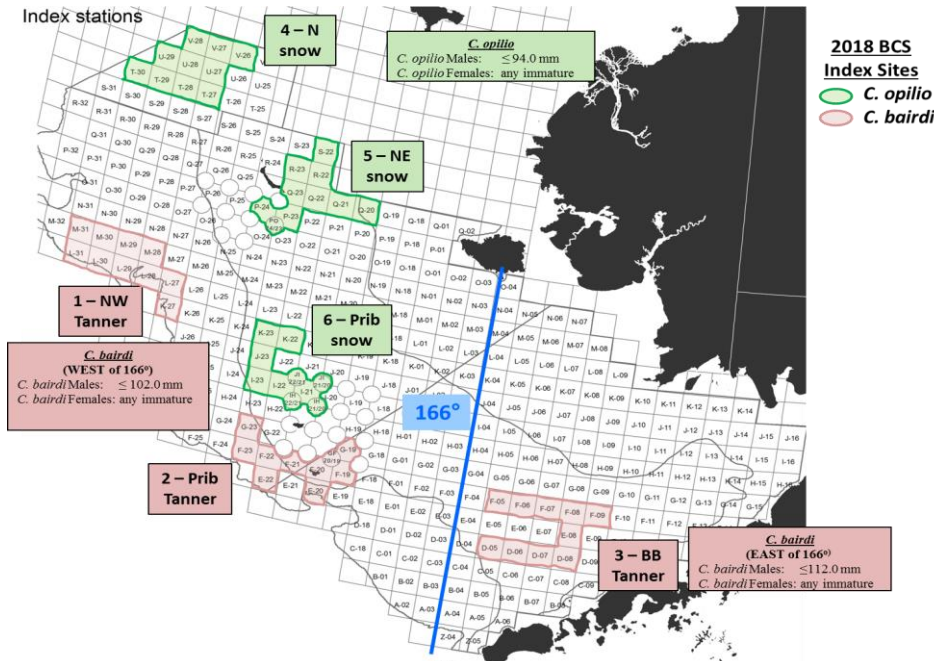
- Drop in CPUE in 2020
- Would expect to see increase in CPUE if US crab going north in Russia

# What happened?

## 3: They died

- Predation, disease, thermal stress, OA, etc

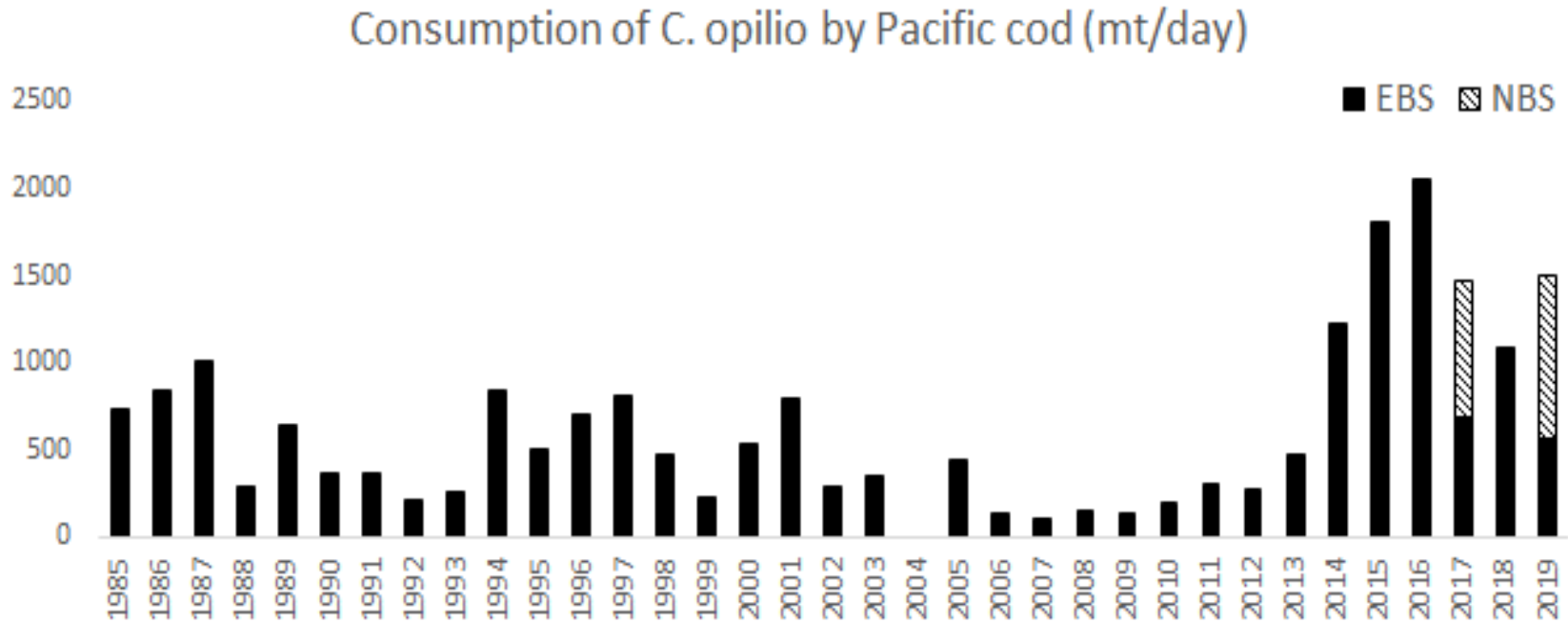
### Bitter crab syndrome monitoring



Contribution: Pam Jensen, NOAA

# Consumption of snow crab by cod

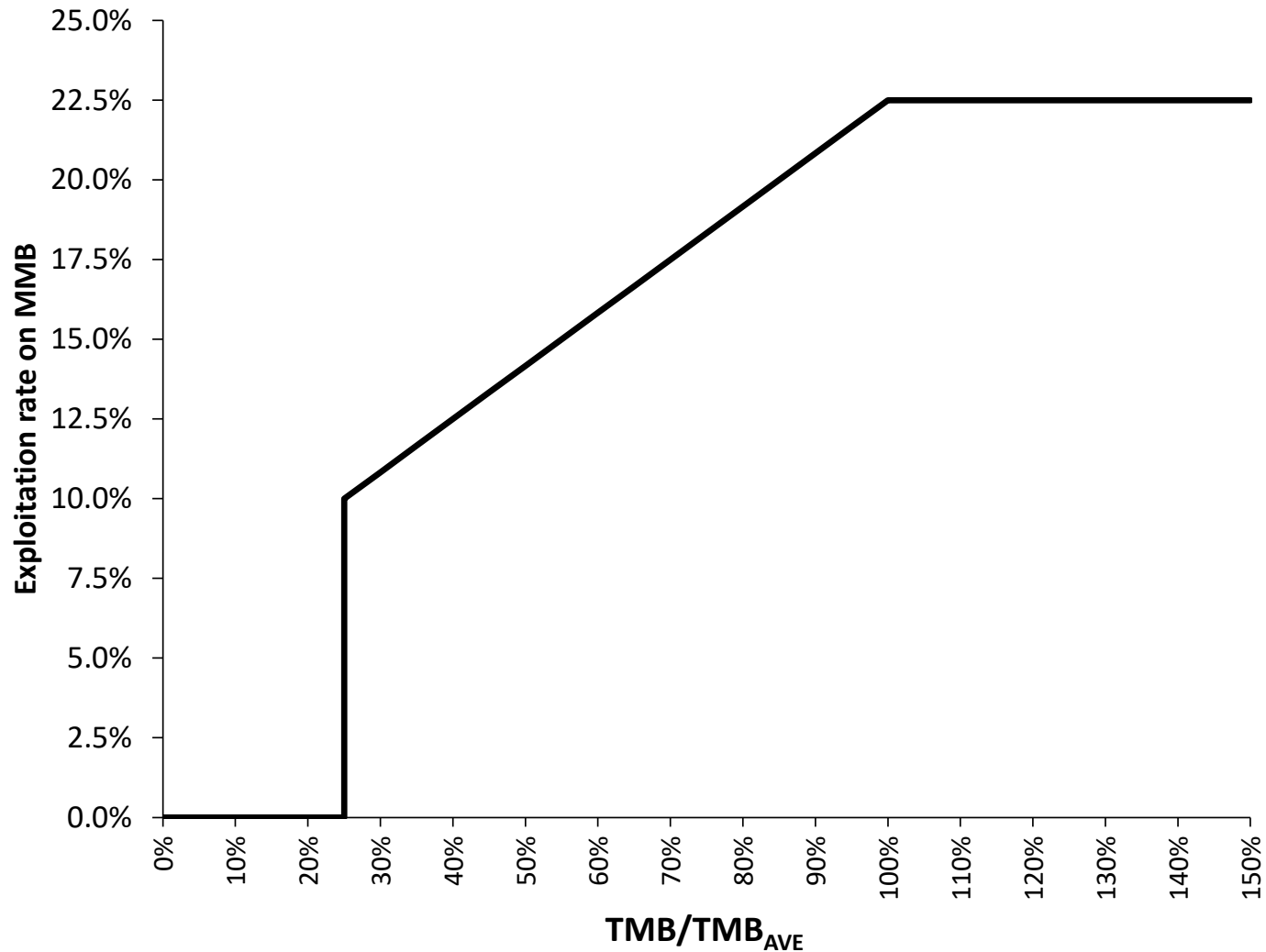
- 50,772 Pacific cod stomachs collected in EBS/NBS 1985-2019
- **Summer** bottom trawl survey samples



# Harvest Strategy: developed in 2002

1. Threshold for opening fishery: 25%  $B_{MSY}$
2. Exploitation on MMB:
  - $B < 25\% B_{MSY}$ , = 0%
  - $0.25 * B_{MSY} \leq B < B_{MSY}$ , exploitation increases linearly from  $1/3 F_{MSY}$  to  $0.75 * F_{MSY}$ , by equation:  $[F_{MSY}/3 + (B - 0.25 * B_{MSY}) * 0.417 * F_{MSY} / (0.75 * B_{MSY})] * 100\%$ .
  - $B > B_{MSY}$ , = 75% of  $F_{MSY} = 0.75 * 0.3 = 22.5\%$
3. Max Cap: 58% harvest rate on exploitable legal males (4-inch males: 100% new shell + **25% (or other)** old shell)

# Exploitation rate on MMB



# State harvest strategy (5 AAC 35.517)

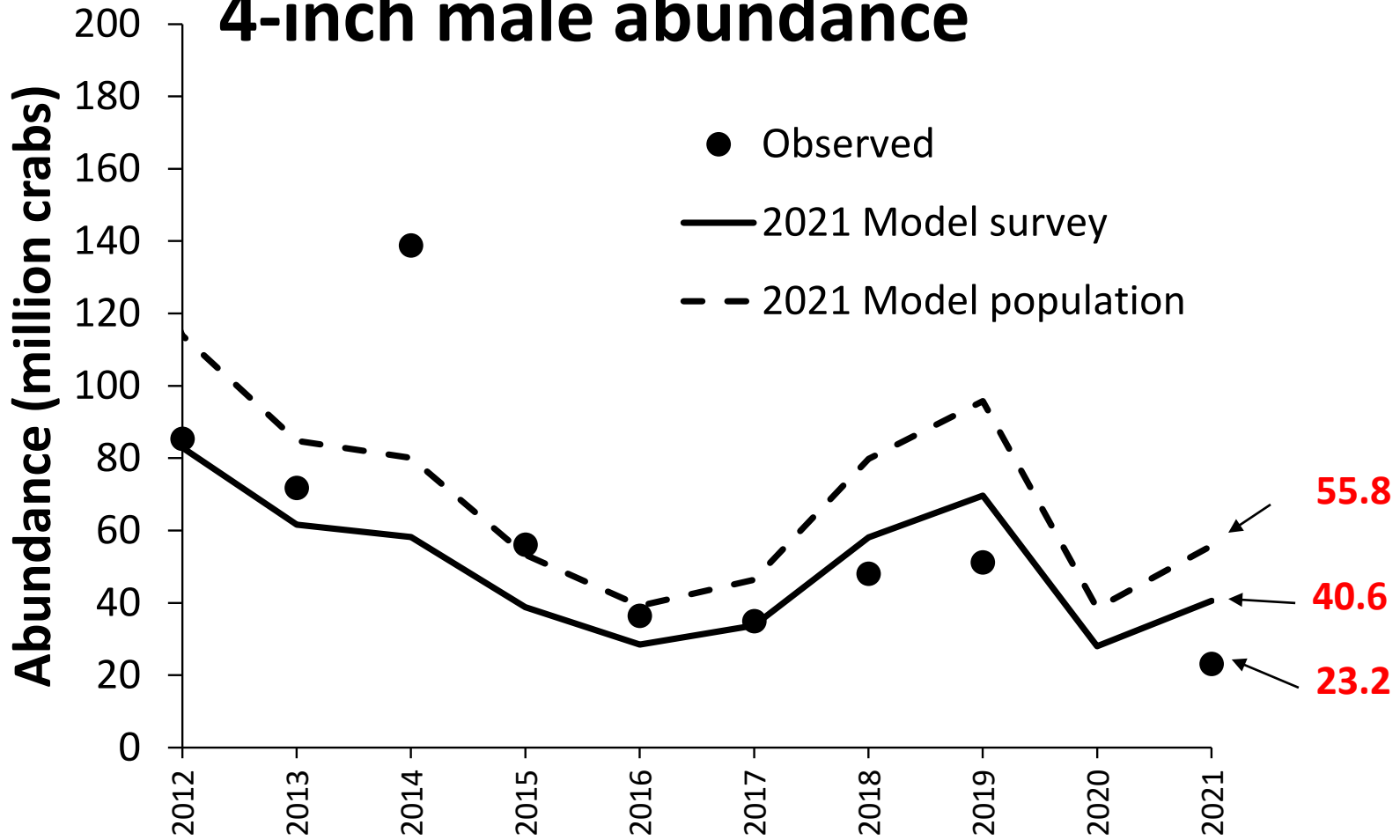
(5) “exploited legal males” means 100 percent of the new-shell male *C. opilio* Tanner crab that are at least 102 millimeters (four inches) in width of shell, plus a percentage of old-shell male *C. opilio* Tanner crab that are at least 102 millimeters in width of shell estimated at the time of survey; the percentage of old-shell male *C. opilio* Tanner crab will be based on the **expected fishery selectivity** for old-shell versus new-shell male *C. opilio* Tanner crab



# 4 sets of population estimates

1. **“Area Swept” estimates**.....raw area-swept, defining male maturity at  $\geq 95$  CW and female maturity as morphometric (abdomen shape)
2. **“Model observed” estimates**.....model estimates of area-swept, defining male and female maturity within the model using maturity ogives informed by morphometric data using historic chela height data and female abdomen shape
3. **“Model survey” estimates**.....the fitted line that interprets what the model observed estimates “should have been”, attempting to correct for survey sampling error
4. **“Model population” estimates**.....the fitted line that applies a survey selectivity curve by sex and size, attempting to correct for trawl efficiency (Q) .....estimates of the underlying population..... “the population estimate if all crabs in the line of the survey trawl net were caught”
  - Q = proportion of animals in trawl path captured
  - Q < 1 in 2010–2021 stock assessment models

# 4-inch male abundance



# 2021 TAC calculations

Computed 2021/22 TACs: area-swept and Model estimates. Assumed old-shell fishery selectivity = 0.75 relative to new-shell.

	Raw area-swept (MM GE95)		Survey Observed (Model Maturity Status)		Survey (Model Predicted)		Population (Model Estimated)	
	TMB	MMB	TMB	MMB	TMB	MMB	TMB	MMB
1983-2019 Average (millions lb)	<b>436.3</b>	221.6	<b>604.7</b>	380.8	<b>567.9</b>	342.9	<b>732.2</b>	500.0
2021 Estimate (millions lb)	<b>119.6</b>	<b>53.8</b>	<b>207.0</b>	<b>137.2</b>	<b>200.0</b>	<b>110.1</b>	<b>243.4</b>	<b>152.0</b>
(2021 Est)/(1983-2019 Avg)	<b>27%</b>	24%	<b>34%</b>	36%	<b>35%</b>	32%	<b>33%</b>	30%
$F_{MSY} =$		<b>0.3</b>		<b>0.3</b>		<b>0.3</b>		<b>0.3</b>
Exploitation Rate on MMB		<b>0.104</b>		<b>0.115</b>		<b>0.117</b>		<b>0.114</b>
Computed TAC = Exp Rate X MMB (mill lb)		5.59		15.84		12.89		17.29
Max TAC (58% cap on exploited legal males (mill lb)		15.86		14.83		25.86		35.69
<b>TAC</b>		<b>5.592</b>		<b>14.830</b>		<b>12.888</b>		<b>17.29</b>

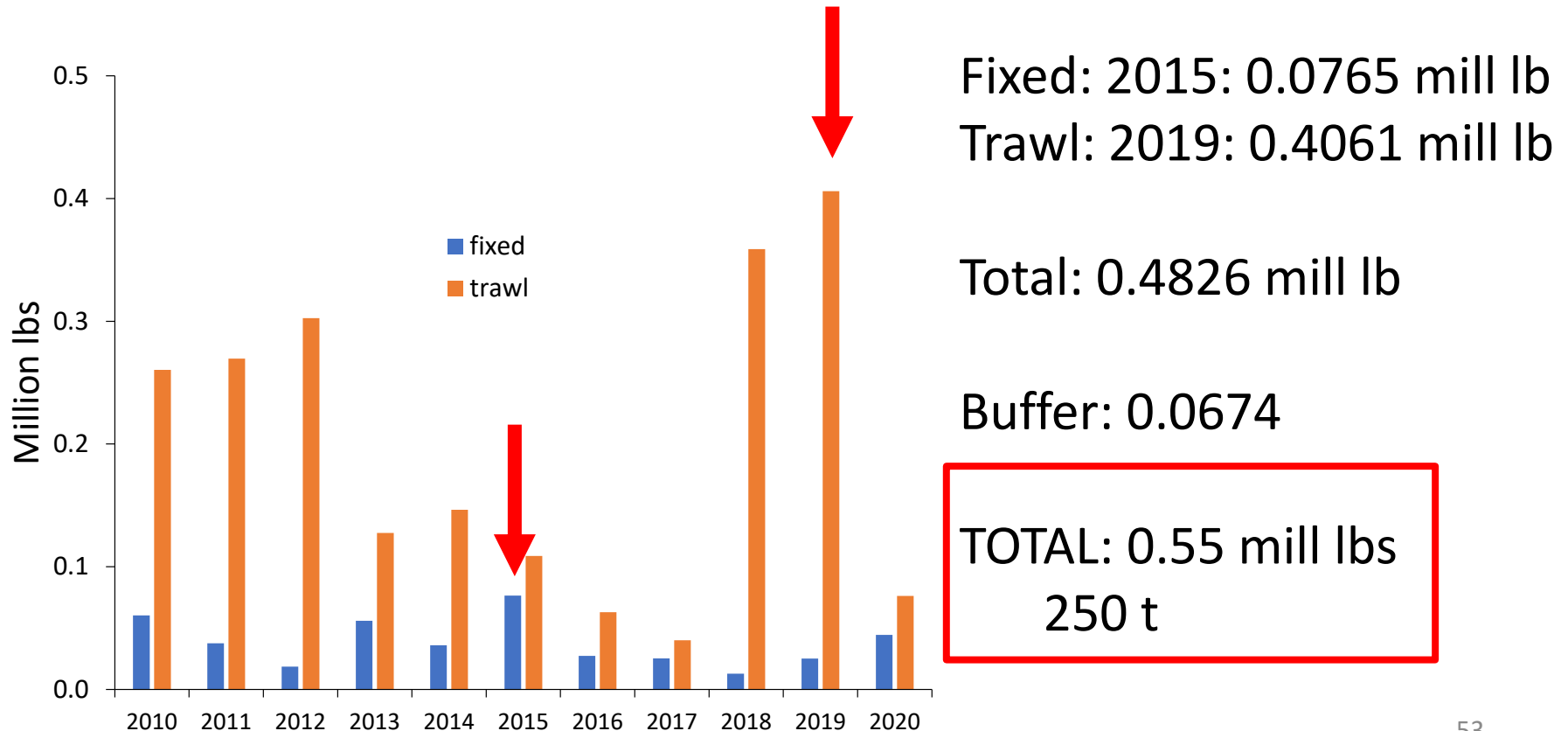
	Area-swept (Raw NOAA values)	Survey Observed (Area-swept Est.)	Survey (Model Predicted)	Population (Model Estimated)
Abundance of ♂♂ ≥ 4-in CW (millions)	23.5	23.2	40.6	55.8
Average wt (W; from 2020/21 fishery; lb)	1.200	1.200	1.200	1.200
% old shell (from area-swept)	32%	32%	32%	32%
Expected old shell selectivity	0.75	0.75	0.75	0.75
Exploited legal males ("ELM"; millions)	21.6	21.3	37.3	51.3
<b>Max TAC (= 0.58xELMxW; millions lb)</b>	<b>15.06</b>	<b>14.83</b>	<b>25.96</b>	<b>35.69</b>

**ABC= 12.35 million lbs**

# Assumptions about 2021/22 fishery bycatch mortality

# Groundfish fisheries bycatch mortality

**NOAA recommendation**: max bycatch in fixed and trawl fisheries during past 10 years + a buffer



# Bycatch Working Assumptions

## Groundfish fisheries:

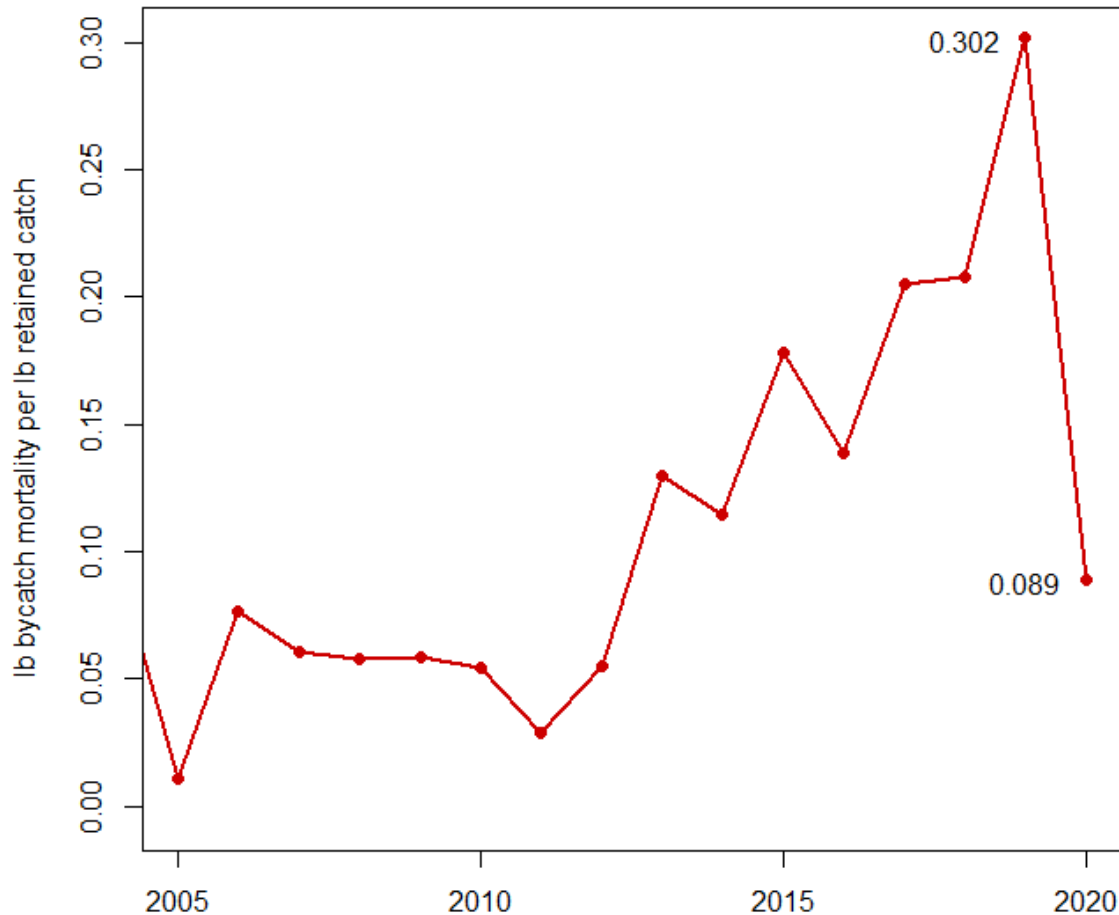
- NOAA recommendation of 0.55 million lbs

## Tanner crab fishery:

- 2020/21 snow crab bycatch mortality rate: 0.222
- If a 1.1 mill lb Tanner TAC, snow crab bycatch mortality would be 0.244 million lbs

# Directed fishery

Snow crab discard mortality rate



Why the drop  
in discarding?

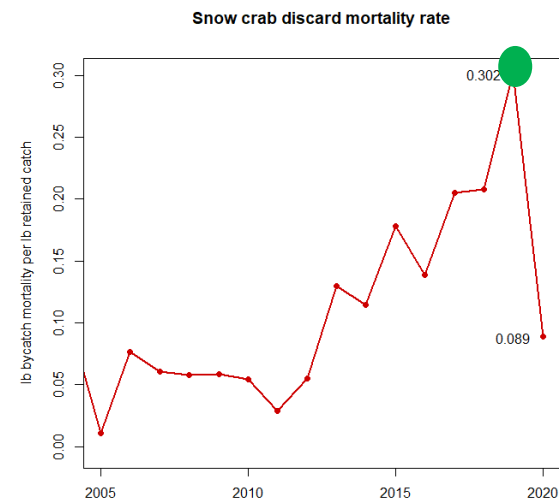
What might we  
expect for  
2021/22?

# Bycatch Working Assumptions

2021/22 maximum TAC relative to avoiding ABC = 12.35 million lb total fishery mortality

Assumptions	Mortality (million lb)
Assume max mortality in groundfish fisheries, past 10 yrs =	0.55
Assume mortality rate in Tanner, past season =	0.24
Remaining for directed (incl. bycatch mort), mill lb (ABC-Subtotal) =	11.56
Assume maximum (lb discard mort)/(lb retained) in directed fishery, past 4 yrs =	0.302
<b>Maximum TAC = (remaining for directed)/(1+0.302) =</b>	<b>8.88</b>

**Assume max discarding rate  
(2019) in directed fishery: 0.302**

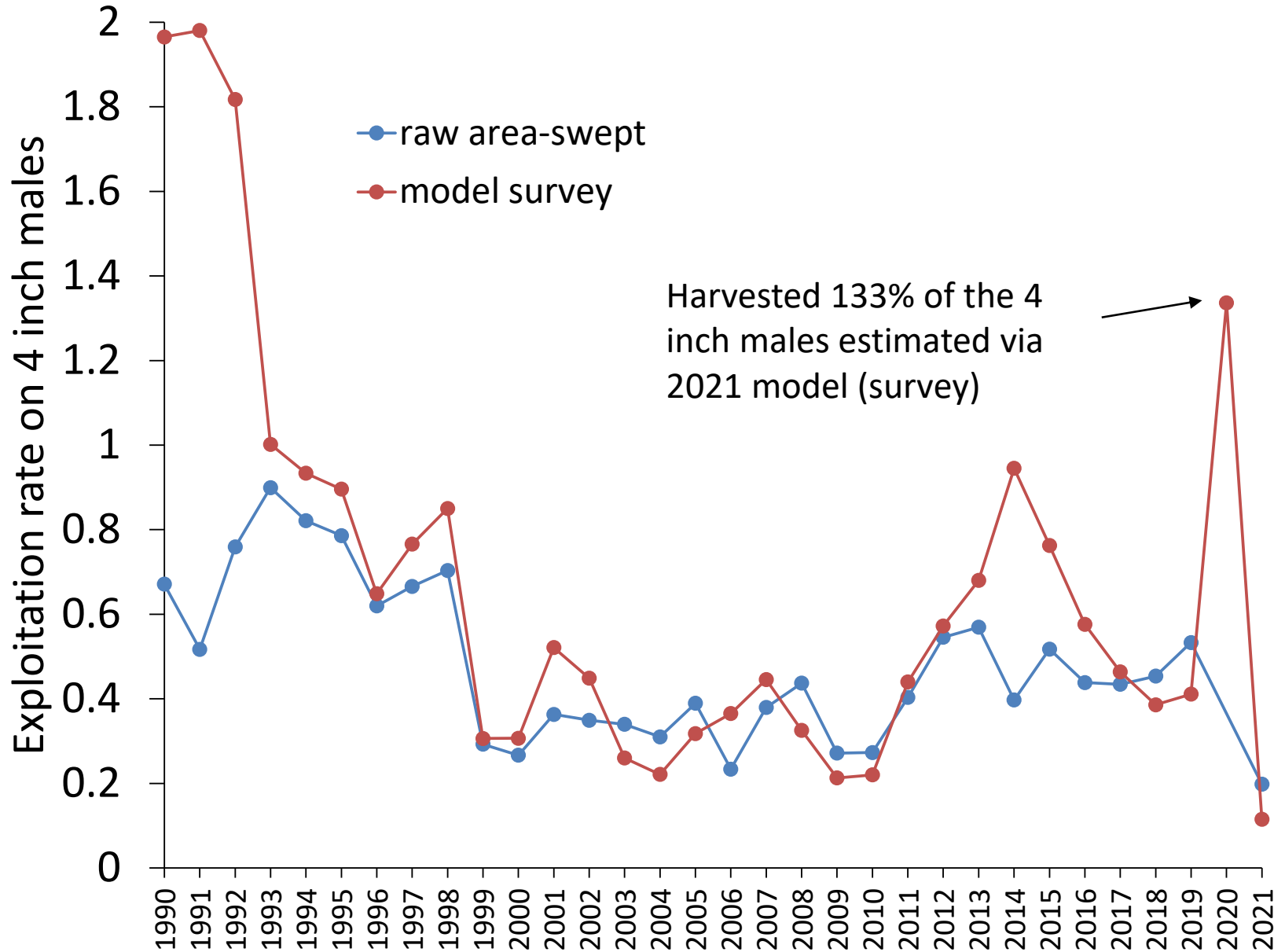




# Thoughts on “ABC – bycatch” TAC

- Unwise to fish to the ABC on a depressed/overfished stock
- We don't know if mortality event is ongoing
  - Warrants conservative approach
- An 8.9 mill lb TAC really translates to an ABC-level (12.35 mill lb) removal
- We need to make sure we do not exceed ABC
  - Bad for conservation
  - What if sea ice inhibits fishing on good northern fishing areas and forced to fish in south....scratchy fishing + high discarding?

# Exploitation rate on 4 inch males



# Final Thoughts

Lots of uncertainty related to cause of decline

- mortality vs movement
- fishing behavior
- Russian border issues
- model convergence issues

Assuming the crab moved north, we can't predict those crab will be available to the fishery

- sea ice limitations
- Russian border

Reducing discarding is more important than ever

# Final Thoughts: 5.6 mill lbs

- Conservative approach: functional maturity (95 mm) as “currency”: TAC = 5.6 mill lb
- Process: consistent with prior TAC setting approaches
  - Uses the state harvest strategy
- Errs on the side of functional maturity
  - But, 95 mm definition is likely oversimplified relative actual mating dynamics
- Uncertainty of small morphologically mature male crab participating in mating
- Important to collect fishery data

# Difficulties with defining male maturity in *Chionoecetes* crab

**Females:** narrower range of sizes, obvious physical change at maturity (abdomen assessed visually), all females measured on survey are classified as mature/immature

**Males:** broader size range, chela morphology (large vs small claw) less obvious, NOT all male chelas on survey are measured

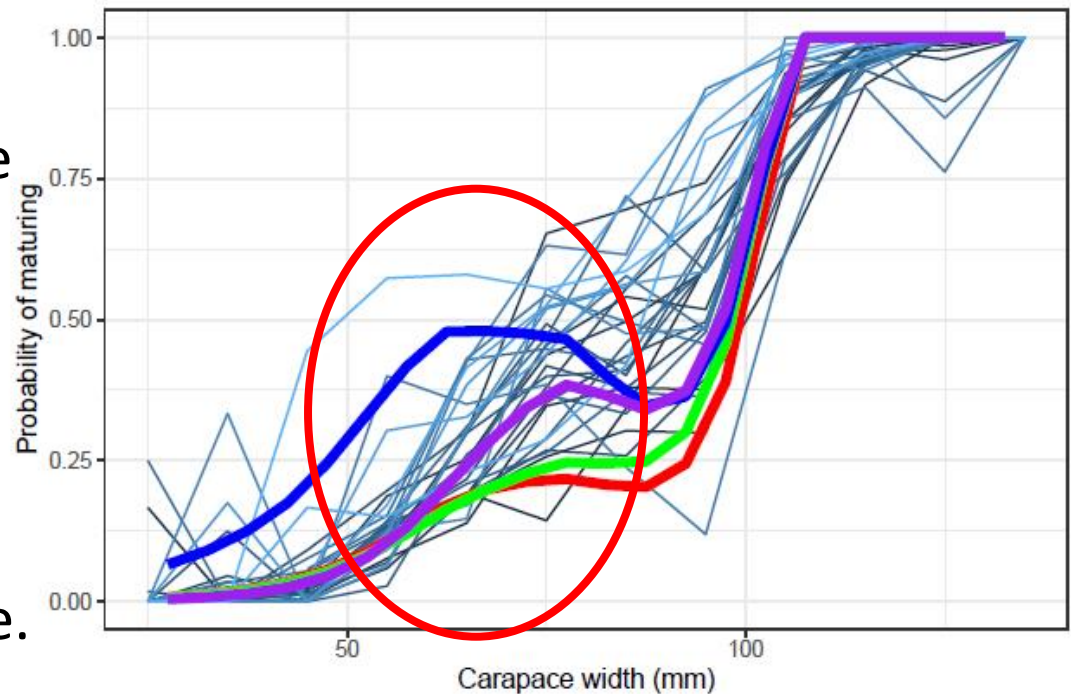
- ***Physiological maturity*** (adolescent): small claw but can make sperm
- ***Morphological maturity***: large claw (terminally molted), competitively dominant
- ***Functional maturity***: individuals participating in population mating dynamics, likely large-claw, vigorous, competitively dominant (i.e., the “studs”)

# Male maturity

Current approach uses morphometric (i.e., based on chela morphology) maturity as currency of management

So what's the problem?

- Accounts for small mature males
- Uncertainty if its appropriate to do so because its unknown if those individuals are participating in mating (i.e. “functional maturity”)



# Male maturity

Desire to move toward functional maturity as currency for management

- Uncertainty about how best to define
- >95 mm CW is likely a step closer
- **Canadian research** (Gulf of St Lawrence)
  - Conan and Comeau 1985: “**We also believe that among morphometrically mature animals only the larger ones (approximately 95 mm and more) are functionally mature**, i.e. apt to grab a female, carry it around (precopulatory embrace), and mate.”
  - Sainte-Marie et al., 2008: “**Considerable opportunity apparently exists for natural/sexual selection in snow crabs— especially on males—that results from sexual competition, female mate choice, and sexual conflict in a context of unstable population demography and OSR.**”

# Work by ADF&G on snow crab mating dynamics

- No evidence of sperm limitation
- Clutch fullness good indication of egg production
- Annual female remating after terminal molt needed: sperm storage provides little buffer
  - This highlights the importance of conserving reproductively active males
- Spatiotemporal variability in sperm reserves likely reflects size comp and maturity status of males
- Spatial trends in male size at morphological maturity



# What now?

## Shelf edge survey?

## Tagging?

## Male size-at-maturity

- If the population continues to be in the north, research on size-at-maturity is important in order to define fishery yield potential
- Reductions in size at maturity will mean fewer crab will grow to 4.0 inches
- Defining maturity: physiological vs morphological vs functional

## Improved spatial management?

- Separate TACs by area North vs South....or East vs West 173 W?

Tanner crab

# 2021 Assessment: scenario 21.22a

- SSC + Council adopted CPT recommendations
- Stock status: 118% of  $B_{MSY}$
- OFL: 59.89 million lbs
- ABC: 47.91 million lbs
  - including bycatch mortality of males and females in all fisheries
  - based on a 20% buffer on OFL

# 20% ABC Buffer: status quo

- Lack of 2020 survey data
- Decline in recruitment in 2019
- Poor fit to terminal year biomass
- Poor fit for large crab
- Recruitment pulses of small size crab have not led to large year classes in modelled population

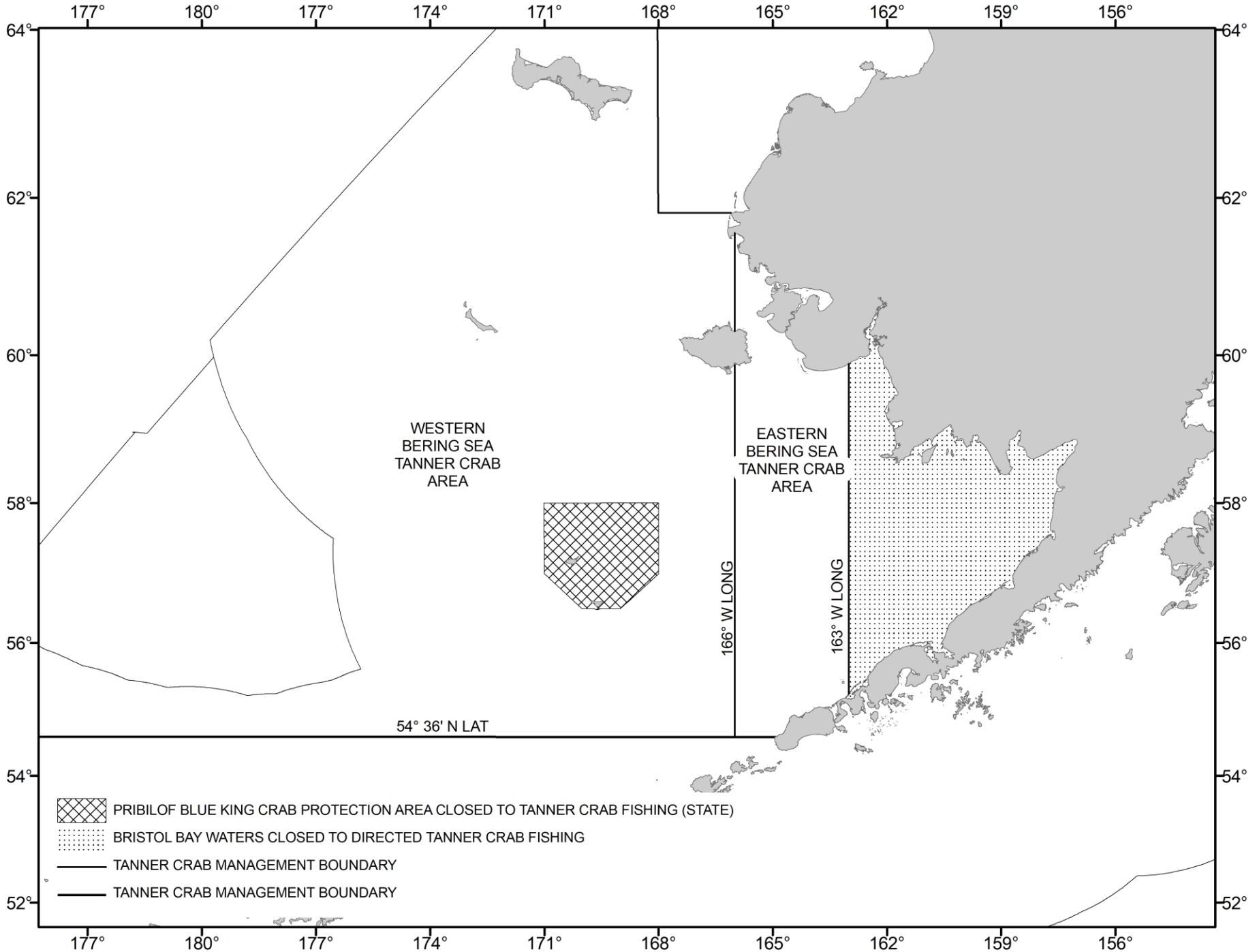
# Tanner TAC setting

## Harvest strategy: 2 control rules

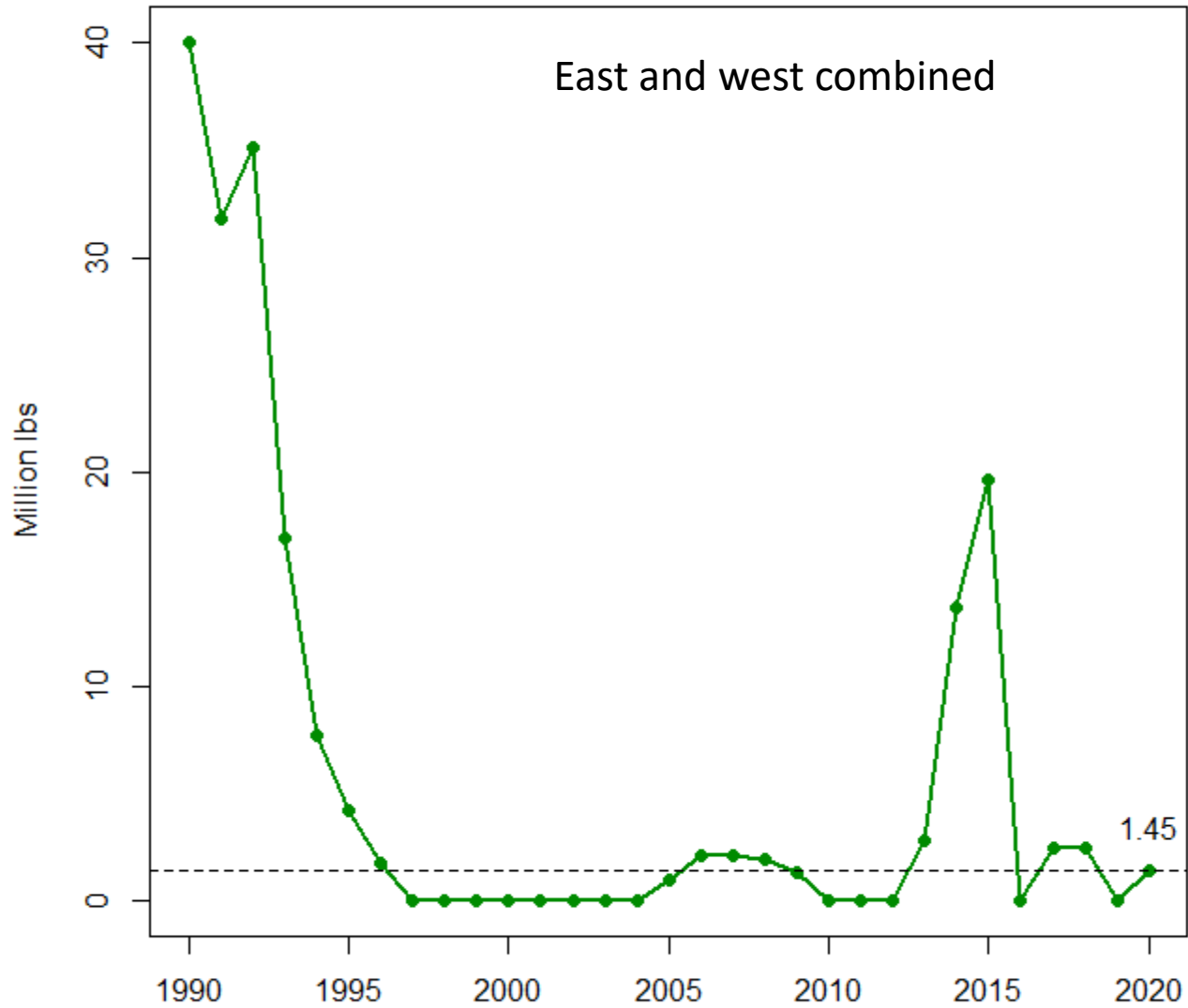
- 1. Exploitation on MMB via “female dimmer” control rule
- 2. 50% ELM CAP

## Model challenges

- Outputs are for entire EBS, not E/W 166° W
- Tendency to overestimate +5-inch males

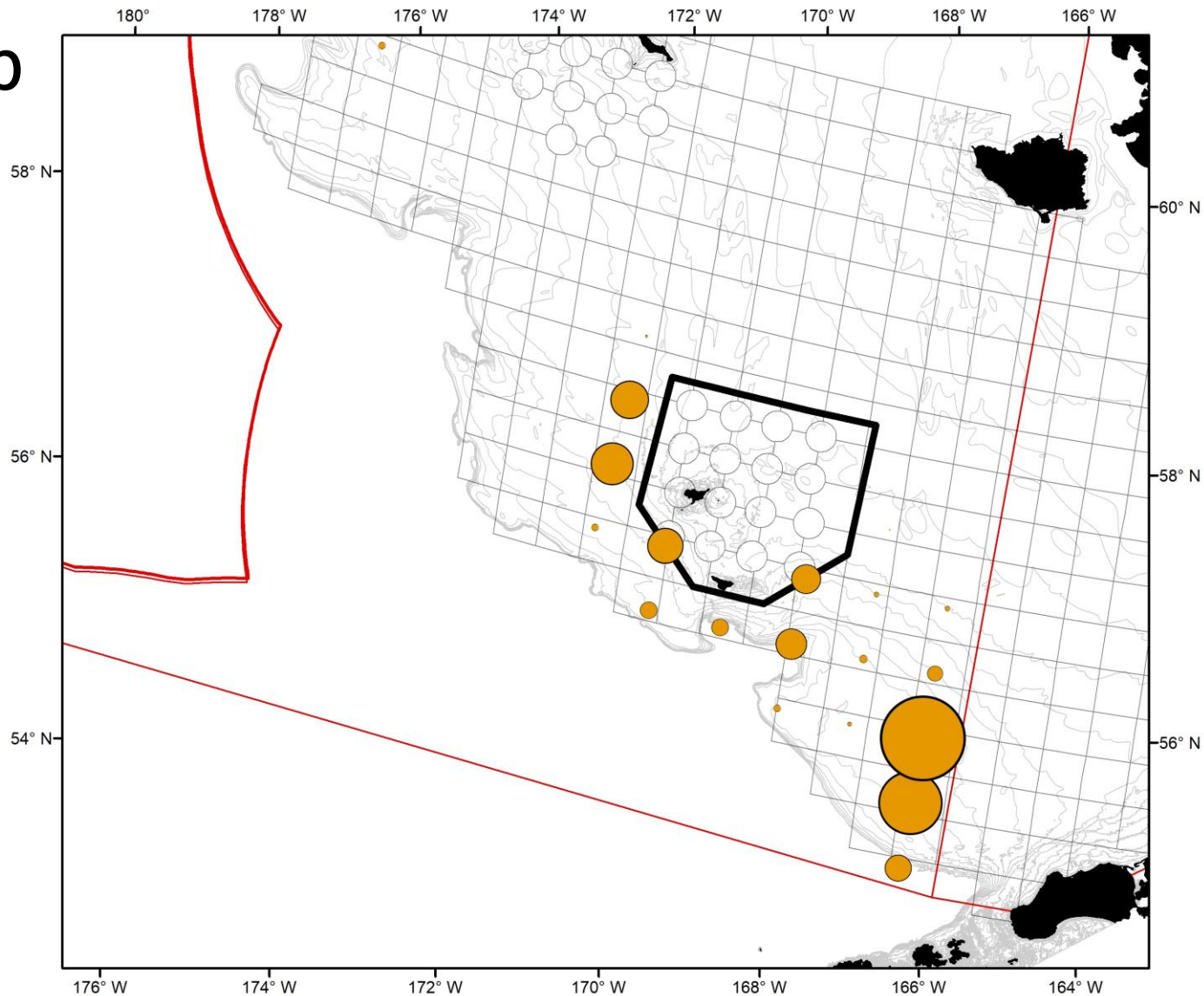


### Tanner crab retained catch



2020/21 TAC East=0, **West=2.348** mill lb

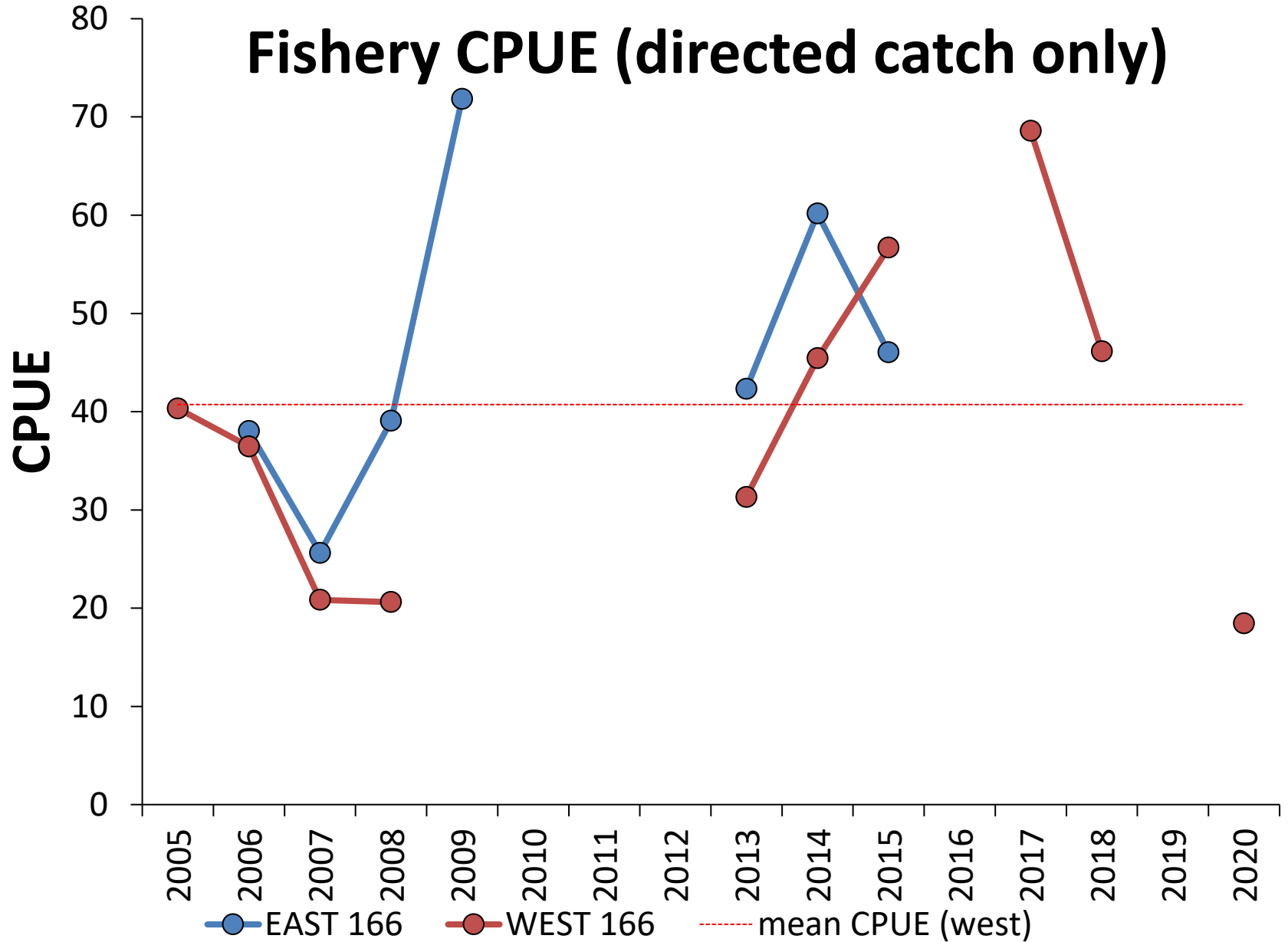
# 2020/21 Tanner crab retained catch



\* Excludes stat areas with <3 vessels



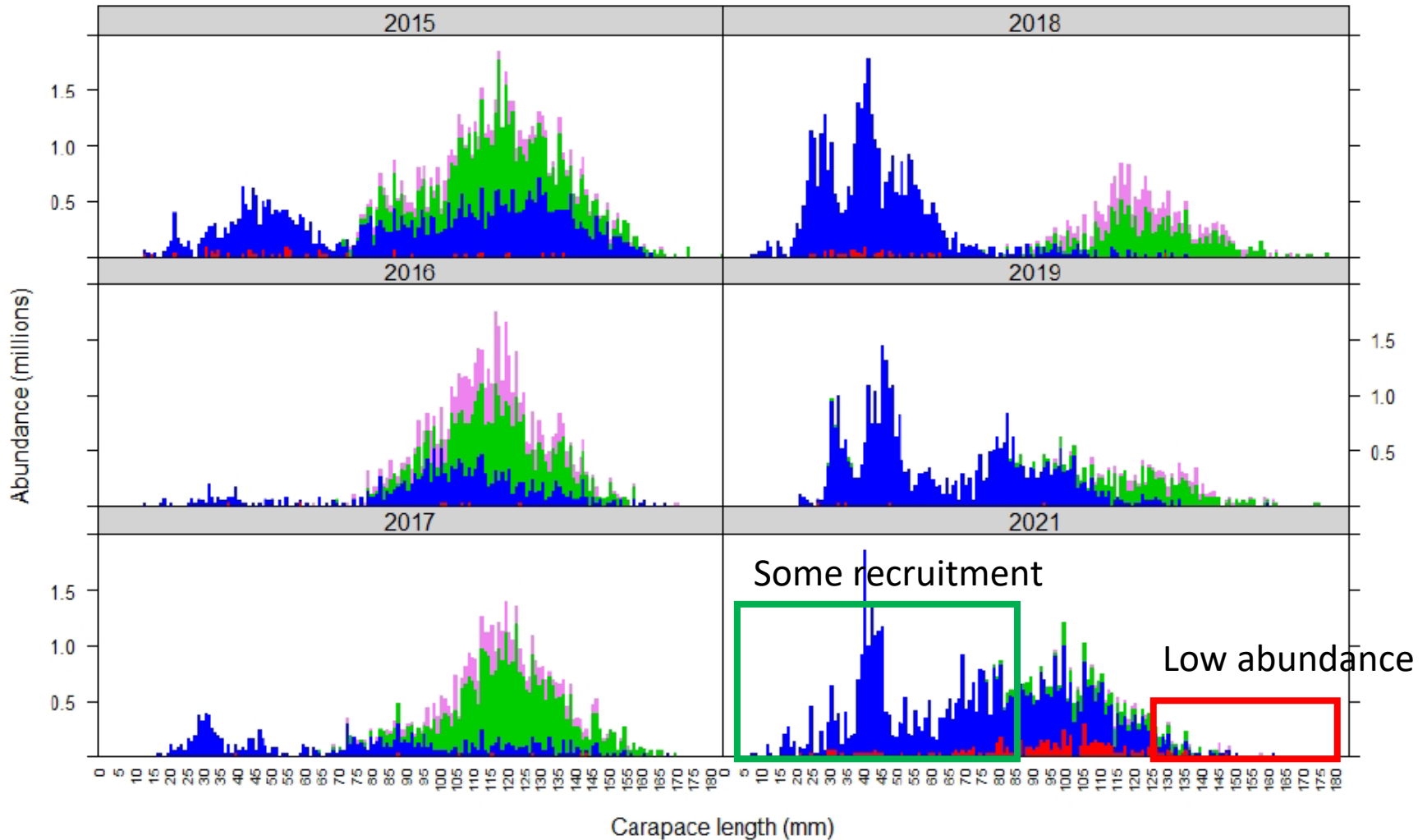
# Fishery CPUE (directed catch only)



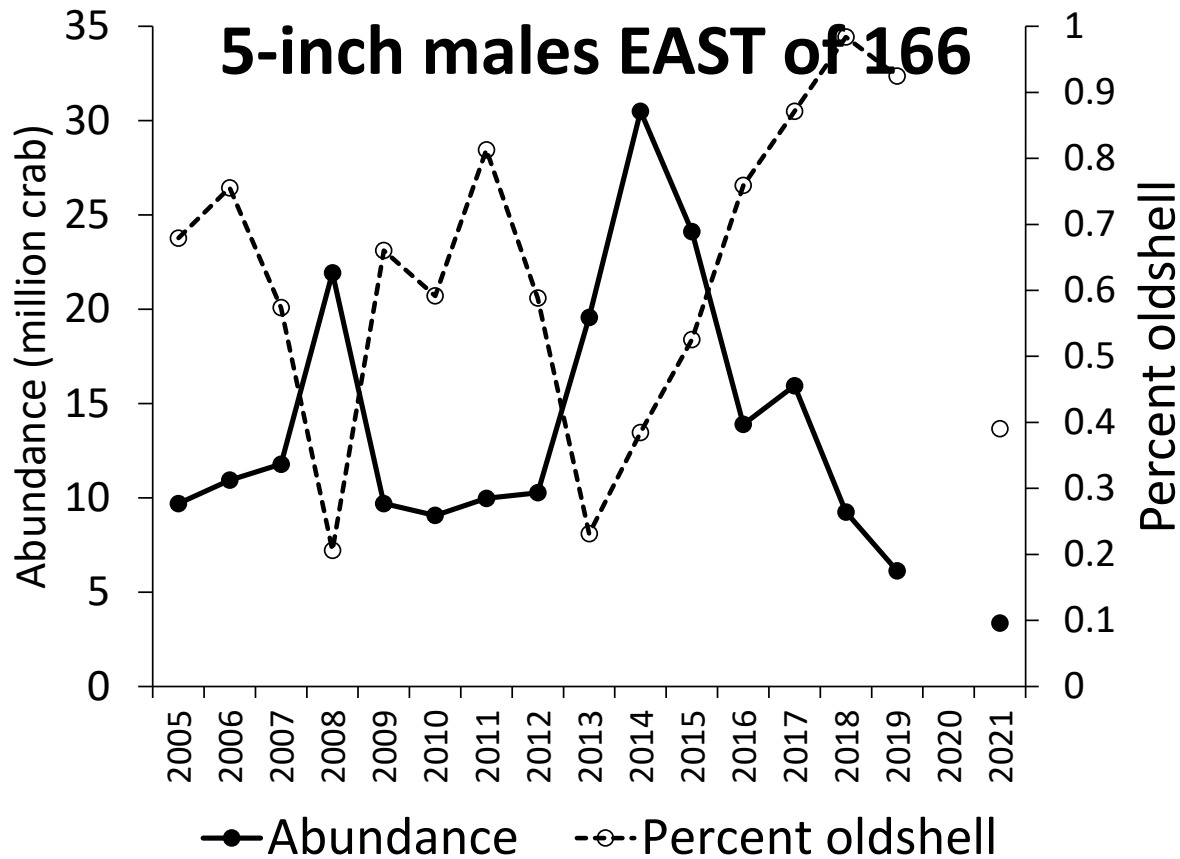
# EAST

## Tanner Crab east of 166°W

Shell condition  
Molting & soft ■ New - hard ■ Old ■ Very old ■



# EAST

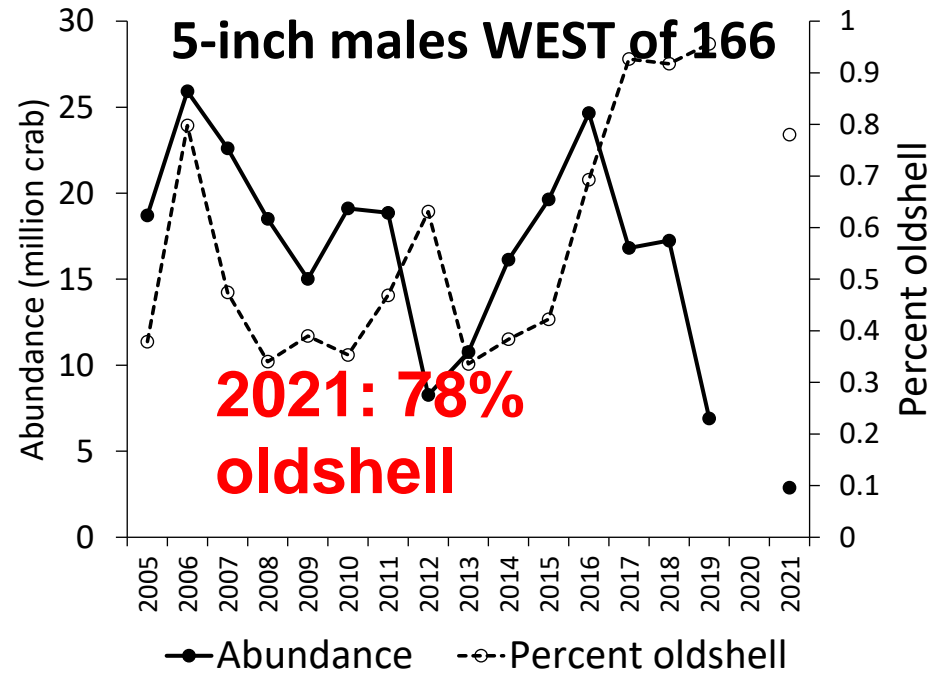
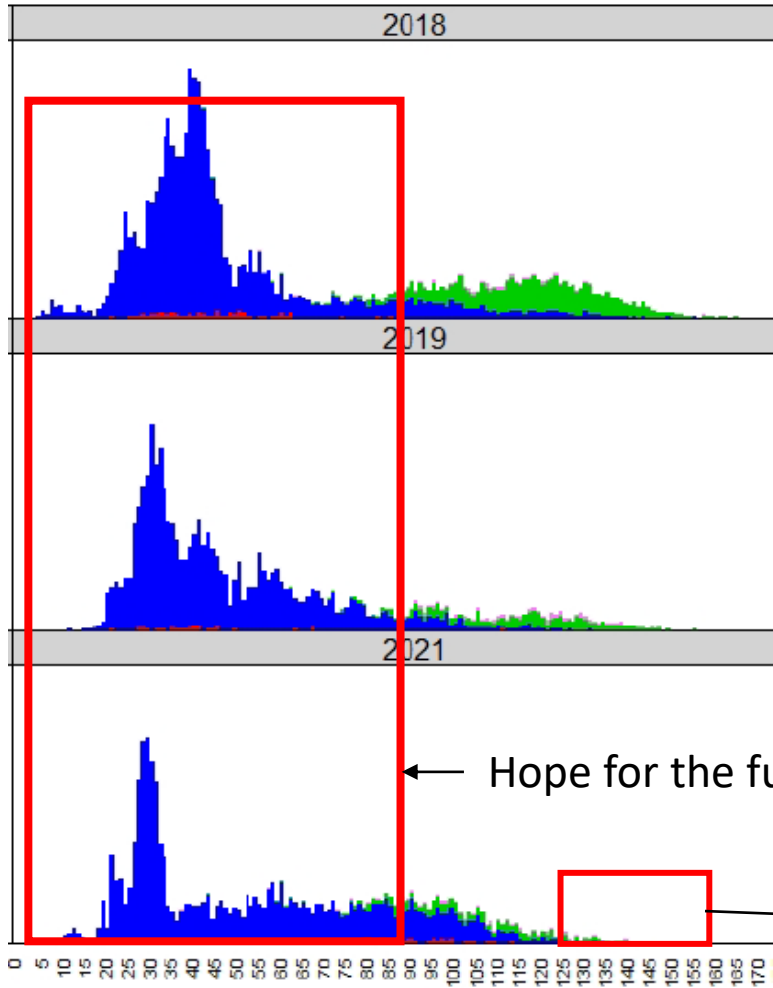


**2021: 39% oldshell**

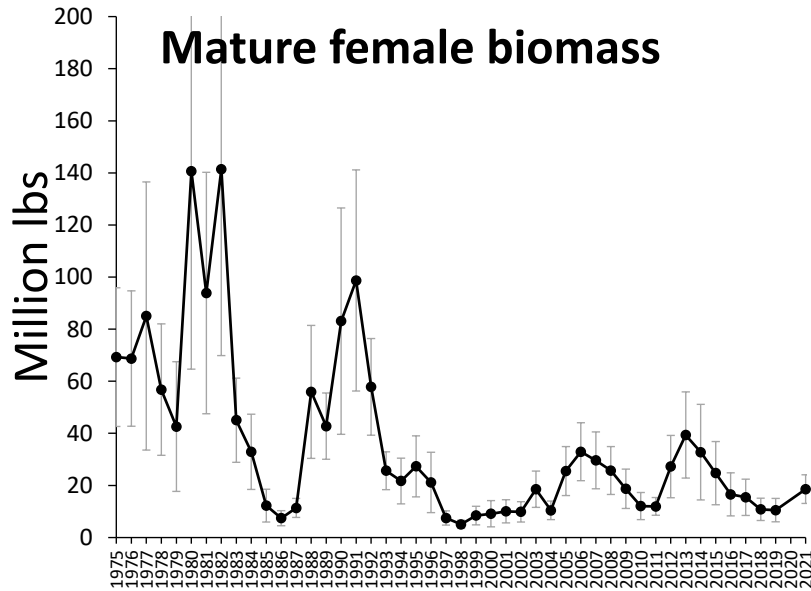
**2021 lowest  
abundance in the  
timeseries**

# WEST

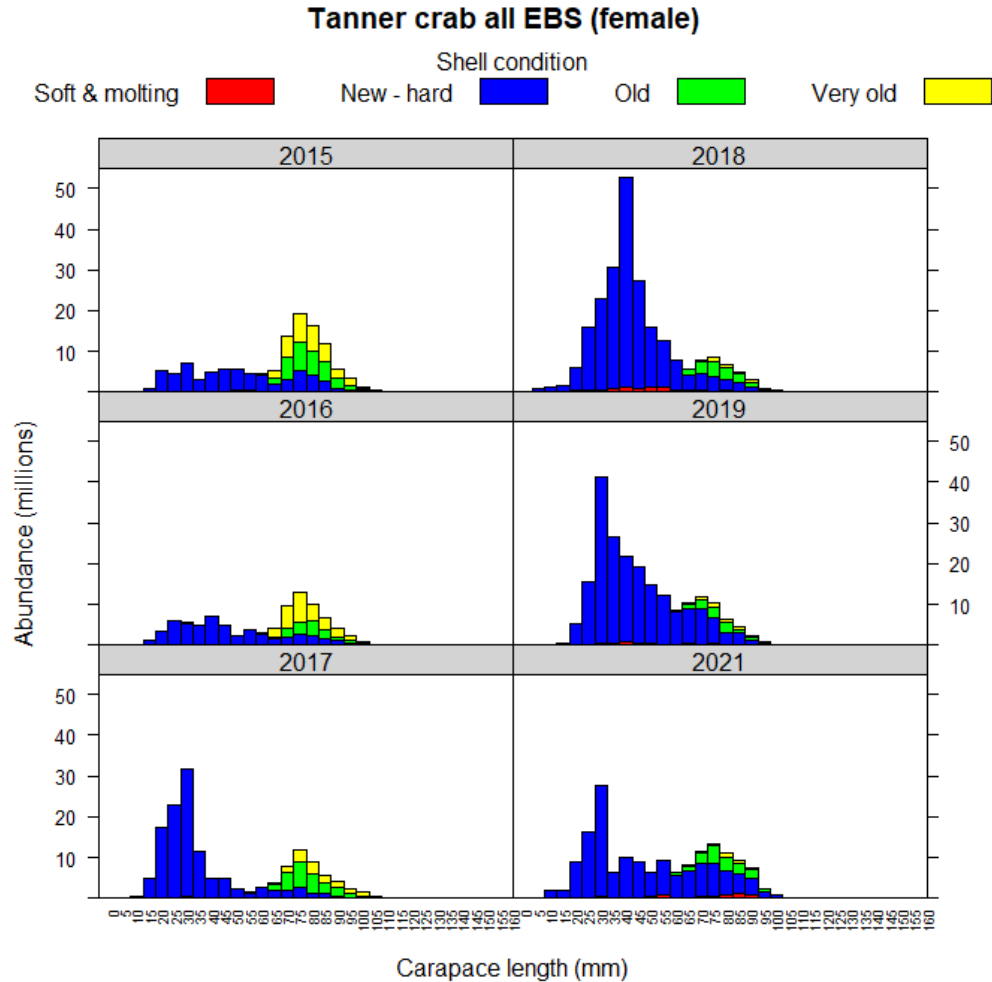
WEST males



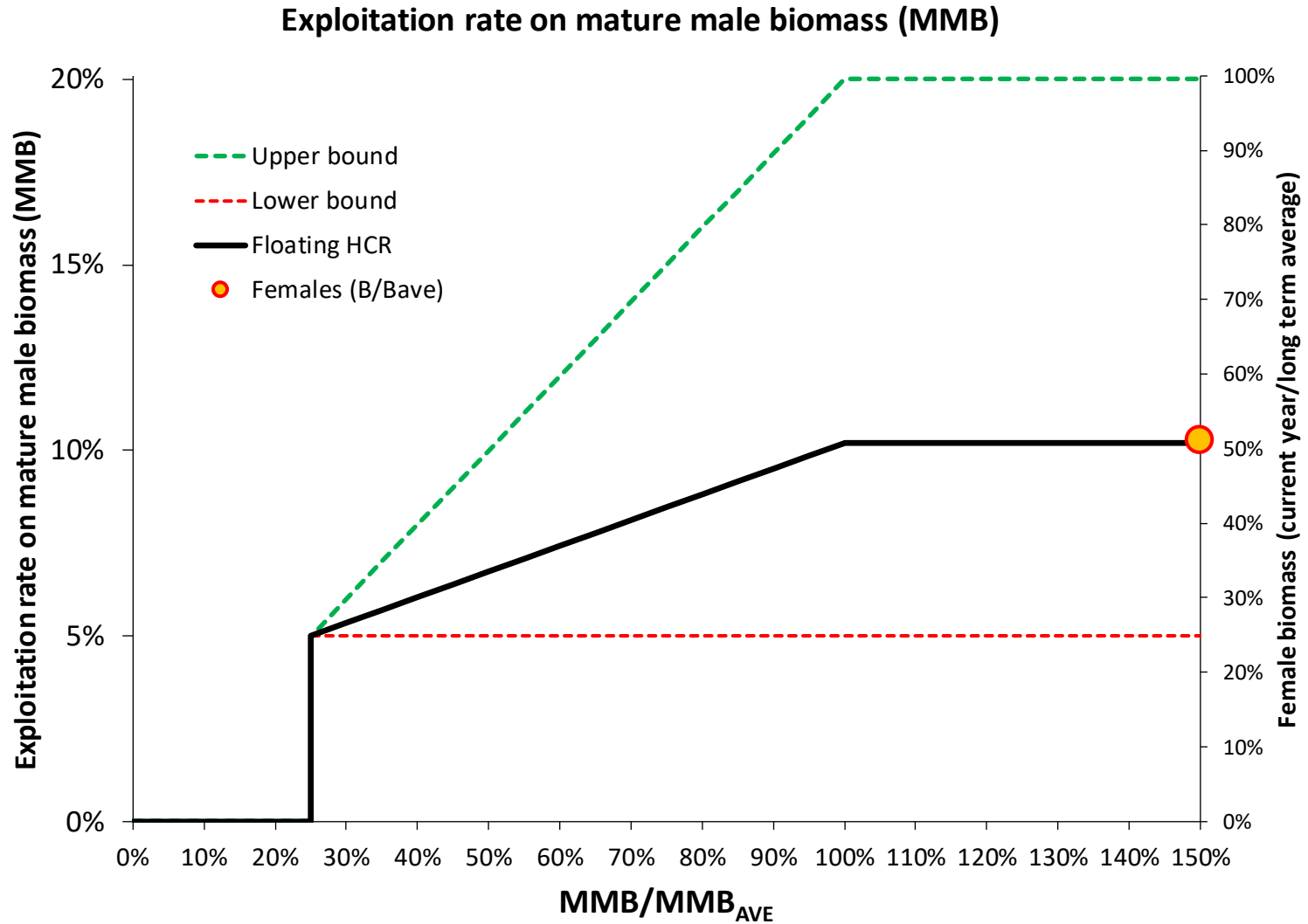
# Mature females: EBS-wide



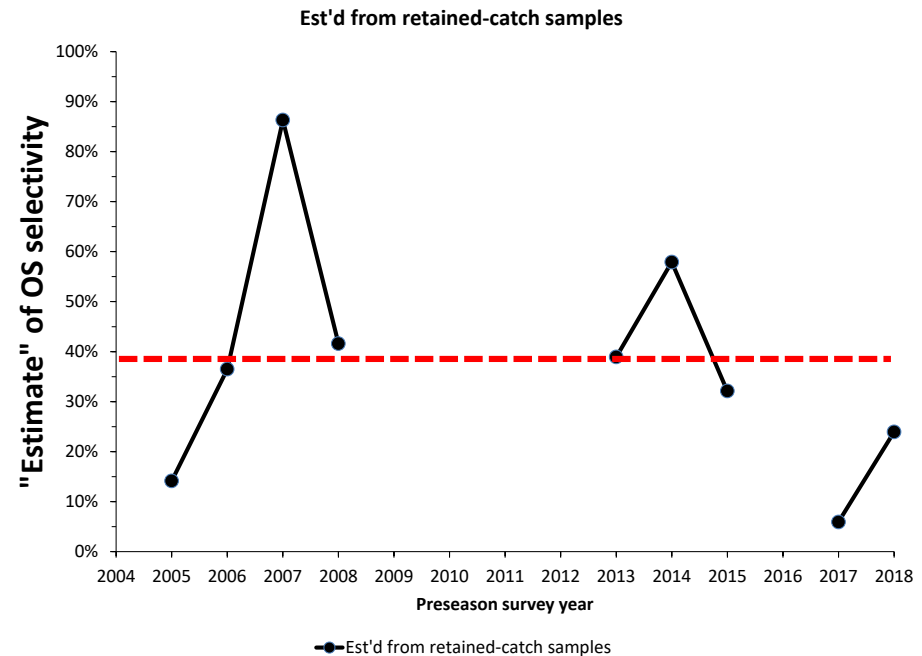
Increase in mature female biomass



# “Female dimmer”



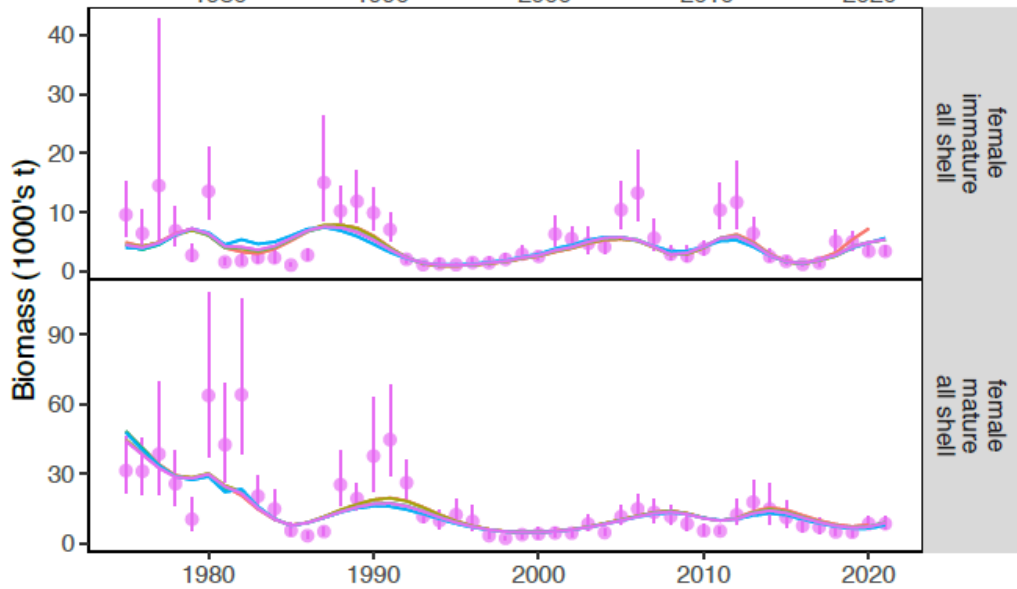
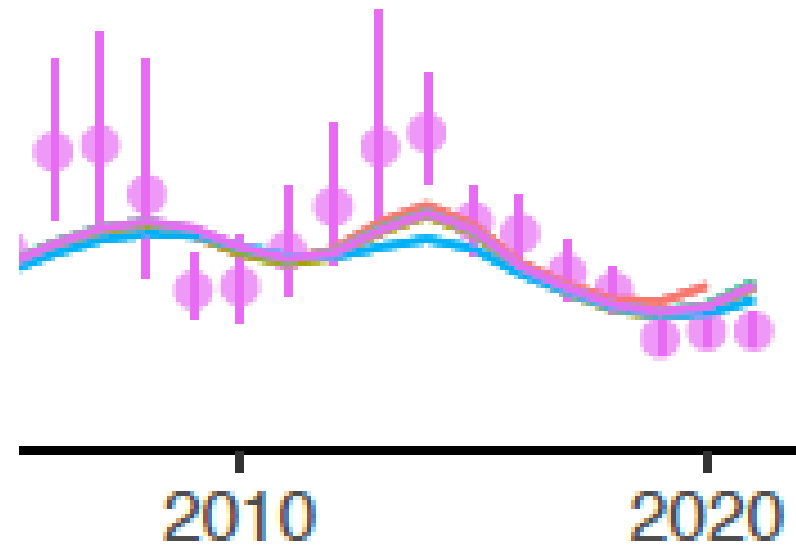
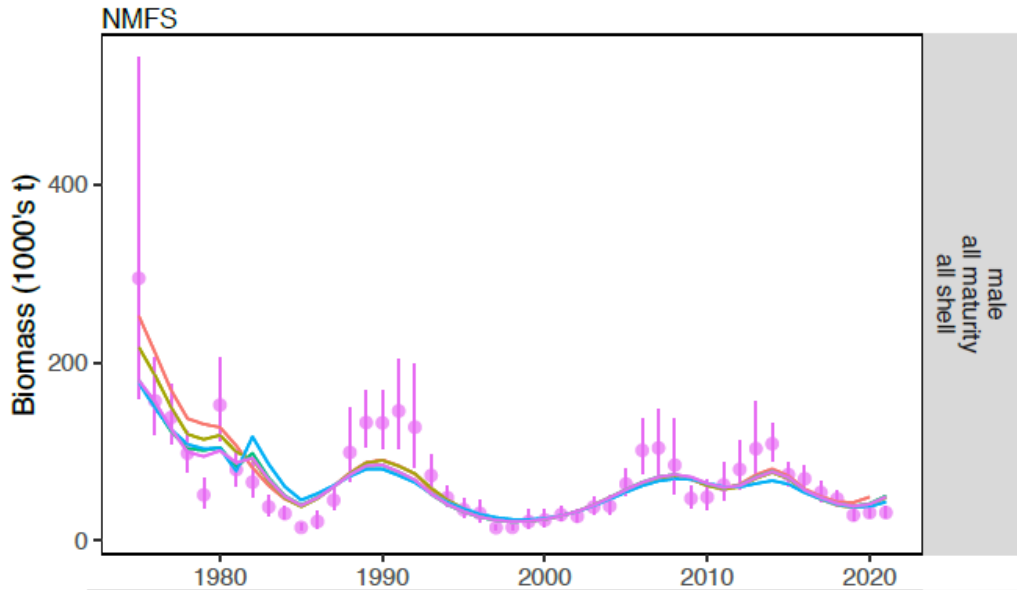
# 50% ELM Cap



ELM= “exploitable legal males”

- 5 inch males: 100% newshell + 40% oldshell
- Considers selectivity of oldshell crabs: industry generally prefers “clean” crab (i.e., mostly newshell)
- Mean OS selectivity = ~40%
- TAC capped at 50% of ELM:  **$0.5 * \text{ELM} * \text{ave wt}$**

# Model estimates

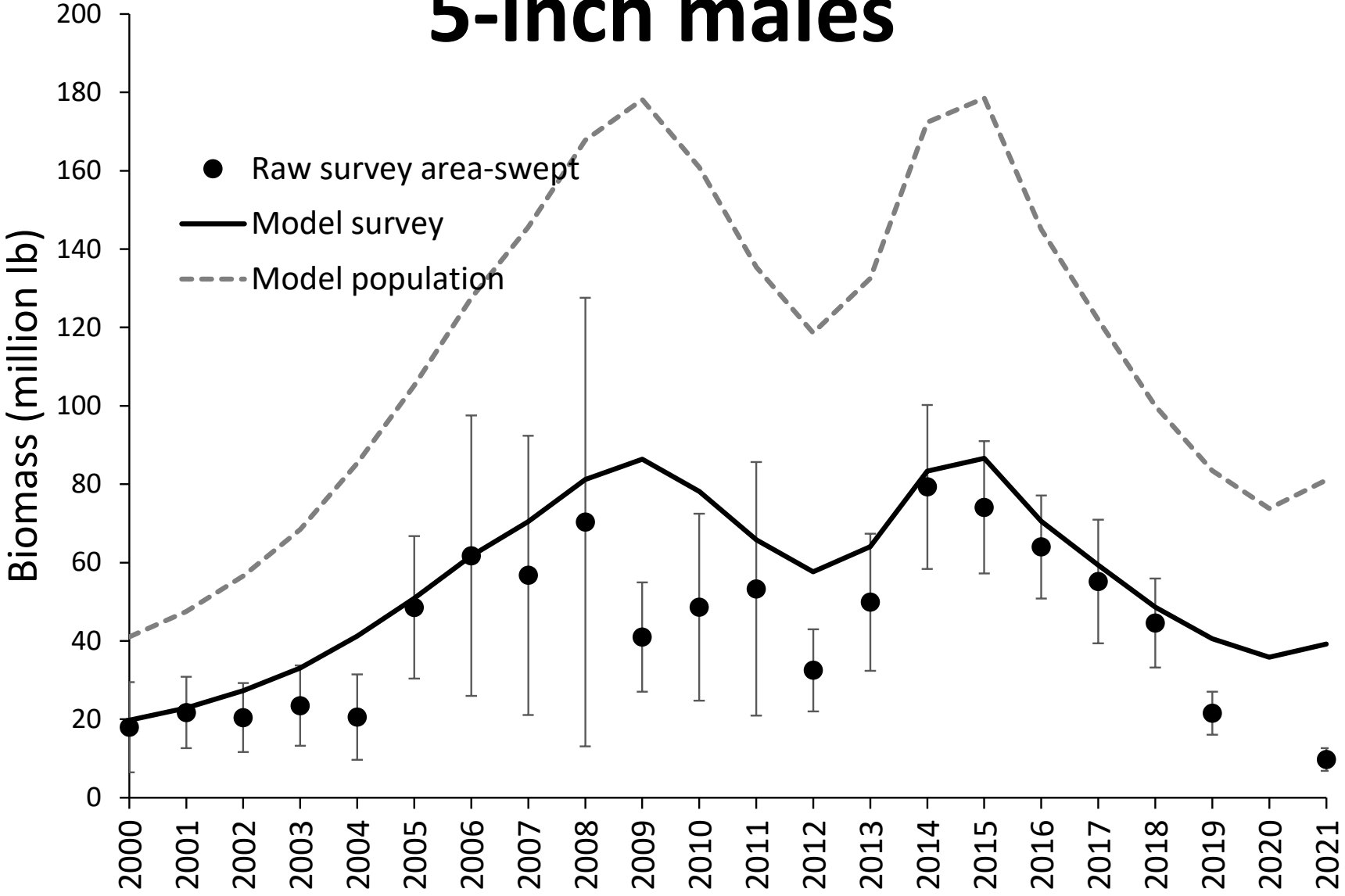


Challenges for setting TAC

- EBS wide
- 2021 estimates



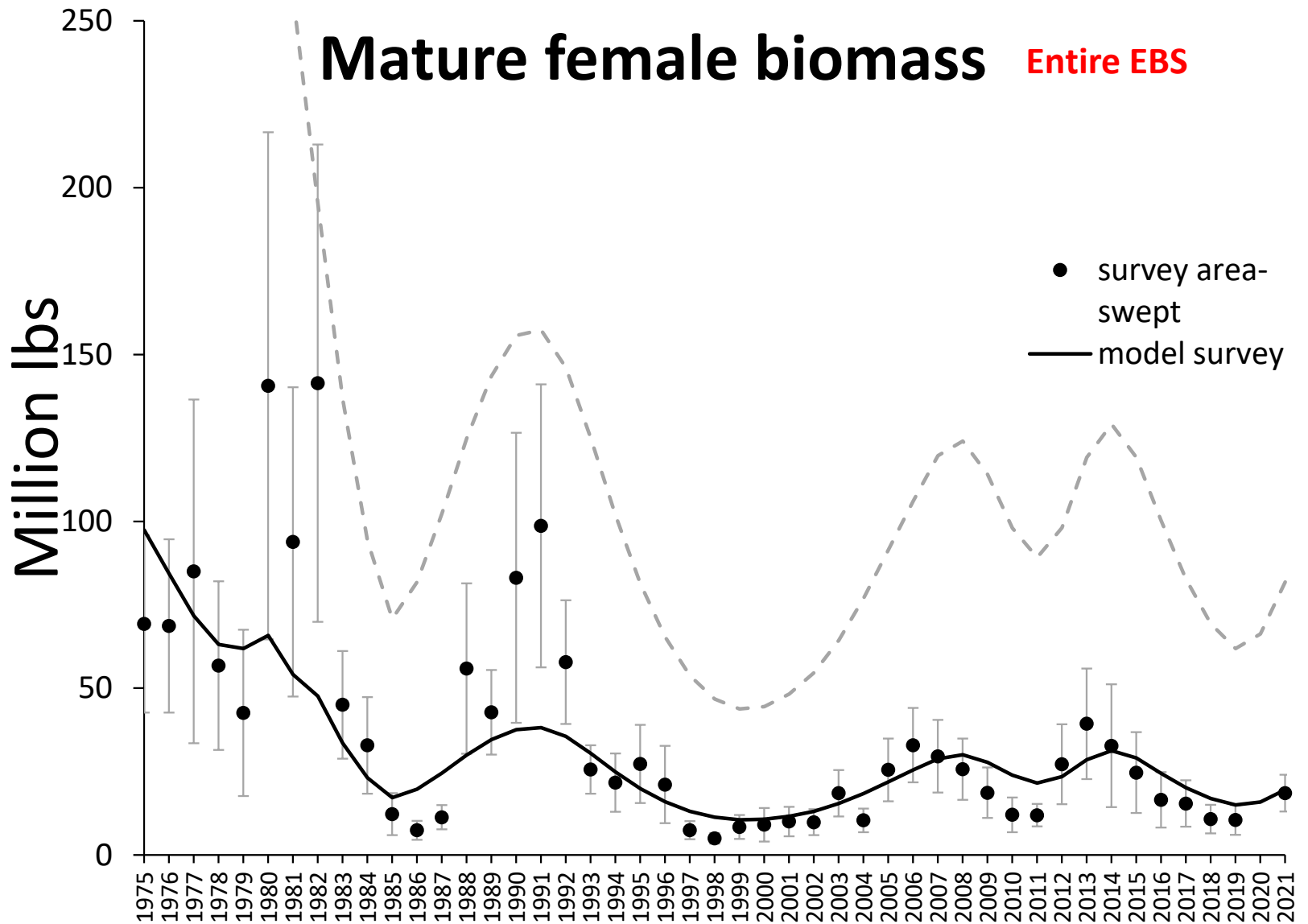
# 5-inch males



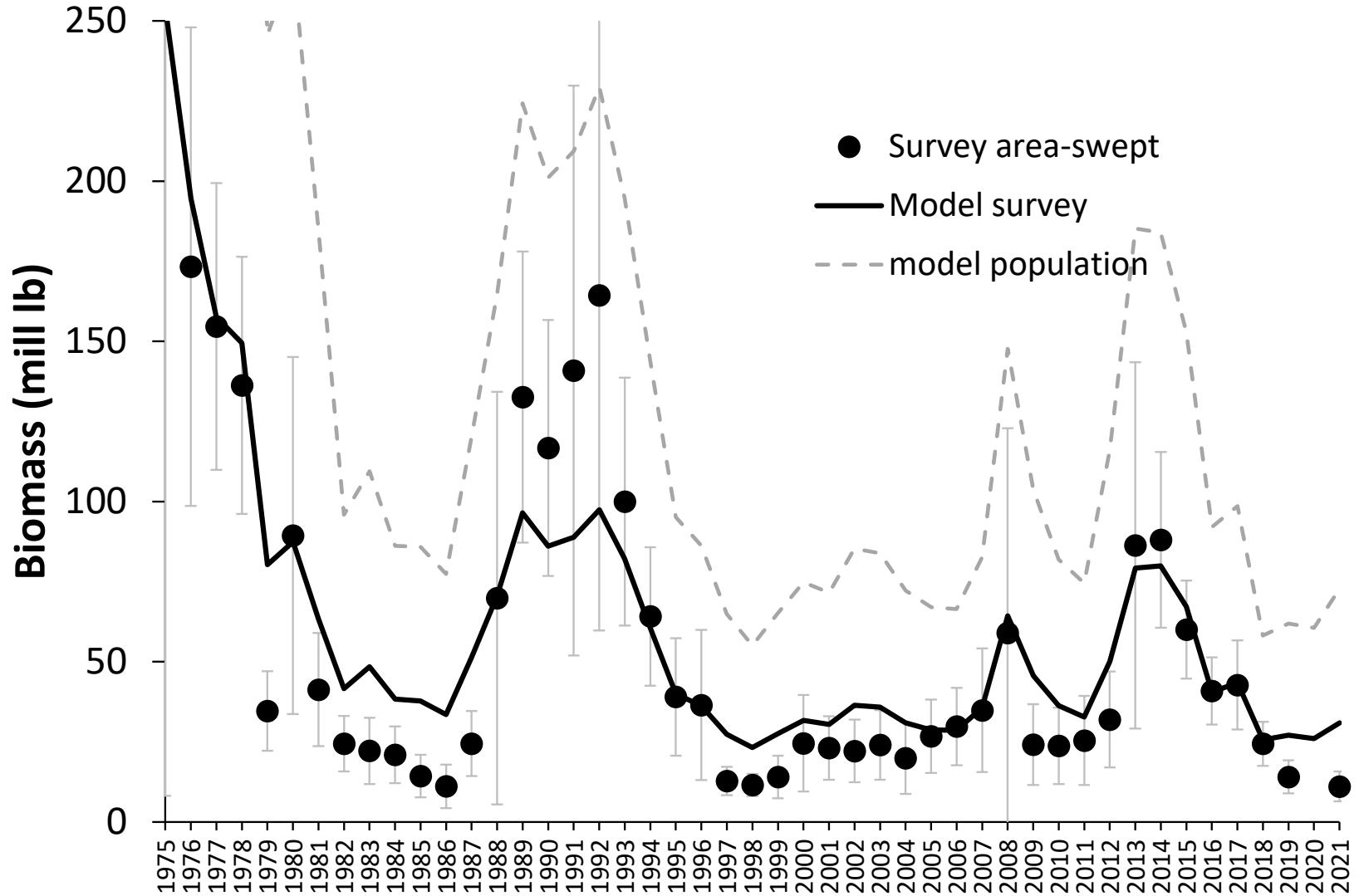
# Model Challenge #1

Apportioning model estimates east-west of 166 W

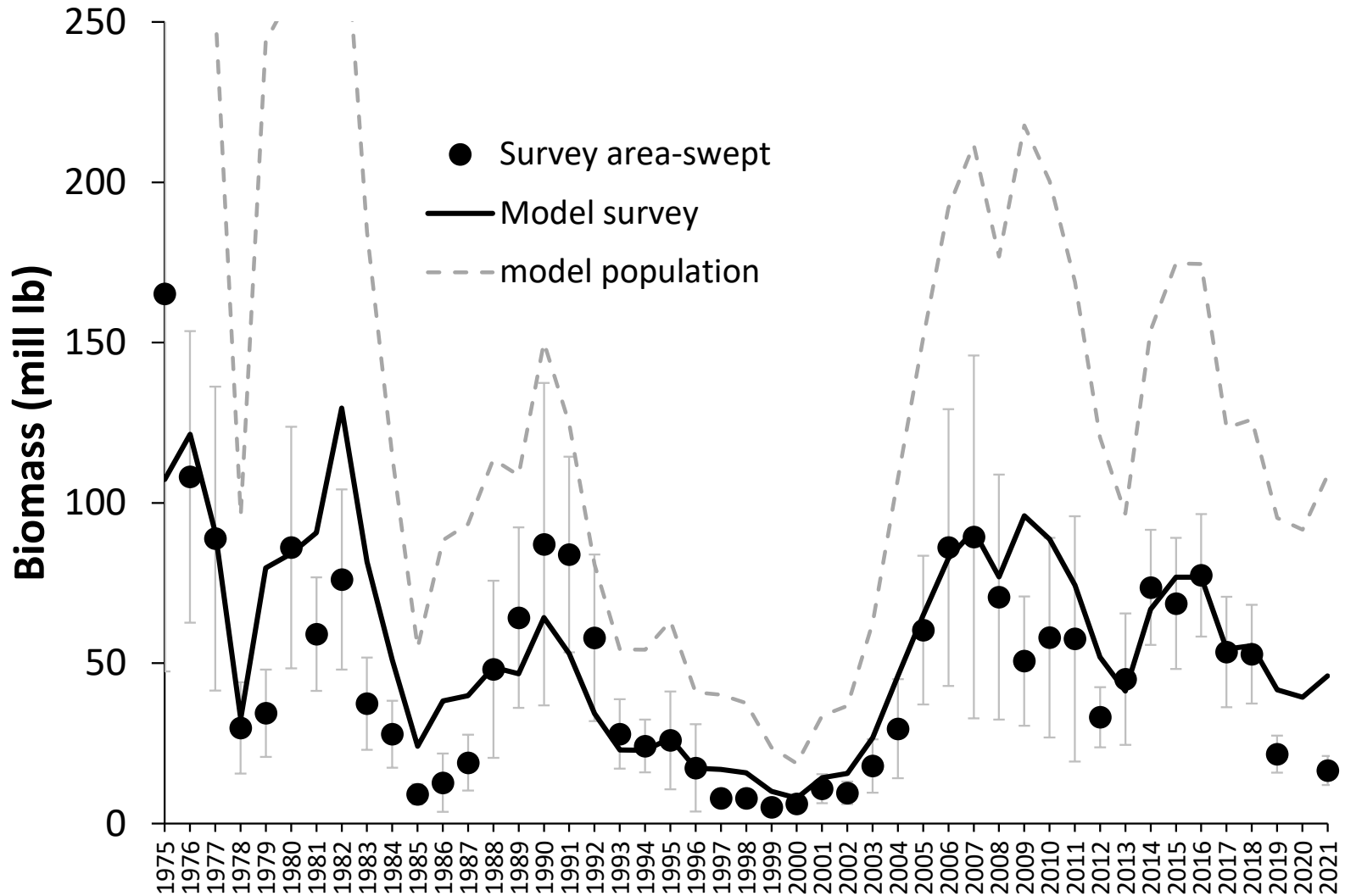
**Approach:** Calculate survey proportions east-west for each harvest strategy input (MMB, 5 inch male abund) apply those proportions to the mode output.



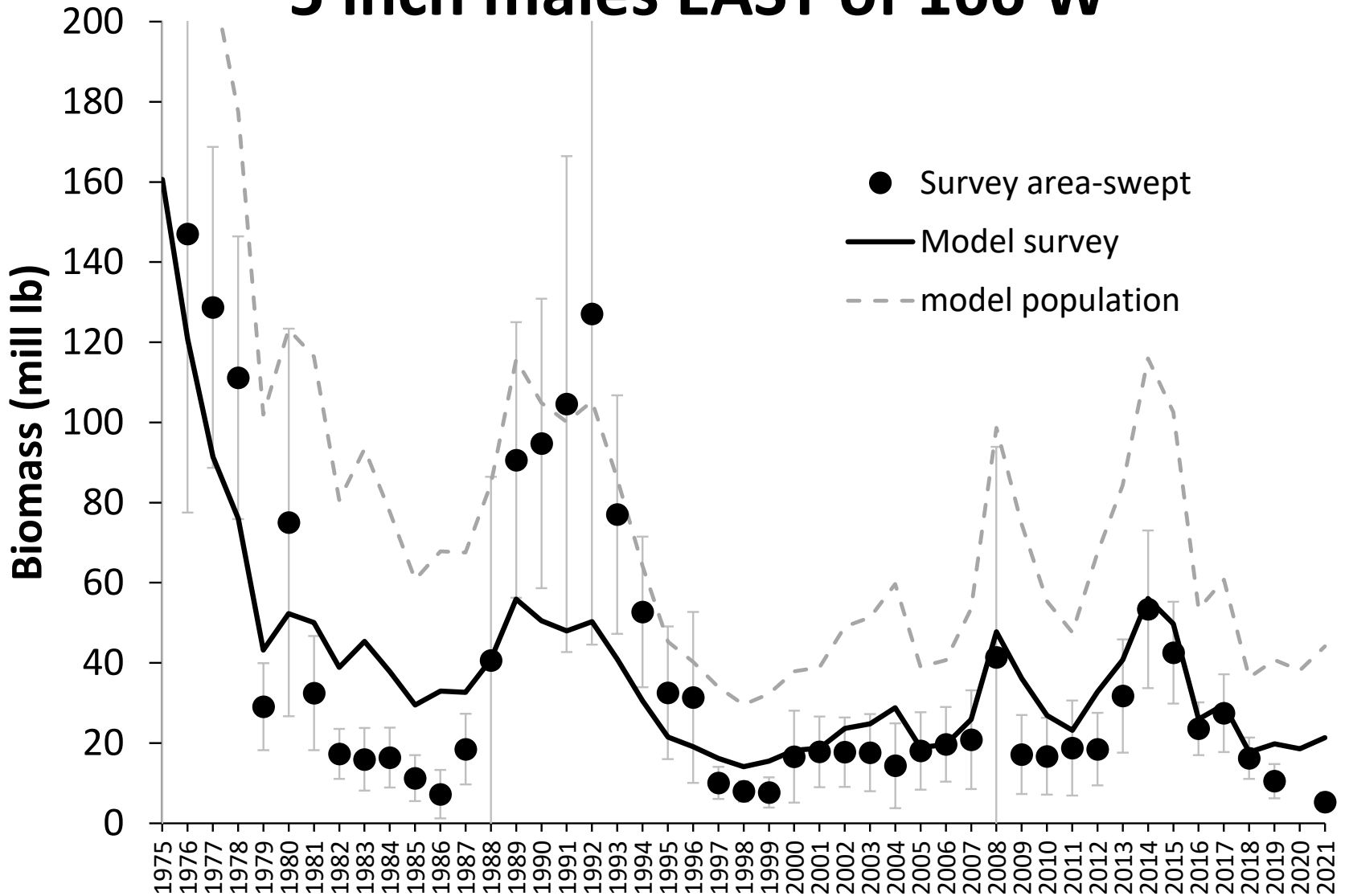
# Mature males EAST of 166 W



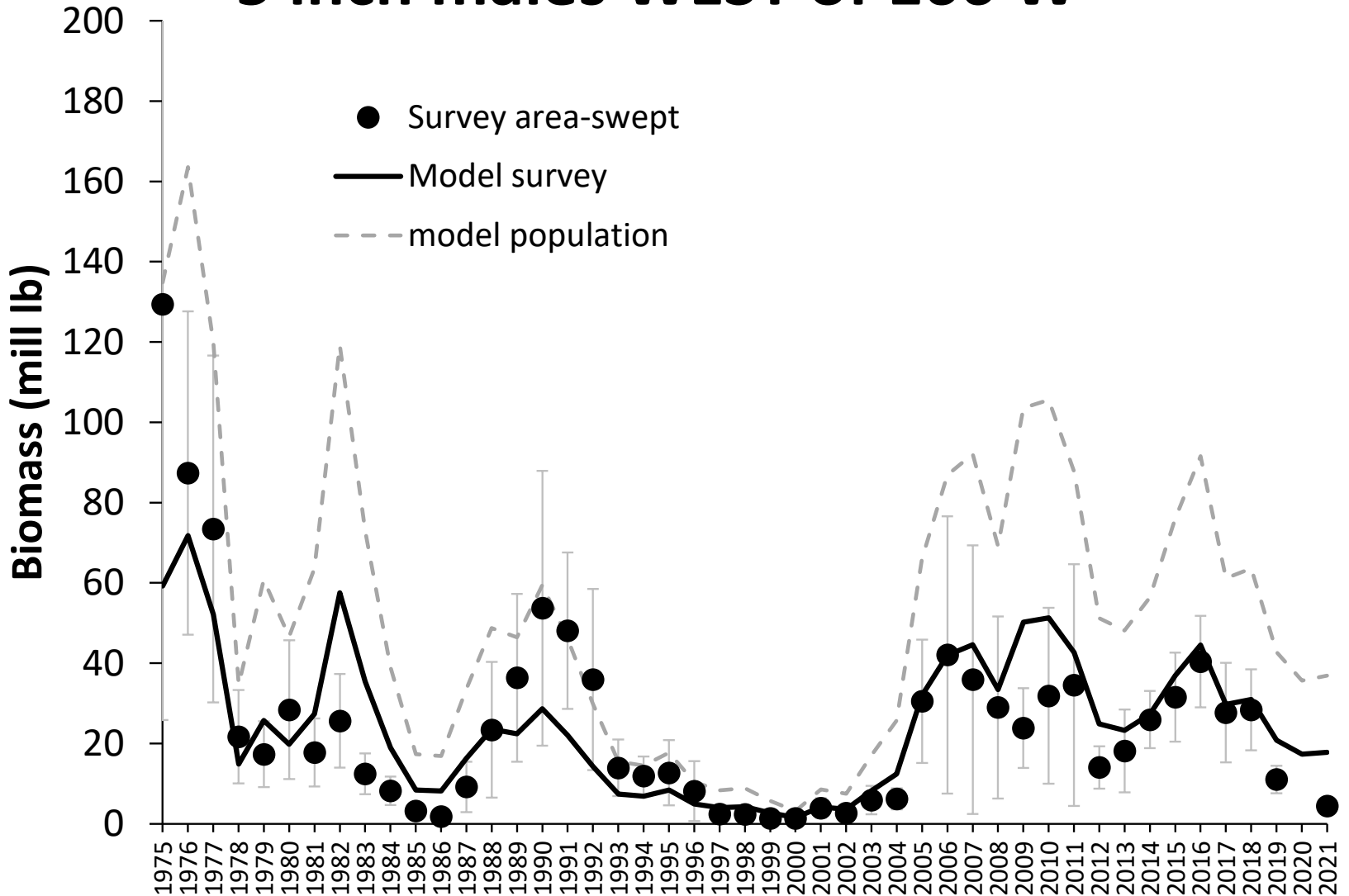
# Mature males WEST of 166 W



# 5 inch males EAST of 166 W



# 5 inch males WEST of 166 W



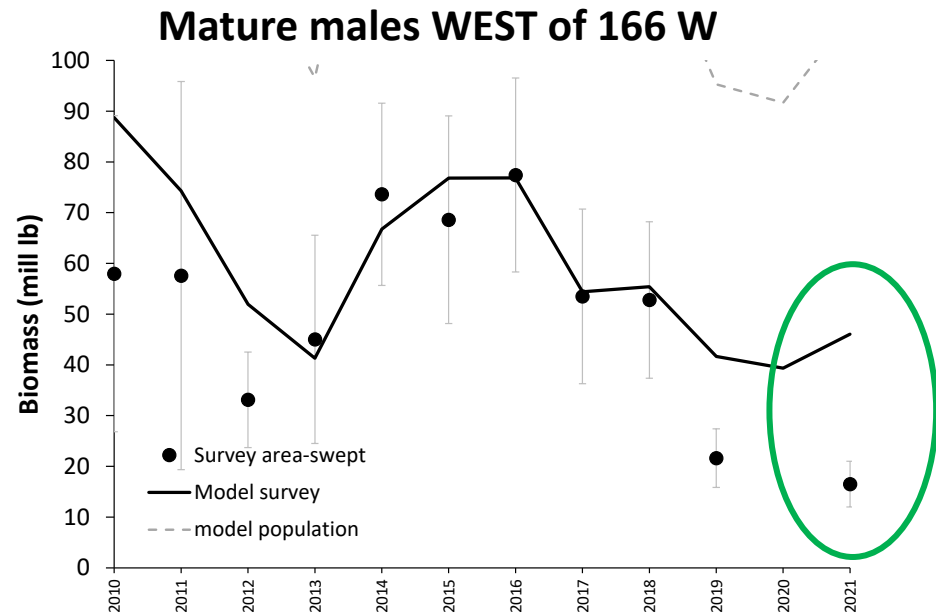
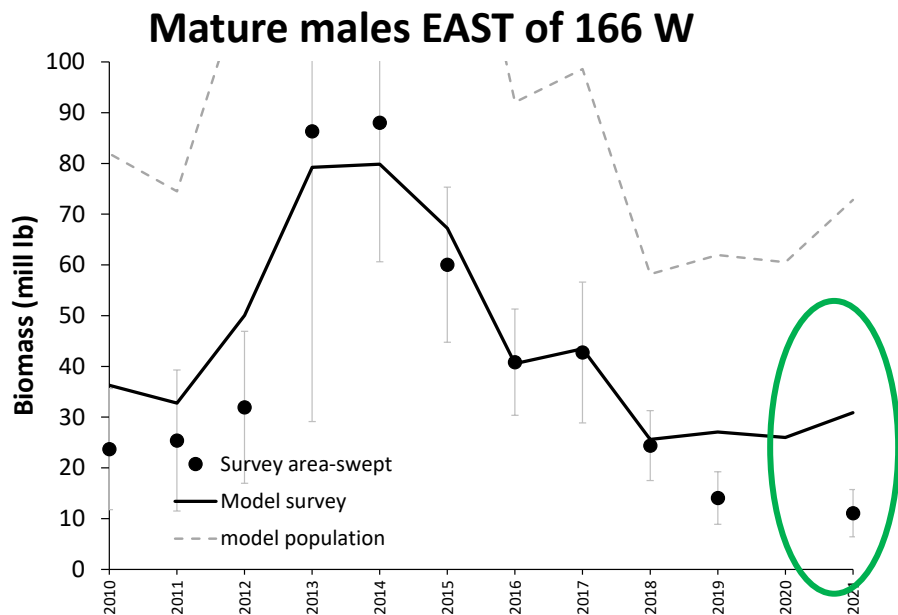
# Model Challenge #2: Model Fit

**Approach: 3 TAC calculations for comparison**

- 1. Survey area-swept** based TAC: raw area-swept, use size cut for male maturity
- 2. Model survey** TAC: model estimates of survey, uses maturity ogive
- 3. Model population** TAC: accounts for survey selectivity



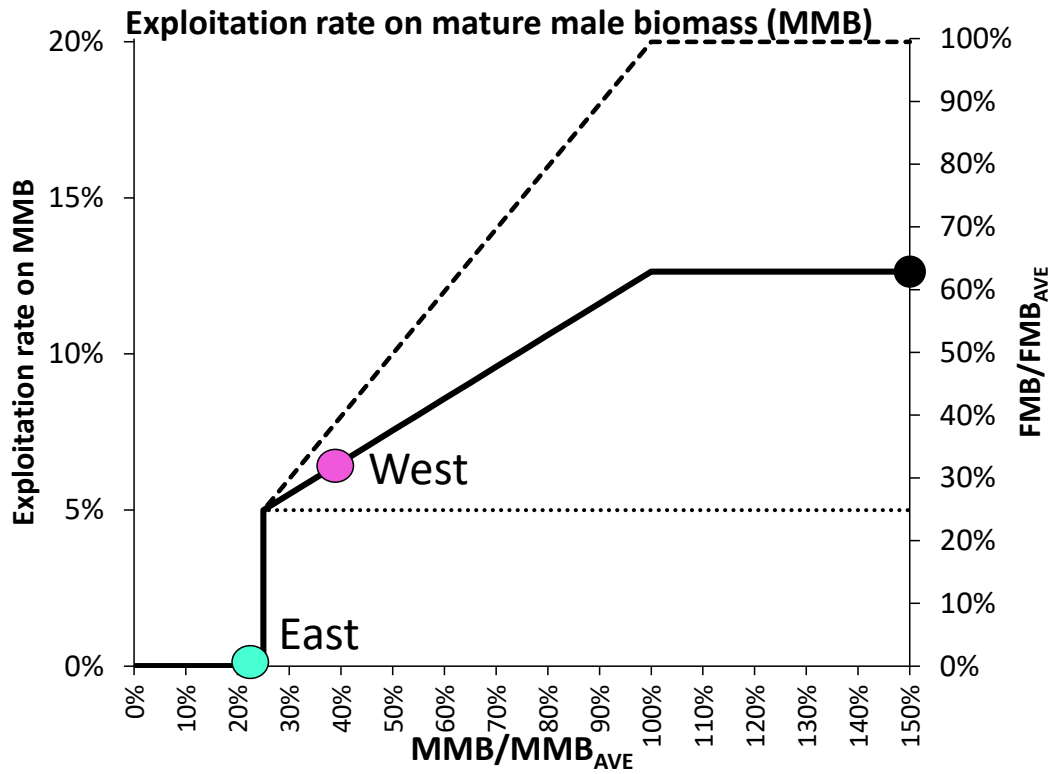
# 2021 Model survey MMB $\sim$ 3X survey estimate



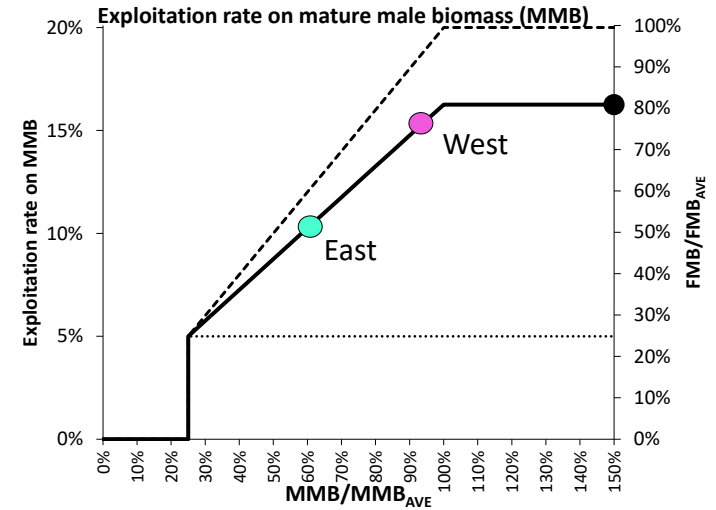
General uncertainty about model estimates

# 2021 Female Dimmer

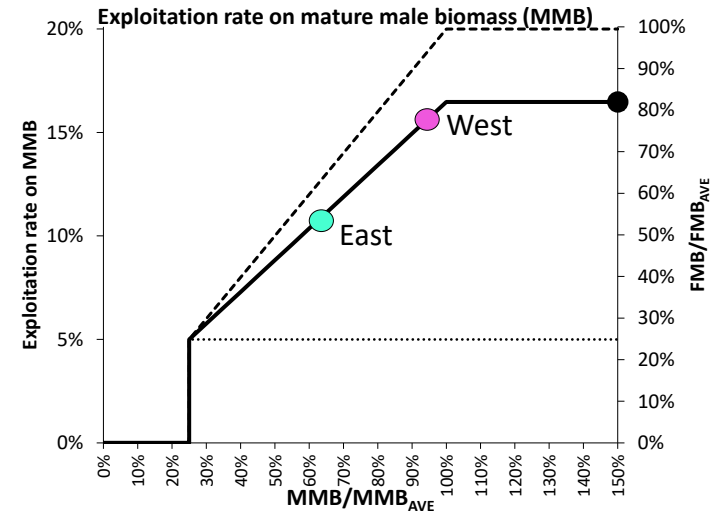
## Survey



## Model Survey



## Model Population



# EAST

**Computed 2021/22 TACs: area-swept and Model estimates. Assumed old-shell fishery selectivity = 0.40 relative to new-shell.**

	Raw area-swept (size cut)		Survey (Model Predicted)		Population (Model Estimated)	
	MFB	MMB	MFB	MMB	MFB	MMB
1982-2018 Average (millions lb)	29.4	46.8	28.8	48.9	99.3	113.7
2021 Estimate (millions lb)	18.6	11.1	19.6	30.9	81.8	72.8
(2021 Est)/(1982-2018 Avg)	63%	24%	68%	63%	82%	64%
Exploitation Rate on MMB		0.000		0.107		0.110
Computed TAC = Exp Rate X MMB (millions lb)		0.00		3.31		7.99
Max TAC (50% cap on exploited legal males (million lb)		2.03		6.94		14.52
<b>TAC</b>		<b>0.000</b>		<b>3.312</b>		<b>7.99</b>

	Area-swept (Raw NOAA values)	Survey (Model Predicted)	Population (Model Estimated)
Abundance of ♂♂ ≥ 5-in CW (millions)	3.4	11.5	24.0
Average wt (W; from survey; lb)	1.578	1.578	1.578
% old shell (from area-swept)	39%	39%	39%
Expected old shell selectivity	0.4	0.4	0.4
Exploited legal males ("ELM"; millions)	2.6	8.8	18.4
<b>Max TAC (= 0.5xELMxW; millions lb)</b>	<b>2.03</b>	<b>6.94</b>	<b>14.52</b>

# WEST

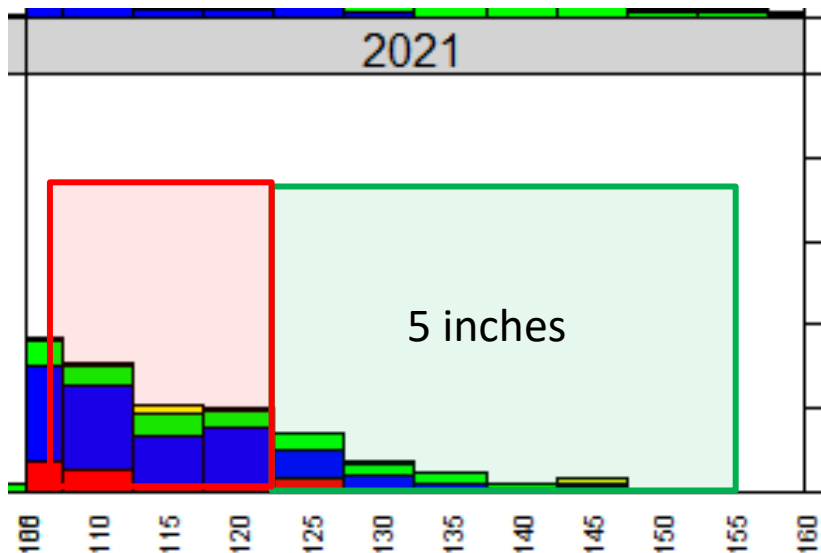
**Computed 2021/22 TACs: area-swept and Model estimates. Assumed old-shell fishery selectivity = 0.40 relative to new-shell.**

	Raw area-swept (size cut)		Survey (Model Predicted)		Population (Model Estimated)	
	MFB	MMB	MFB	MMB	MFB	MMB
1982-2018 Average (millions lb)	<b>29.4</b>	43.0	<b>28.8</b>	50.1	<b>99.3</b>	115.5
2021 Estimate (millions lb)	<b>18.6</b>	<b>16.5</b>	<b>19.6</b>	<b>46.1</b>	<b>81.8</b>	<b>108.6</b>
(2021 Est)/(1982-2018 Avg)	<b>63%</b>	38%	<b>68%</b>	92%	<b>82%</b>	94%
Exploitation Rate on MMB		<b>0.064</b>		<b>0.151</b>		<b>0.156</b>
Computed TAC = Exp Rate X MMB (millions lb)		1.05		6.94		16.89
Max TAC (50% cap on exploited legal males (million lb)		1.18		4.03		8.42
<b>TAC</b>		<b>1.052</b>		<b>4.026</b>		<b>8.42</b>

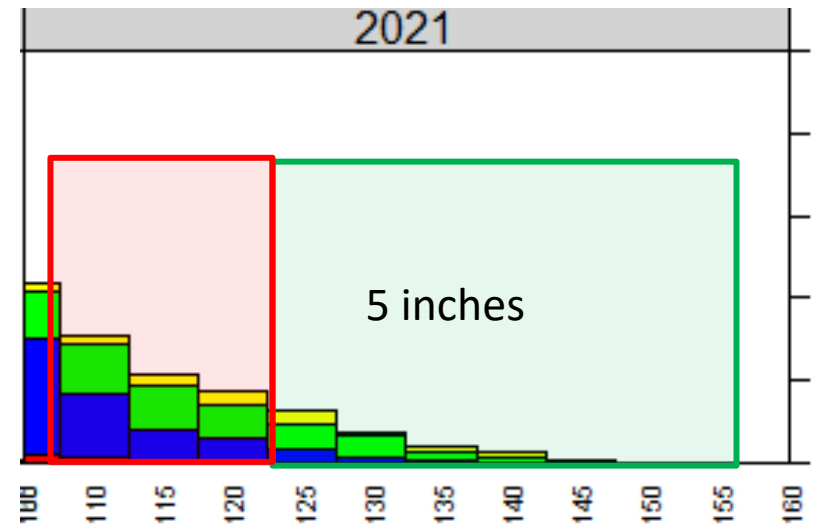
	Area-swept (Raw NOAA values)	Survey (Model Predicted)	Population (Model Estimated)
Abundance of ♂♂ ≥ 5-in CW (millions)	2.9	9.8	20.6
Average wt (W; from survey; lb)	1.539	1.539	1.539
% old shell (from area-swept)	78%	78%	78%
Expected old shell selectivity	0.4	0.4	0.4
Exploited legal males ("ELM"; millions)	1.5	5.2	11.0
<b>Max TAC (= 0.5xELMxW; millions lb)</b>	<b>1.18</b>	<b>4.03</b>	<b>8.42</b>

# Thoughts on discarding

## East



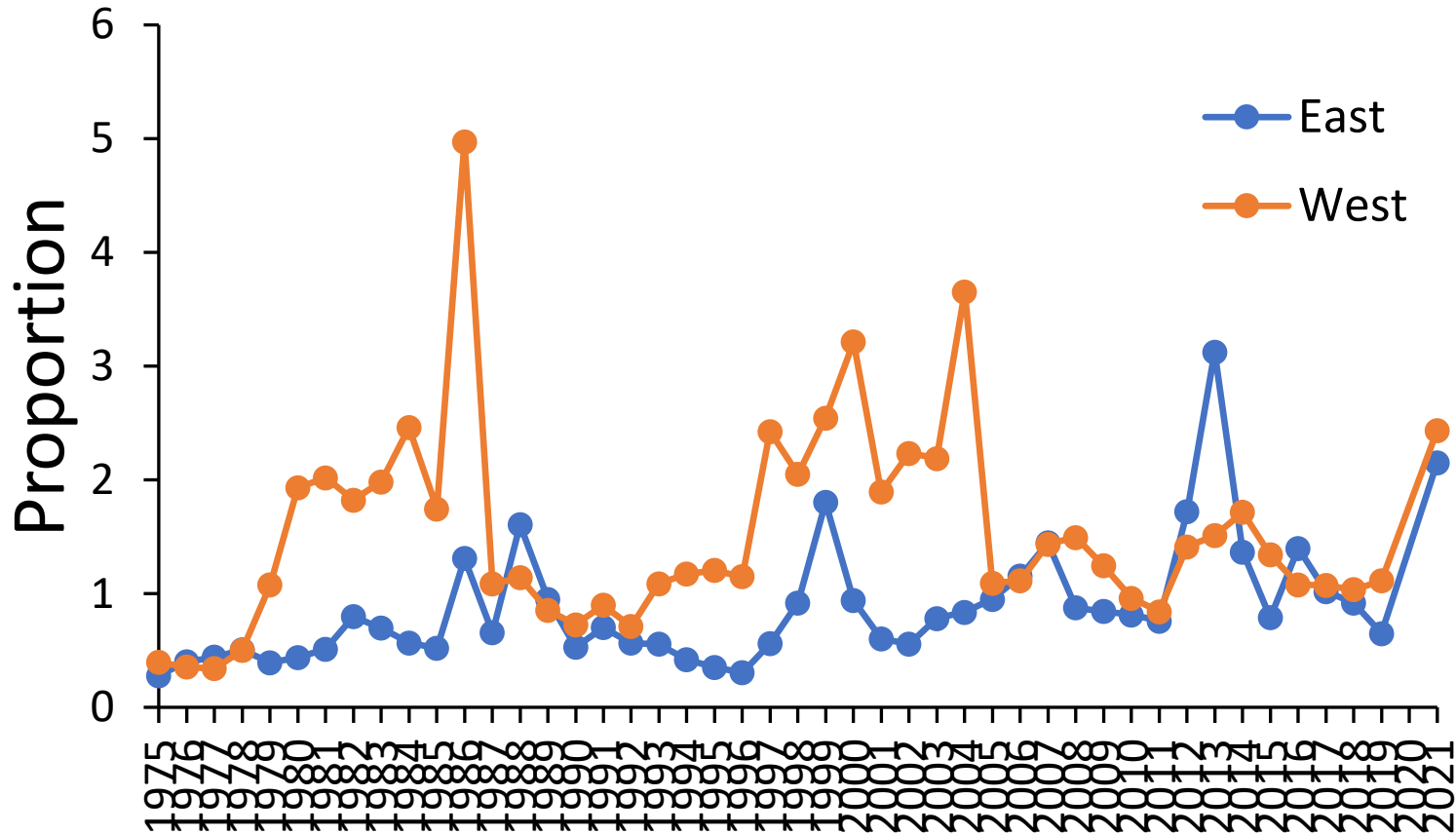
## West



Lets look at ratio for crab in red box to crab in green box to get an idea of how much sorting might be expected in 2021/22 fishery

- Estimate: “For every 5 inch male crab, how many sub-industry-preferred crab are caught”?

## Ratio sub-industry-preferred crab to industry preferred crab



- West: Could expect to encounter  $\sim 2.4$  subindustry-preferred crab for every 5 inch crab
- Relatively high encounter rates with small crab

# EAST TAC Recommendation = 0

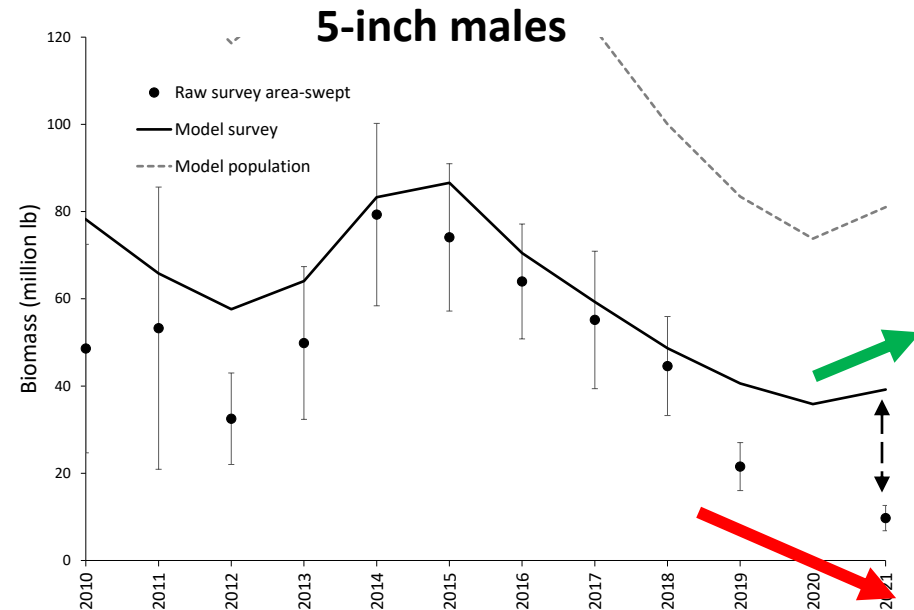
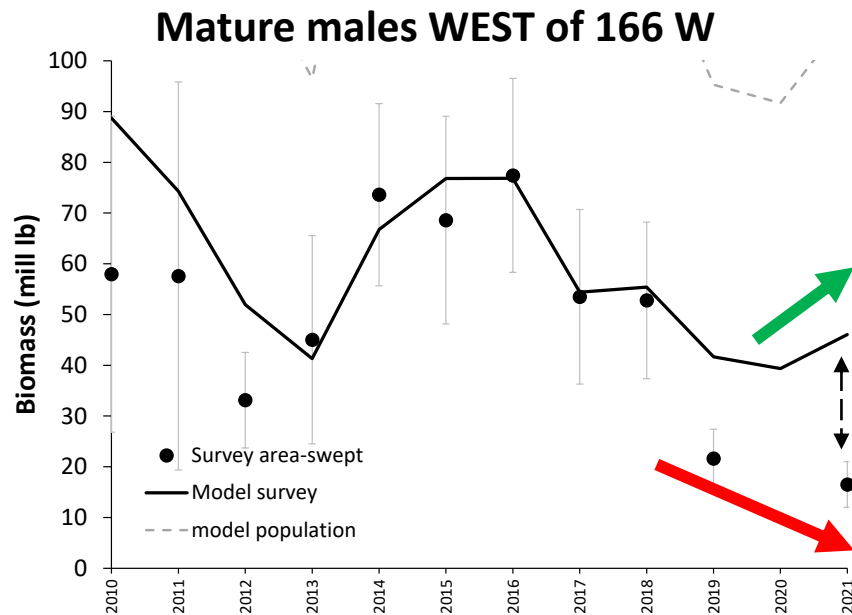
- Survey area-swept estimates below harvest strategy threshold (25% MMB)
- Uncertainty with model 2021 estimates
  - Model MMB ~3x survey
  - Model 5 inch male ~4x survey
- Survey trends for MMB + 5 inch males decreased from 2019
  - Closed in 2020 due to low biomass
- Concerns about BBRKC bycatch
- Same concerns as in 2020

# WEST TAC Recommendation = 1.1 mill lb

- 2021: Survey-based TAC
  - 2020: Mid-point between survey (projected) + model
  - That approach in 2021 would yield 2.5 mill lbs, but 2.35 was not captured last season + survey numbers down in 2021
- Recognizes reductions in survey biomass
- Uncertainty with model 2021 estimates
  - Model MMB ~3x survey
  - Model 5 inch male ~4x survey
- Survey trends for MMB + 5 inch males decreased from 2019
  - 5 inch males likely ~75% oldshell
  - Likely high discarding due to size composition and shell condition of population



# Why did the ABC go up but the TAC went down?



- Mismatch between survey and model trends in last 2 years
- Model estimates much higher than survey in 2021
- Survey data used to calculate TAC

# Why did the ABC go up but the TAC went down?

- OFL/ABC estimation high relative to survey trends (terminal years)
- Concerns about  $F_{35\%}$  as proxy for  $F_{MSY}$ : overly optimistic about stock productivity?
  - 2020 ABC 37 mill lbs but fishery struggled to capture 2.35 mill lb TAC
- Need to rethink MMB as proxy for reproductive success?
- Estimates of survey catchability contribute to inflated OFL relative to last years OFL

# Tanner crab outlook

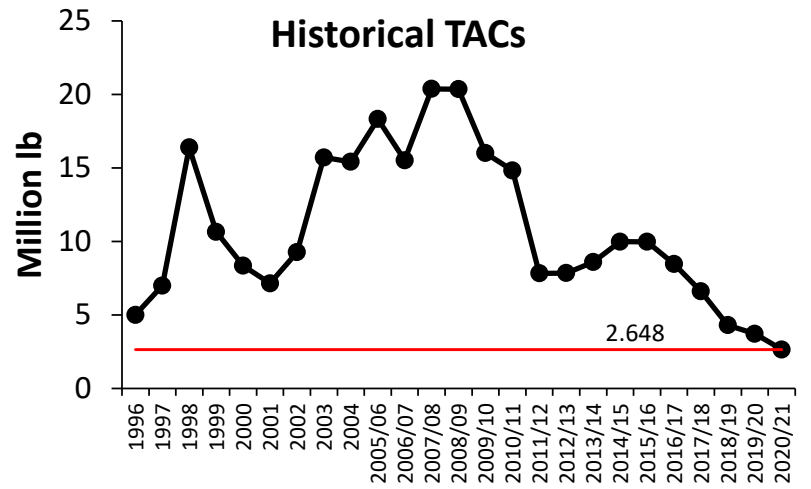
- Mature females: increased in 2021
  - Hope for future
  - Female population trend tends to lead that of males by 1 or 2 years
- Signs of recruitment, particularly in the west
  - Hopefully see improved numbers for 5 inch males in coming years
  - Have not materialized in larger size classes (yet?)

BBRKC

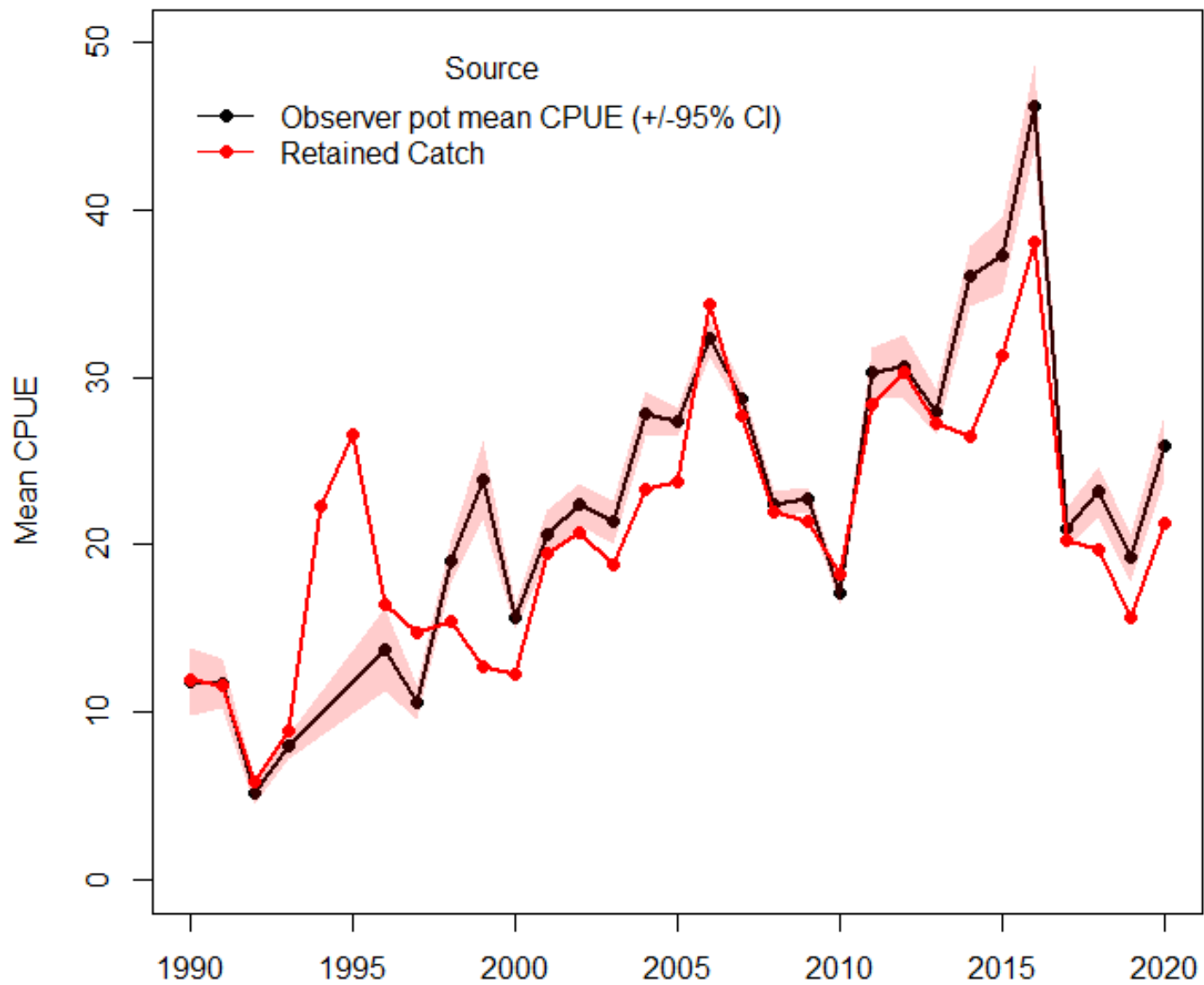
# 2021 Assessment: scenario 21.1

- SSC + Council adopted CPT recommendations
- Stock status: 62% of  $B_{MSY}$
- OFL: 4.91 million lbs
- ABC: 3.68 million lbs
  - including bycatch mortality of males and females in all fisheries
  - based on a 20% buffer on OFL

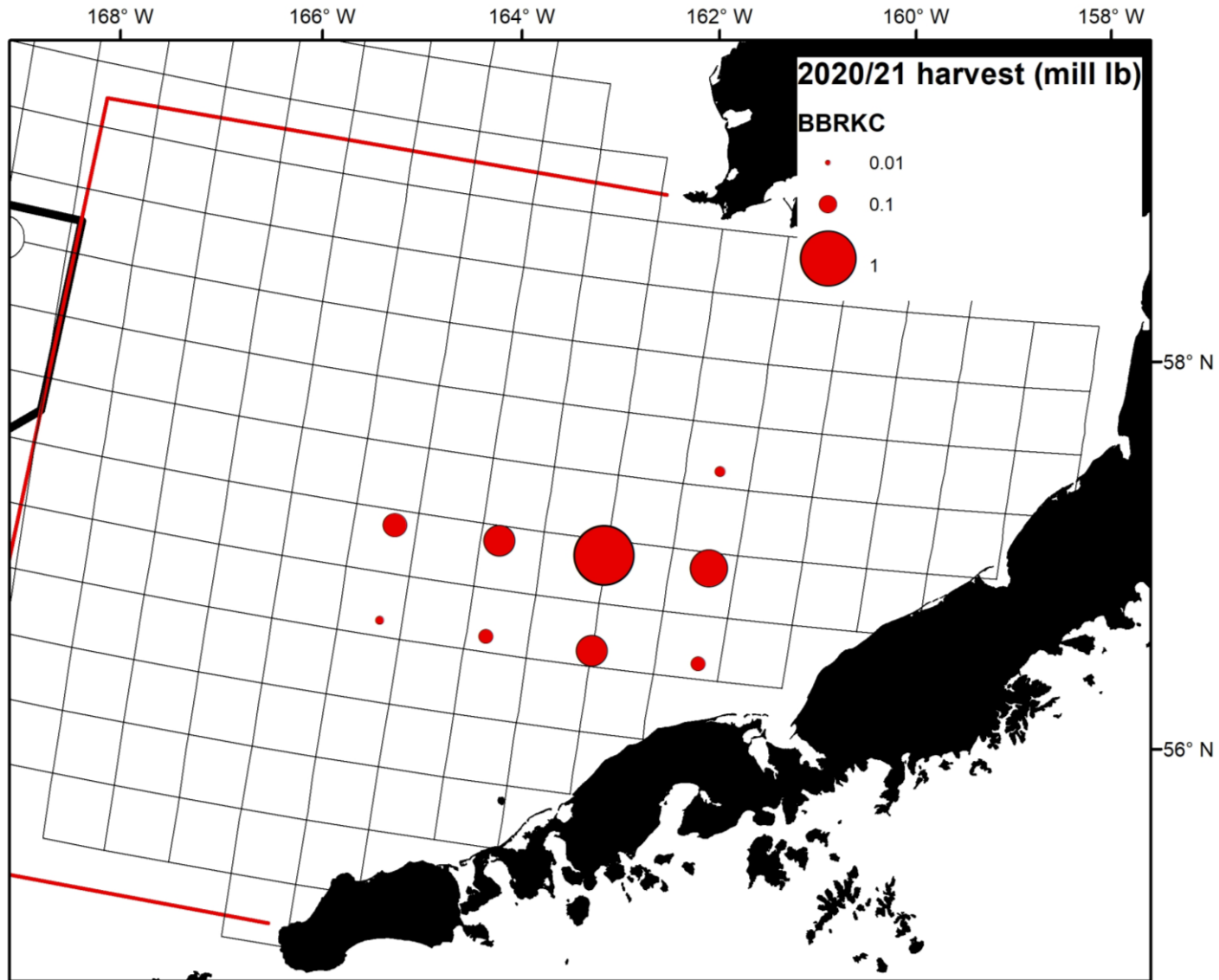
**BBRKC retained catch**



## BBRKC legal male CPUE



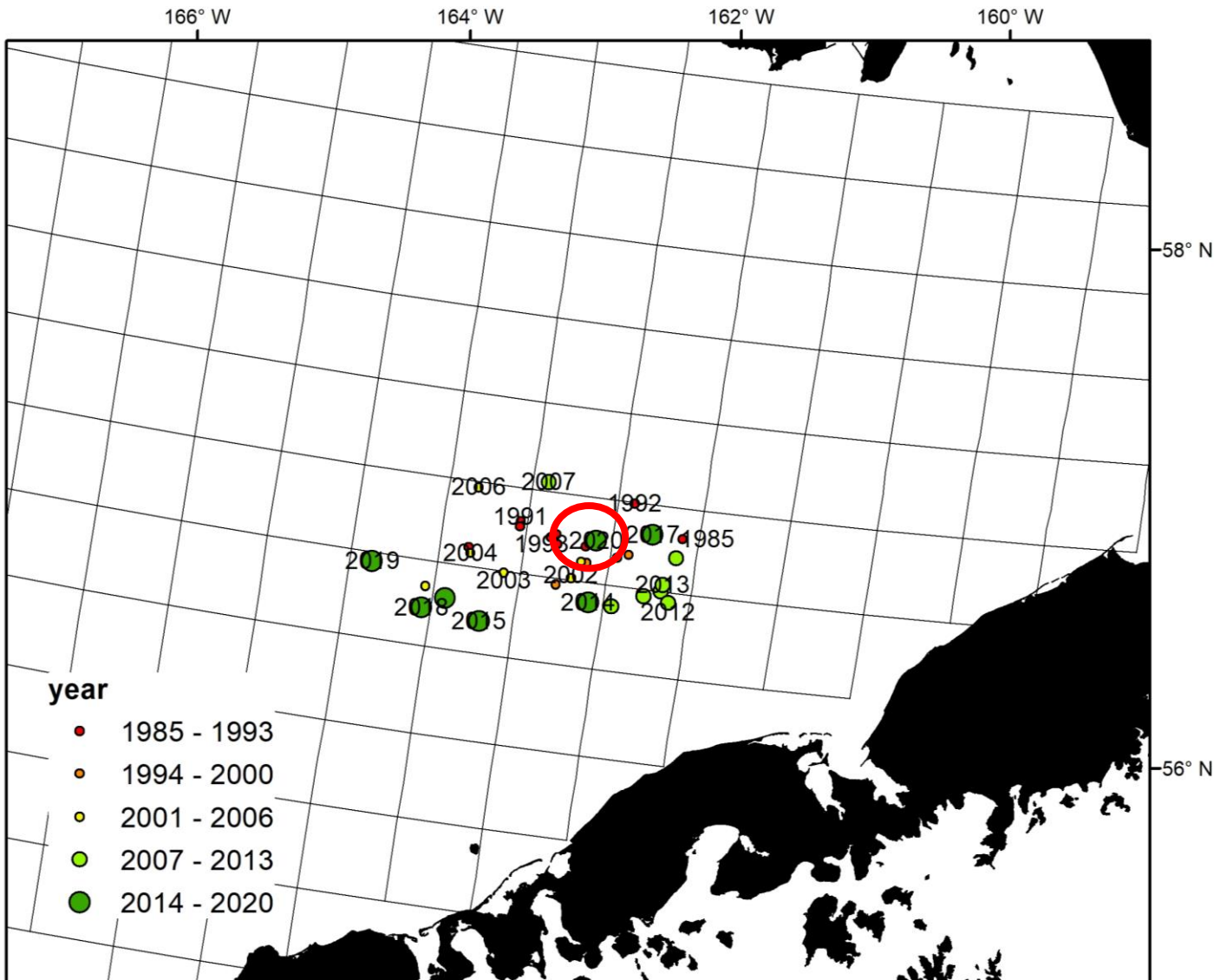
# 2020/21 BBRKC



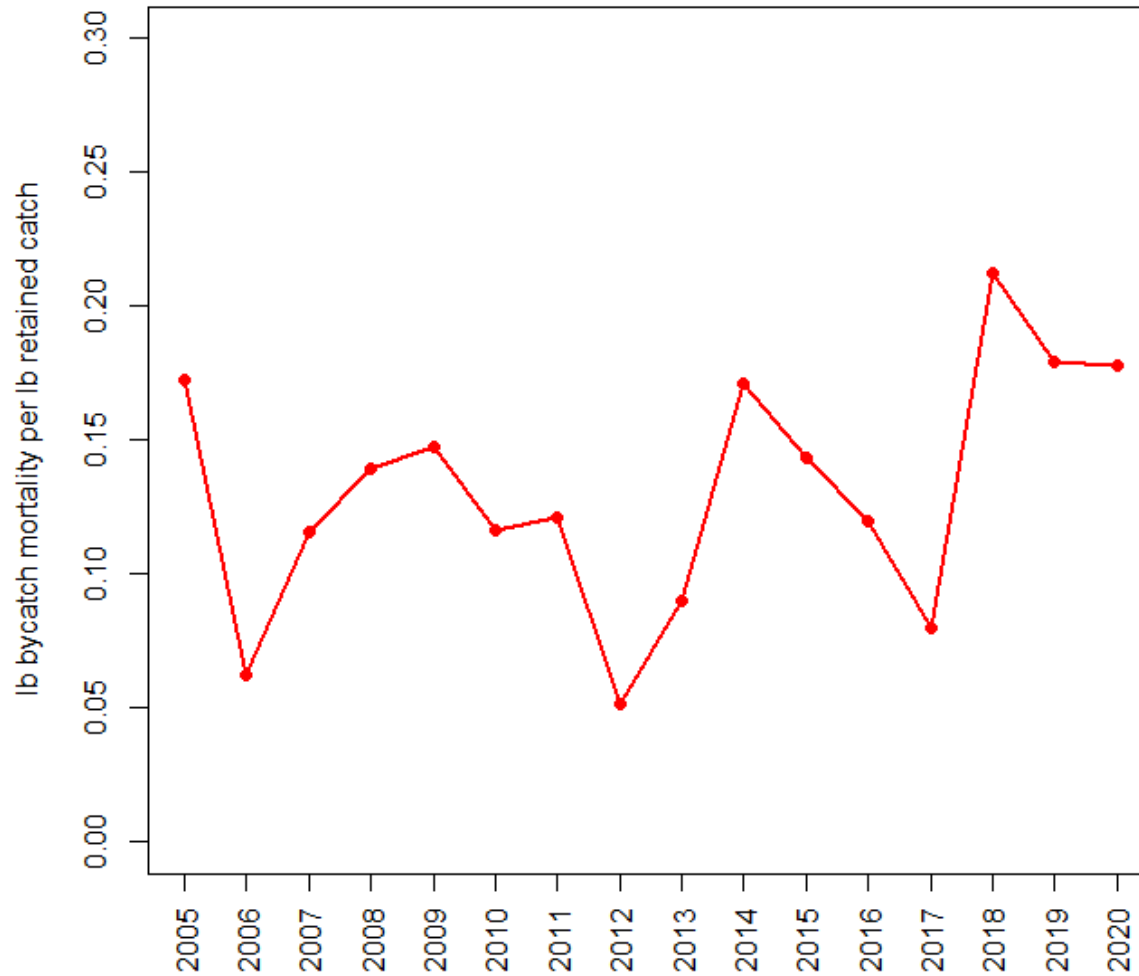
\* Excludes stat areas with <3 vessels



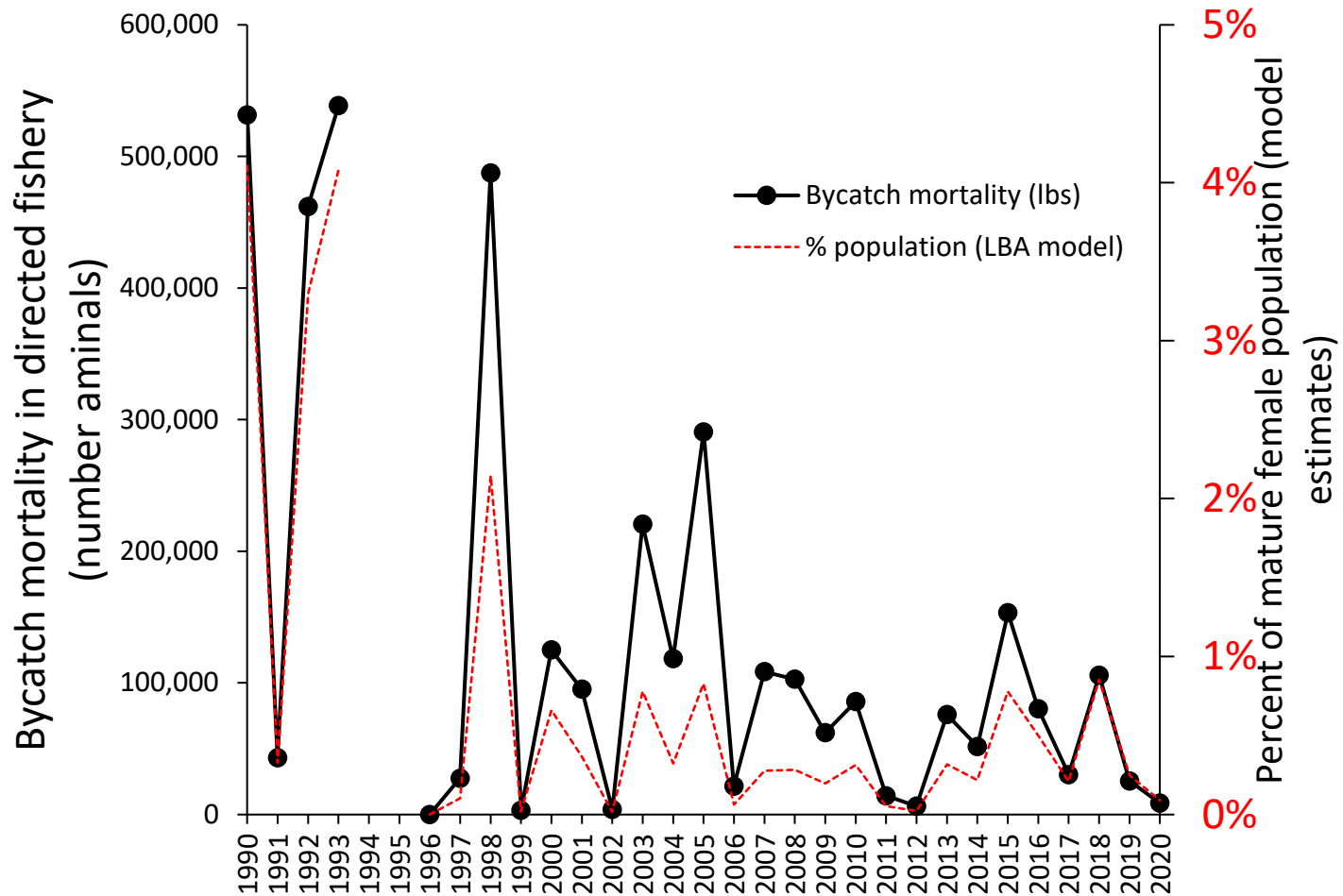
# BBRKC weighted centers of catch



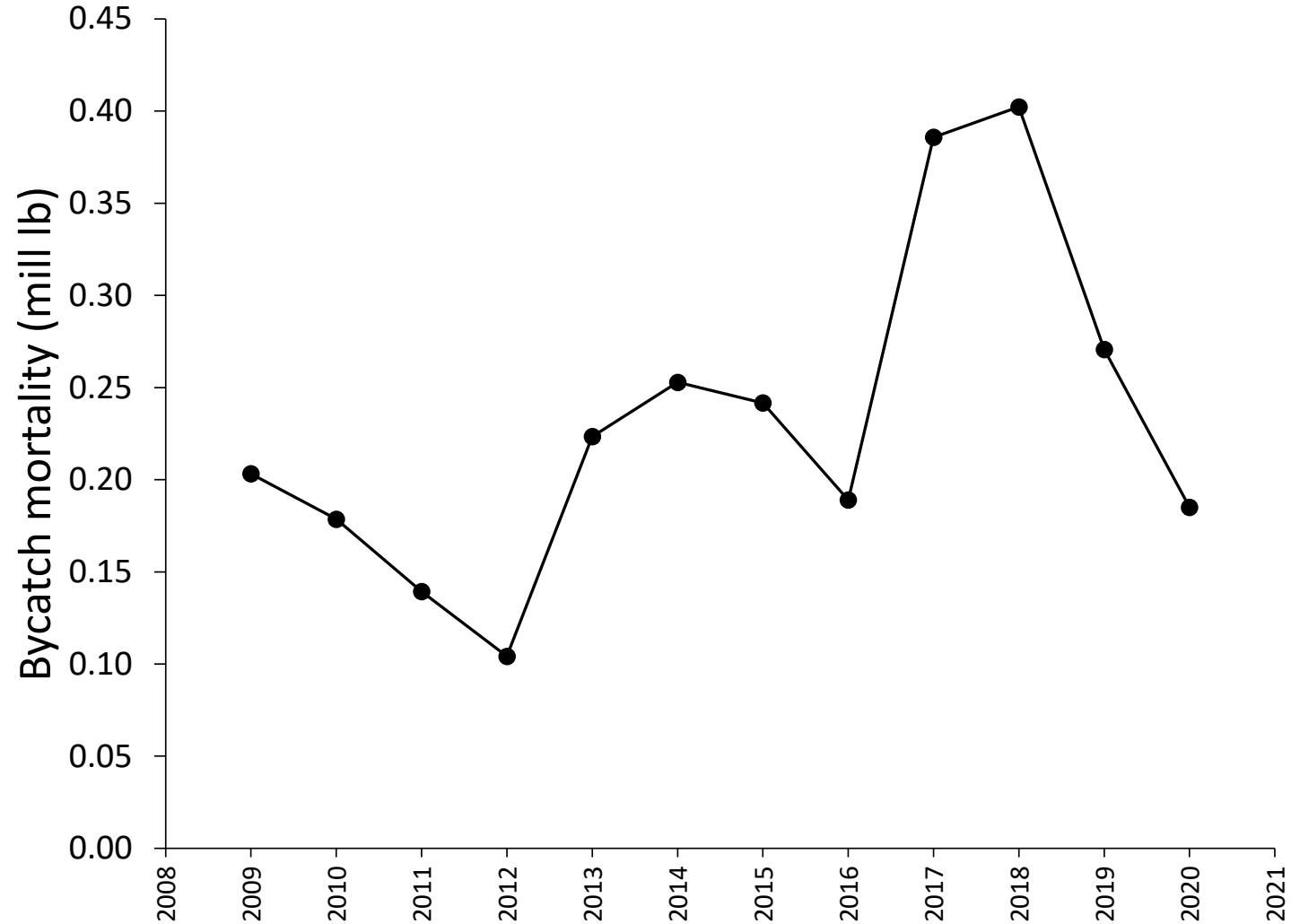
# Directed Fishery Bycatch Mortality Rate



# Mature female discard mortality in directed fishery

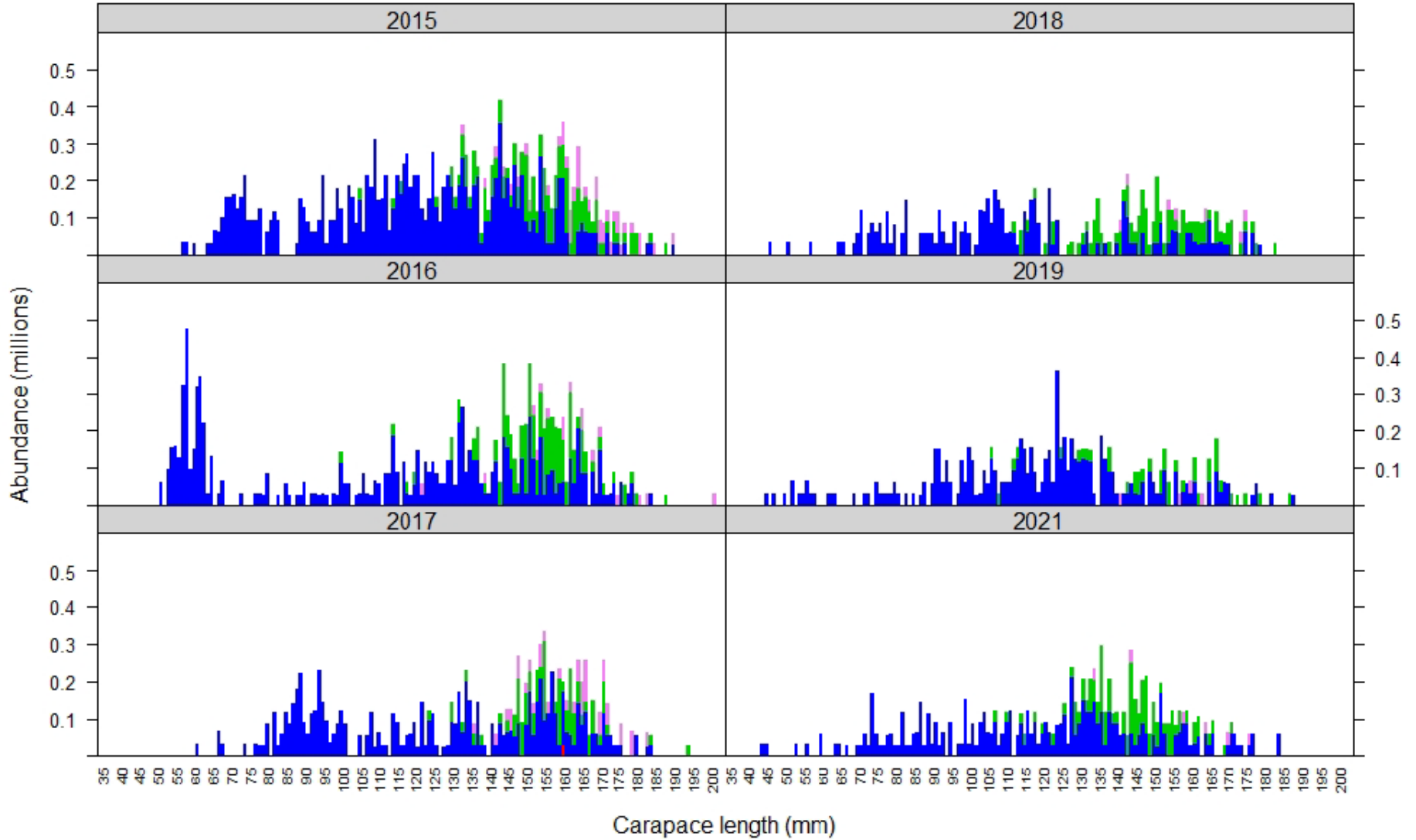


# Bycatch in groundfish fisheries



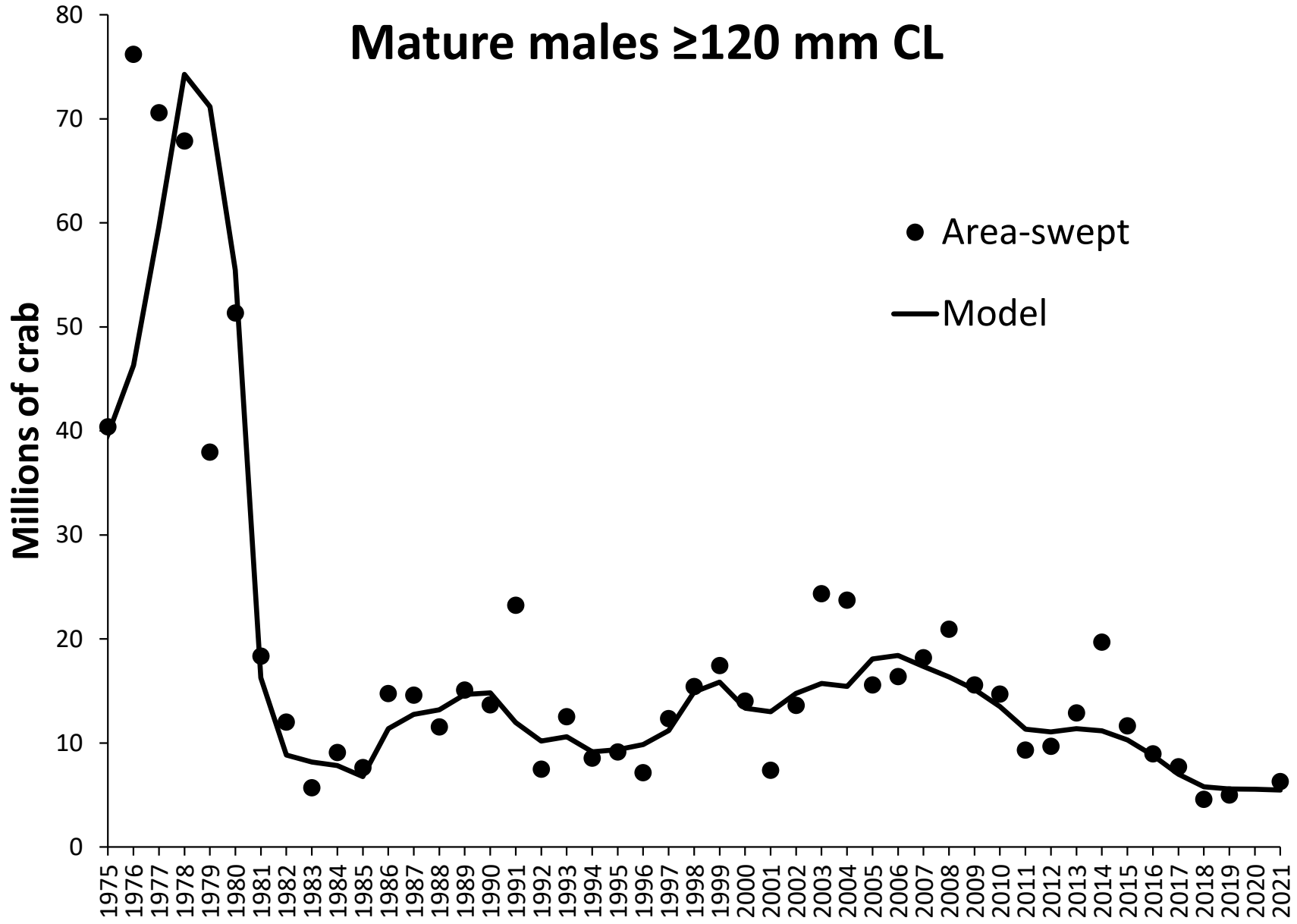
# Bristol Bay Red King Crab (male)

Shell condition  
Molting & soft ■ New - hard ■ Old ■ Very old ■

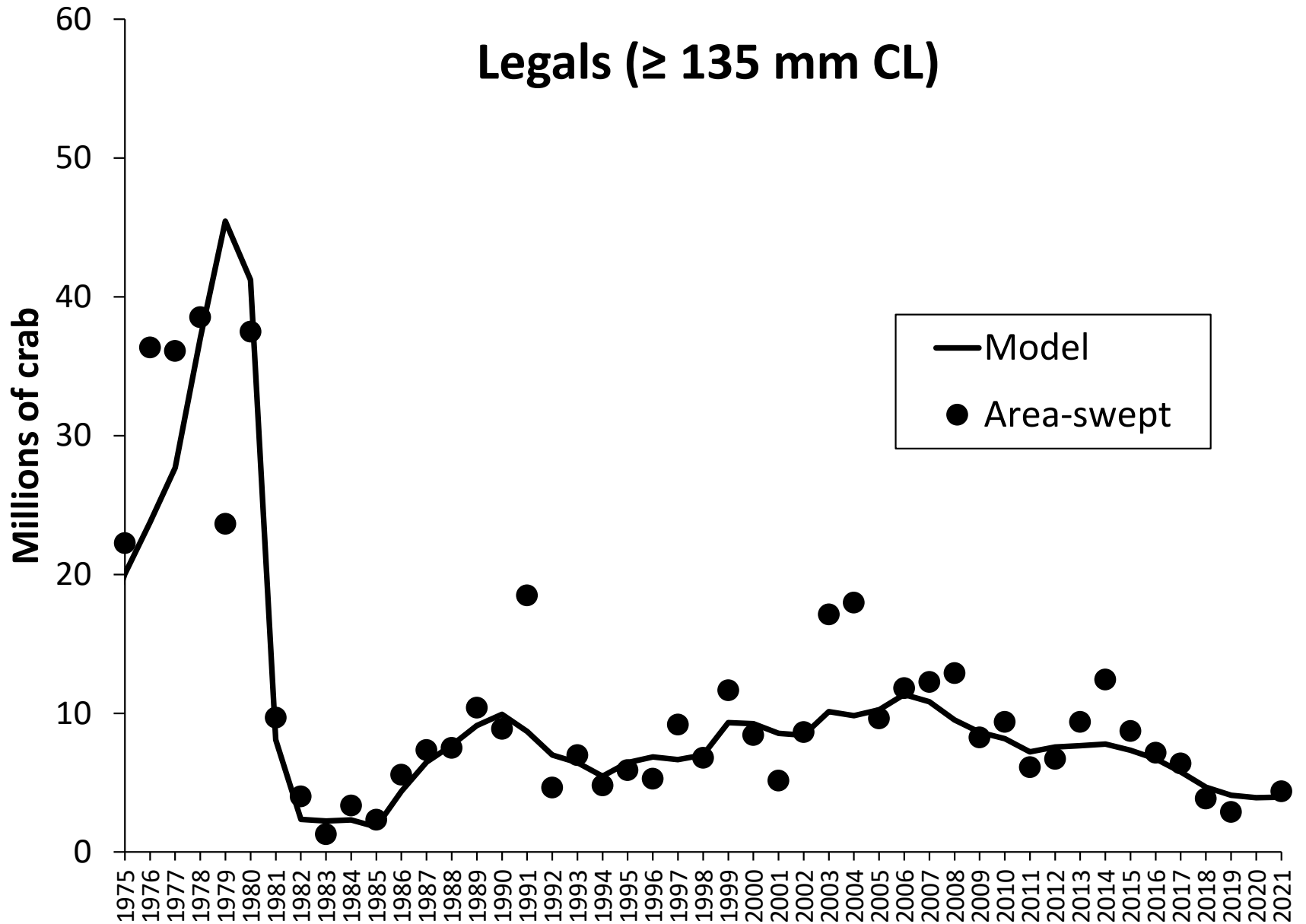


NOAA survey data

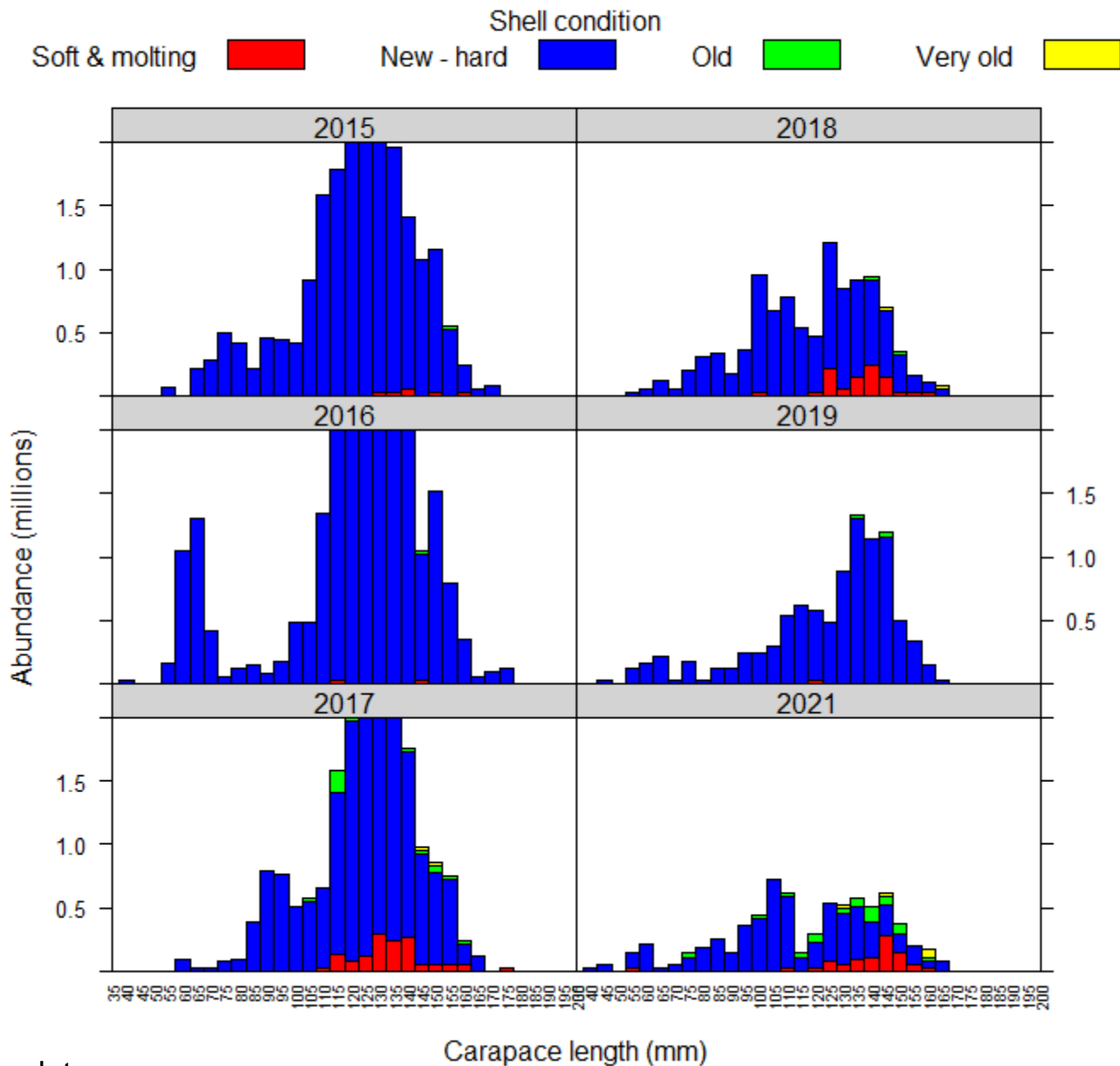
# Mature males $\geq 120$ mm CL



# Legals ( $\geq 135$ mm CL)



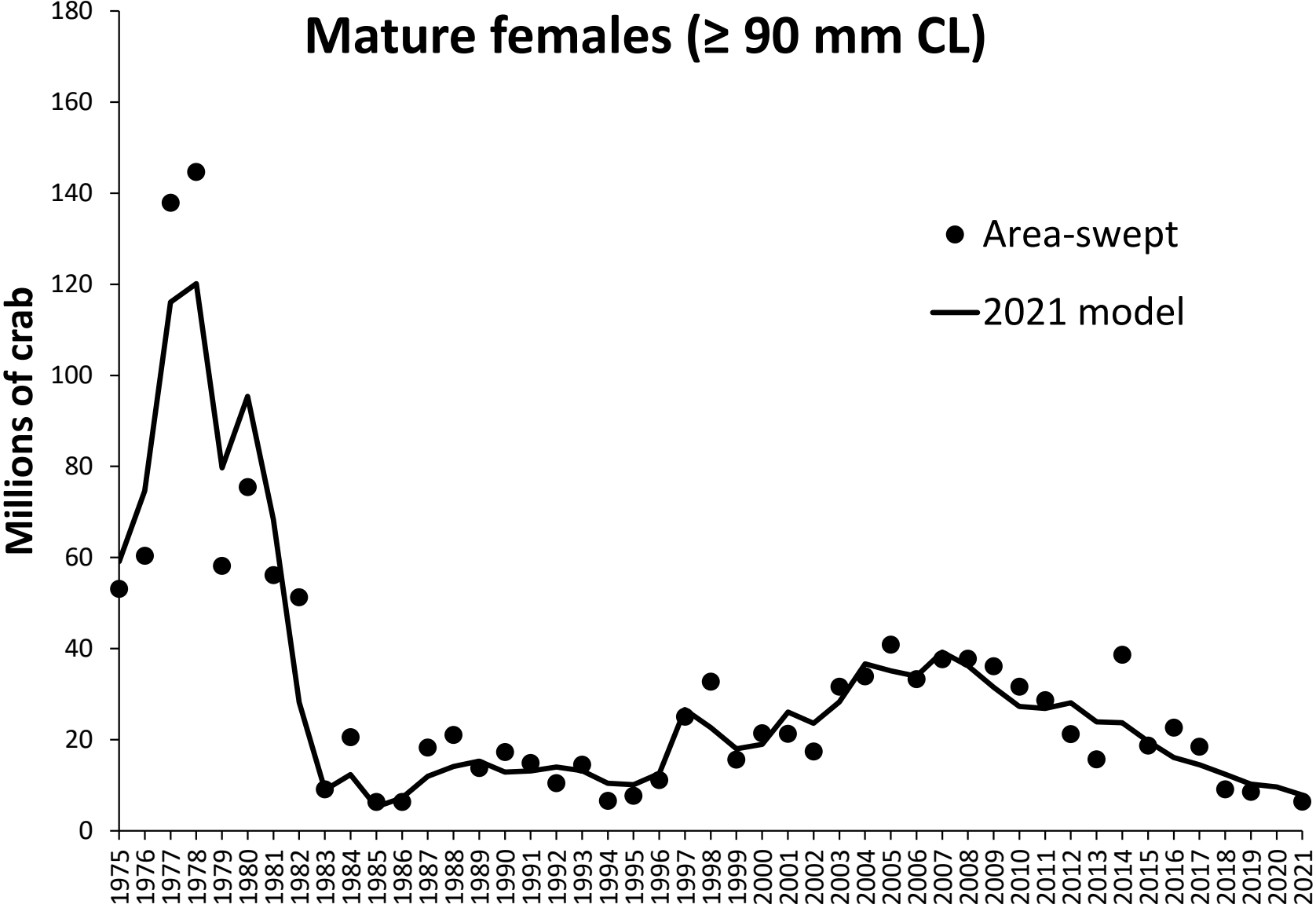
# Bristol Bay red king crab (female)



NOAA survey data



# Mature females ( $\geq 90$ mm CL)



# Recruitment

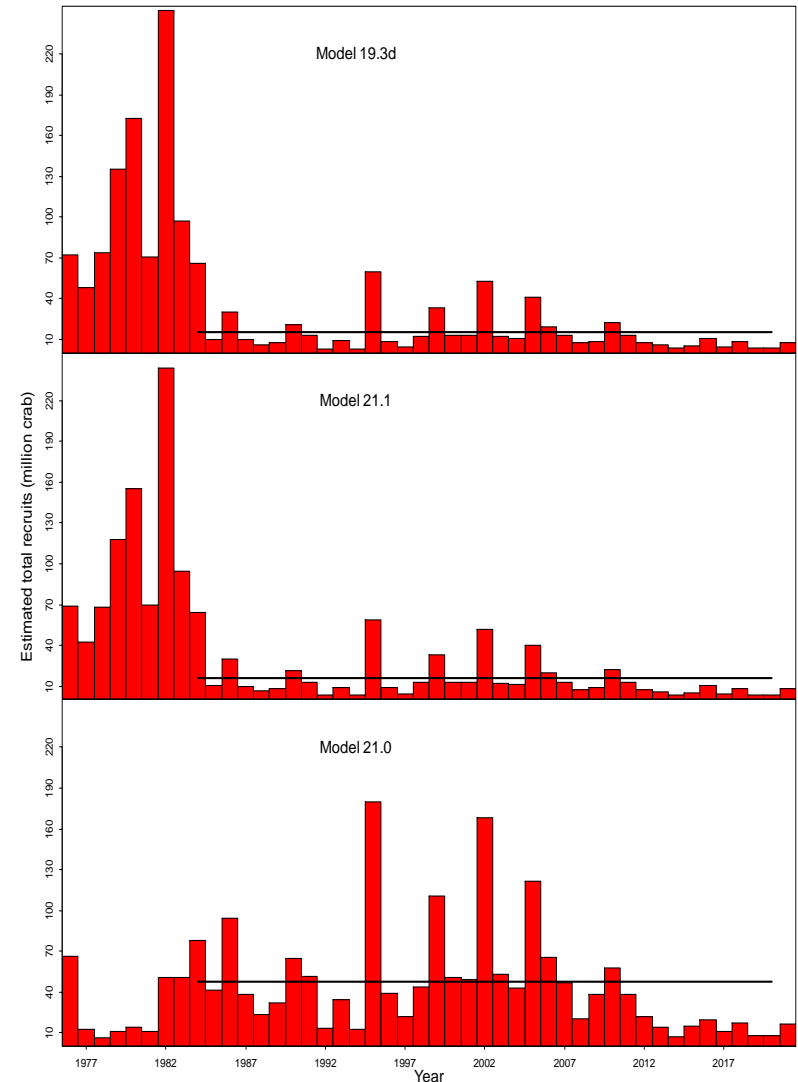
New individuals entering population (or model)

What causes low recruitment?

- Low female abundance
- Poor survival in early life history stages
  - Predation, starvation, thermal stress, OA, etc
- Unfavorable larval advection

BBRKC Model estimates

Crab ~60-85 mm CL



# Stock-recruit relationships

- The estimated number of recruits generated by a given spawning biomass (Ricker or Beverton+Holt models)
- In general, S-R are rare for crab, and there is no reliable S-R relationship for BSAI crab
  - Examples where large mature biomasses can lead to low recruitment OR small biomasses can lead to large recruitments
- This tells us that recruitment is largely driven by environmental conditions, and that the low BBRKC recruitment is likely caused mostly by sub-optimal environmental conditions

# What can we do?

## 1. Protect females

- Minimize fishery mortality: bycatch reduction, closure areas
- Habitat protection

## 2. Optimize mating opportunities

- Maintain adequate males for fertilization

## 3. Understand critical spawning habitats

- Where are females at during larval hatch?
  - Does this position facilitate advection towards favorable settlement habitats?
- What are the critical larval source locations?
- Make sure those locations are being protected

# 2021/22 BBRKC fishery closure

- Protecting females + maintaining adequate males for fertilization

## Analysis of harvest strategies for red king crab, *Paralithodes camtschaticus*, in Bristol Bay, Alaska

J. Zheng, M.C. Murphy, and G.H. Kruse

**Abstract:** A modifiable harvest rate constrained by a minimum spawning abundance (threshold) is currently used to set the annual harvest level for Bristol Bay red king crab, *Paralithodes camtschaticus*. A length-based simulation model was constructed to evaluate effects of recruitment, natural mortality, and handling mortality on this harvest strategy. Evaluation criteria included mean yield, stability of yield, harvest opportunity, and stability of spawning stock. Optimal mature male harvest rates were strongly negatively related to handling mortality. For any given harvest rate, handling mortality is a key factor influencing optimal thresholds. The current harvest strategy produces a high mean yield and low variability in yield under low handling mortality scenarios, but the population is at high risk of collapse with a high handling mortality. Given uncertainties of recruitment, natural mortality, and handling mortality estimates, we recommend reducing mature male harvest rate from 20 to 15% and maximum legal male harvest rate cap from 60 to 50%. If handling mortality rate is greater than 30%, then we recommend increasing the threshold from 6600 to 11 000 metric tons of effective spawning biomass. Our recommended harvest strategy produces a mean yield similar to the current harvest strategy and safeguards against recruitment overfishing.

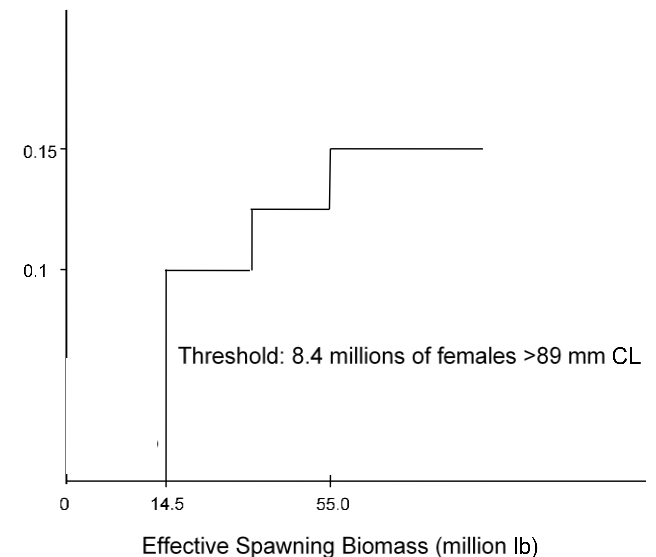
## A length-based population model and stock-recruitment relationships for red king crab, *Paralithodes camtschaticus*, in Bristol Bay, Alaska<sup>1</sup>

J. Zheng, M.C. Murphy, and G.H. Kruse

**Abstract:** A length-based population model was constructed for Bristol Bay red king crab, *Paralithodes camtschaticus*, incorporating stochastic growth, gradual recruitment over length, and a bowl-shaped pattern for instantaneous natural mortality as a function of length. A nonlinear least squares approach was used to estimate abundance, recruitment, and natural mortality. The model was applied to abundance and catch data from 1968 to 1993. The observed population abundances fit well with the model. Natural mortality was estimated to be three to six times higher in the early 1980s than during other periods. High natural mortality coupled with high harvest rates and followed by low spawning biomass may have contributed to the collapse of the population in the early 1980s and its continued lack of recovery. The stock-recruitment data estimated from the length-based model provided a good fit to both general and autocorrelated Ricker models. The general Ricker model is supported by strong recruitment associated with intermediate levels of spawning biomass and extremely low recruitment related to low spawning stock; the autocorrelated Ricker model fit the data slightly better and is supported by the fact that extremely strong and weak recruitment occurred successively over two separate periods.

1121

### Mature Harvest Rate



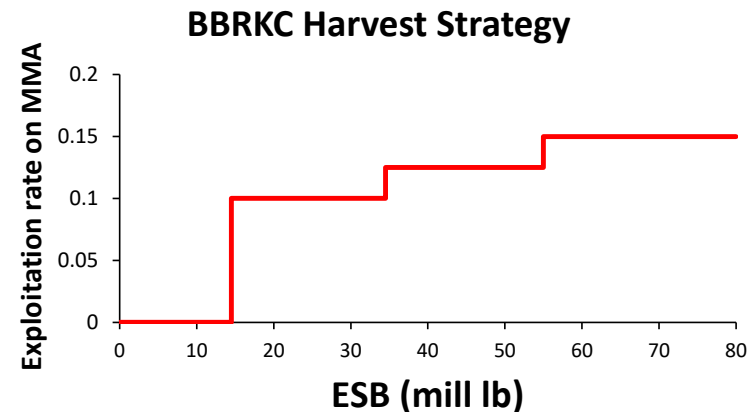
# Bristol Bay Red King Crab Harvest Strategy

## 1. Stock threshold for opening fishery:

- 8.4-million mature-sized females ( $\geq 90$  mm CL), and
- 14.5-mill lb of effective spawning biomass (ESB)

## 2. Exploitation rate on mature-sized ( $\geq 120$ -mm CL) male abundance:

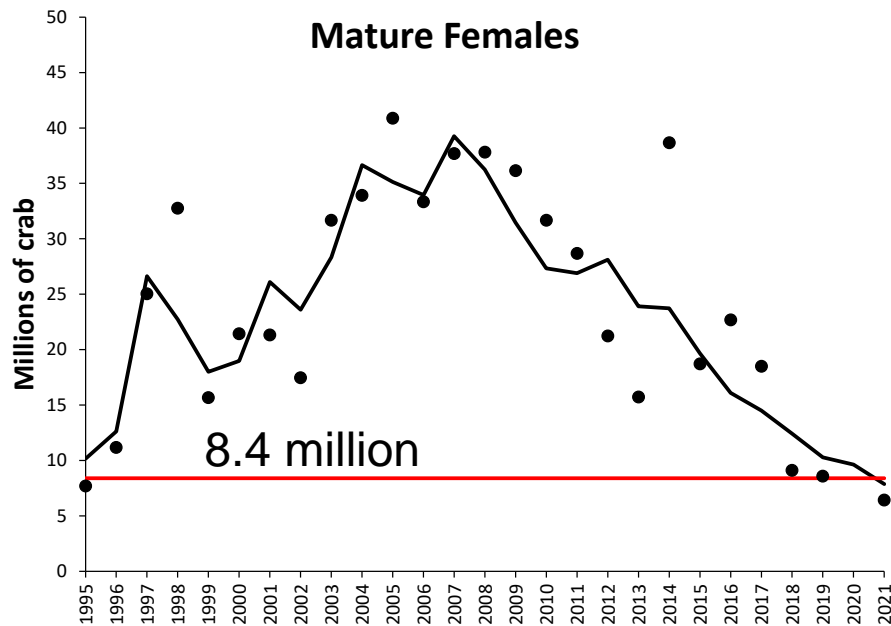
- 10%, when ESB  $< 34.75$ -mill lb
- 12.5%, when ESB is between 34.75-mill lb and 55.0-mill lb
- 15%, when ESB  $\geq 55.0$ -mill lb



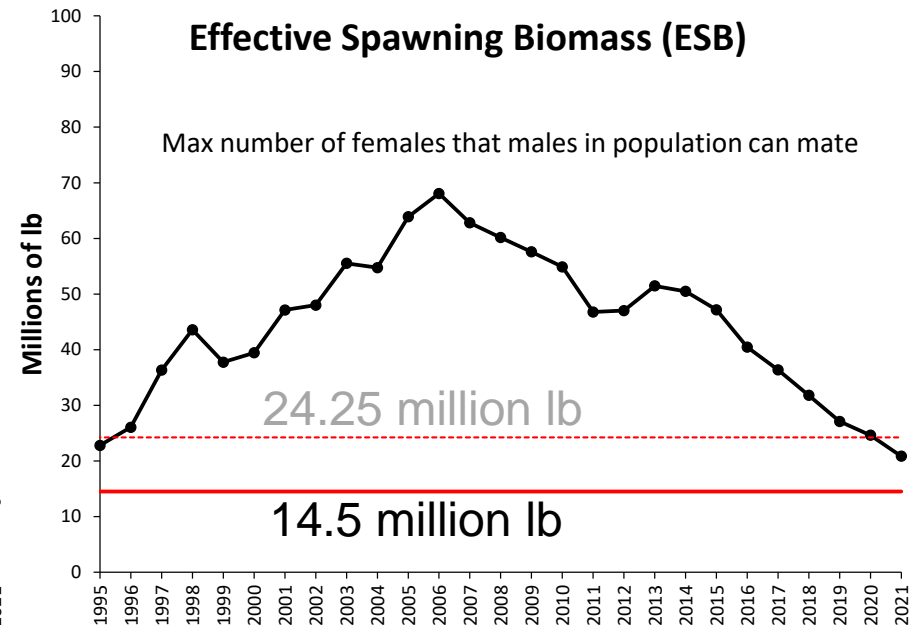
## 3. Harvest capped at 50% of legal male abundance

# Harvest Strategy Closure Thresholds

## 2 thresholds, both based on mature females

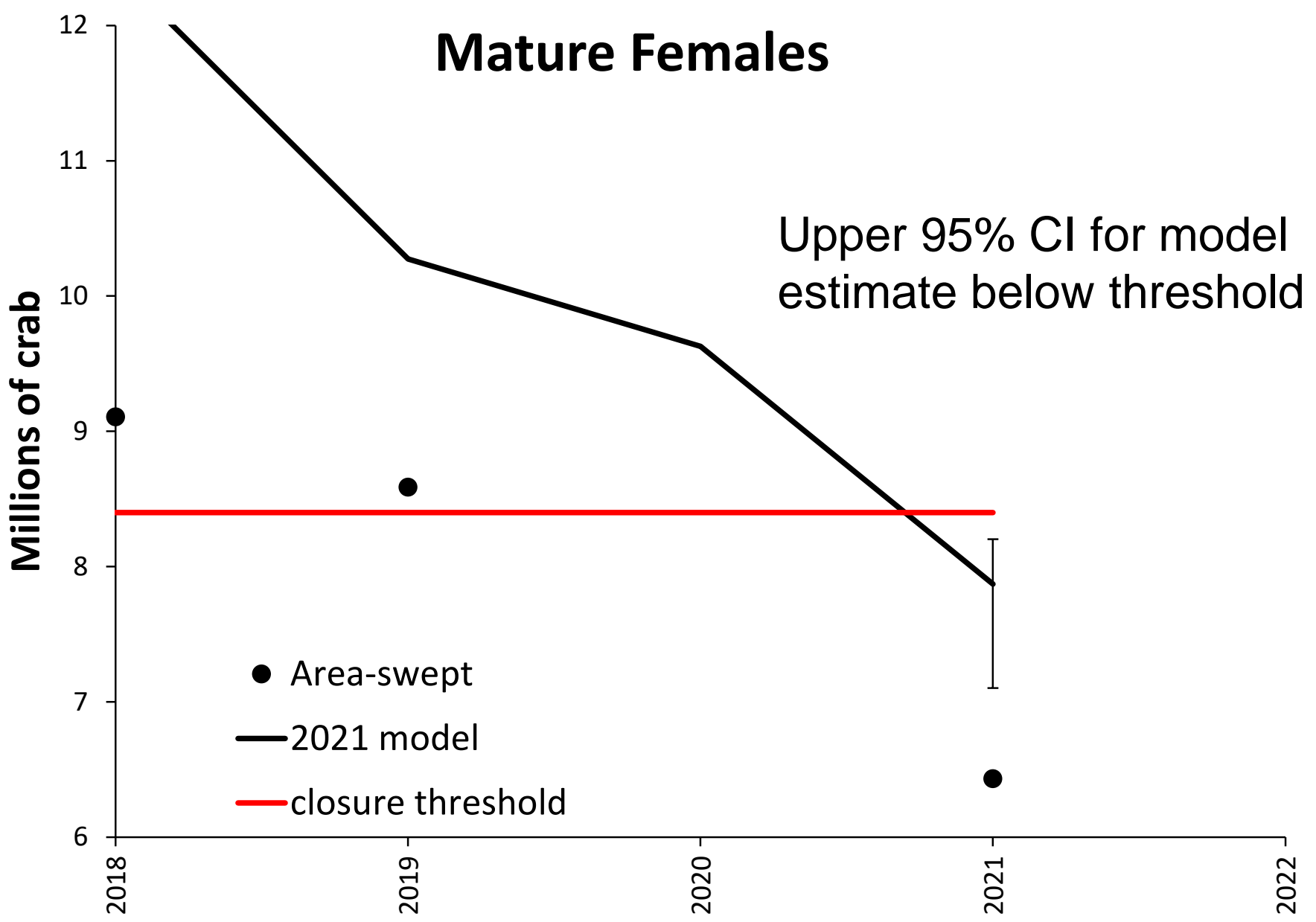


2021 area-swept: 6.43 million  
2021 model: 7.87 million



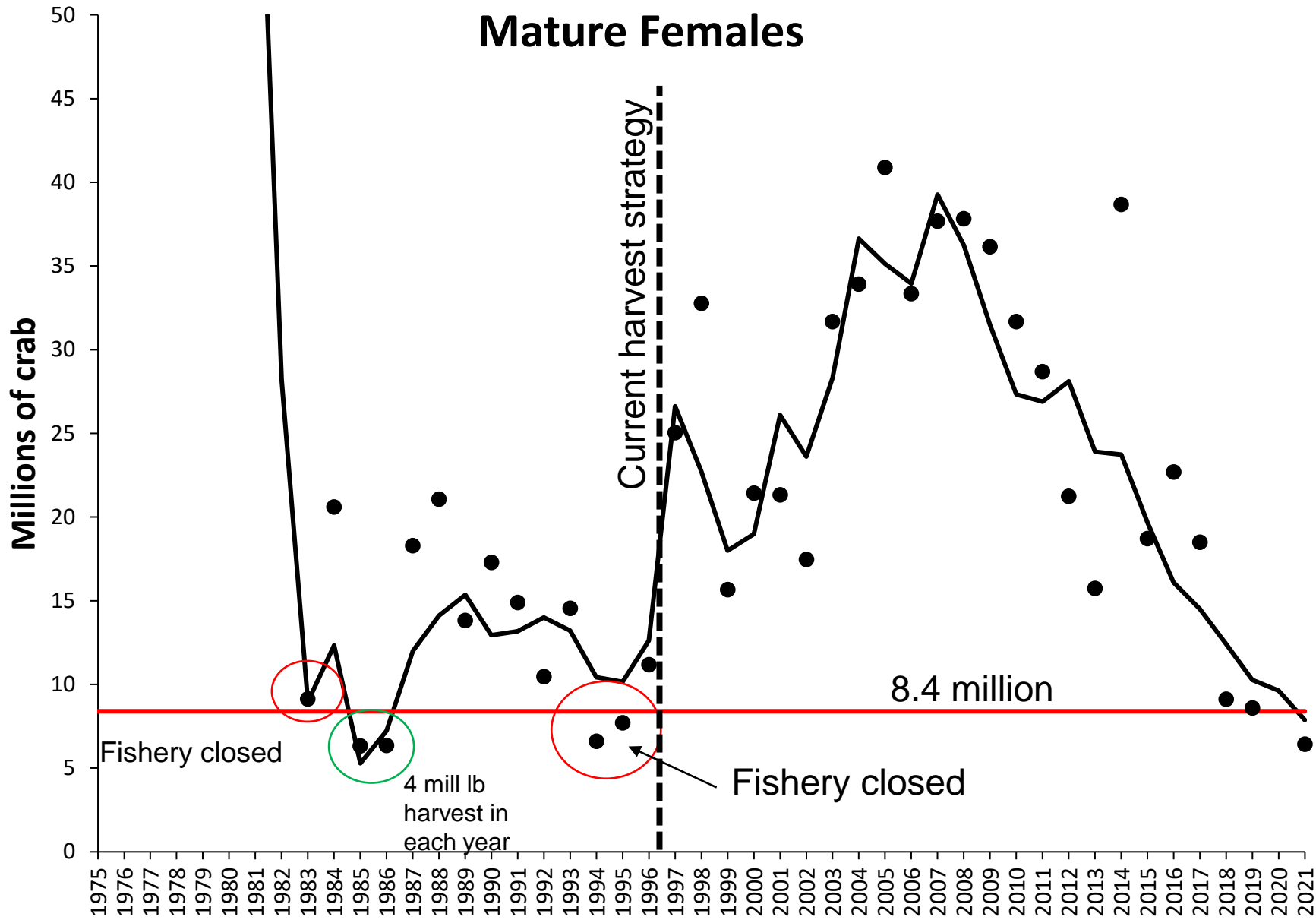
2021 model: 20.86 million lb

# Mature Females



- Area-swept
- 2021 model
- closure threshold





# Mature Female Abundance Threshold

- Blunt tool meant to avoid recruitment overfishing
- **8.4 million MFA threshold:** estimated at 20% of equilibrium level of fertilized females from Ricker stock-recruitment curve (“Thompsons rule”, Thompson 1990)
  - Defined as the minimum mature female abundance *“that allows sufficient recruitment so that the stock can eventually reach a level that produces MSY”* (1989 BSAI Crab FMP)

# Effective Spawning Biomass

- Max number of females that males in population can mate (male reproductive potential, MRP)
  - Assumes males can mate with multiple females in a season (mating pair lab studies, Kodiak field observations)

If  $MFA < MRP$ , then female spawning abundance = mature female abundance

If  $MFA > MRP$ , then male reproductive potential = female spawning abundance

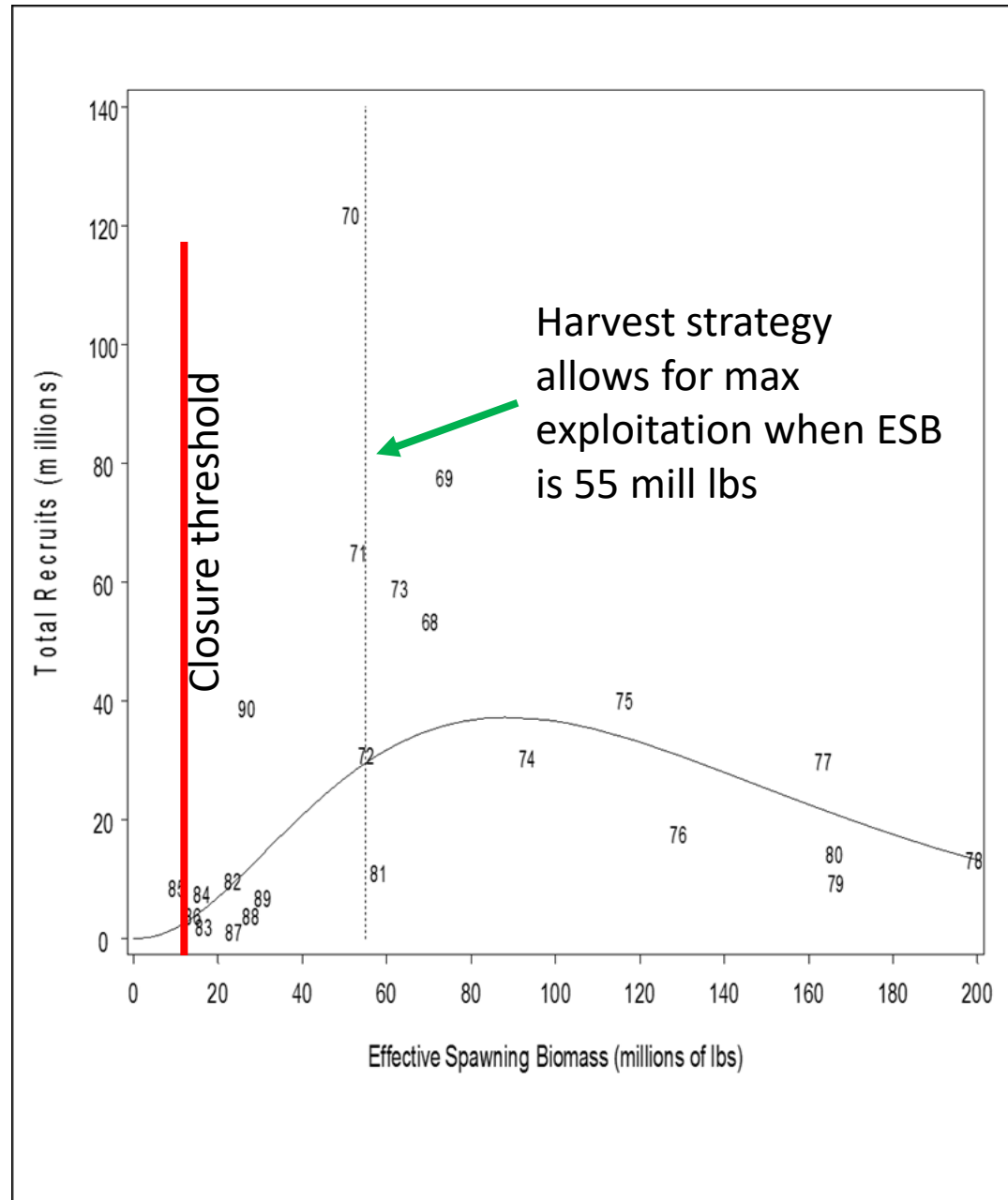
Female spawning abundance then converted to biomass via LW relationship, and defined as effective spawning biomass (ESB)

**Table 1.** Average weight and assumed maximum number of female mates for male red king crab in Bristol Bay by length class.

Male carapace length (mm)	Average male weight (kg)	Number of female mates
0–119		0.0
120–124	1.43	1.0
125–129	1.63	1.2
130–134	1.84	1.4
135–139	2.06	1.6
140–144	2.31	1.8
145–149	2.58	2.1
150–154	2.86	2.4
155–159	3.17	2.7
160+	3.50	3.0

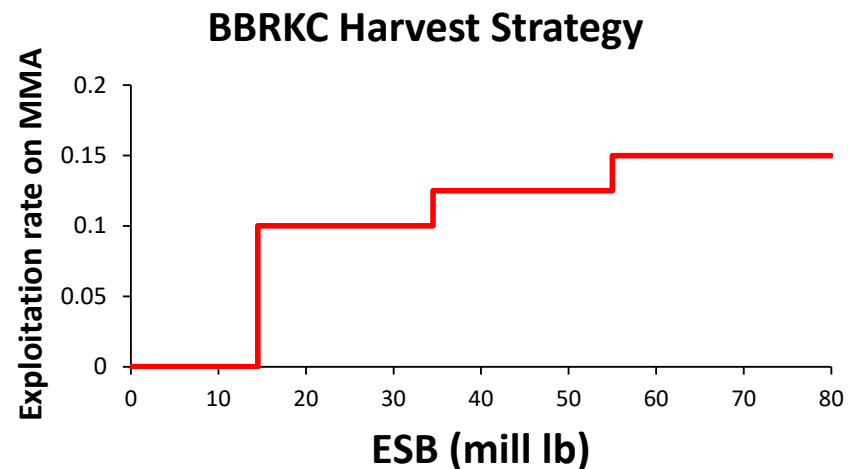
# BBRKC S-R

- Done in 1997 using data from the 70s + 80s when high recruitment occurred
- Fit is much worse with more recent data due to very low recruitment



# 14.5 mill lb ESB Threshold

- 55 million lb rebuilding target: “intermediate level of biomass above which strong recruitment occurs with high frequency in the past” (Zheng et al 1997)
  - At or above this level allows for max exploitation rate of 15%
- 14.5 million lb is meant to approximate 8.4 million females
- 34.75 million lb stairstep was added on later, halfway between 55 and 14.5

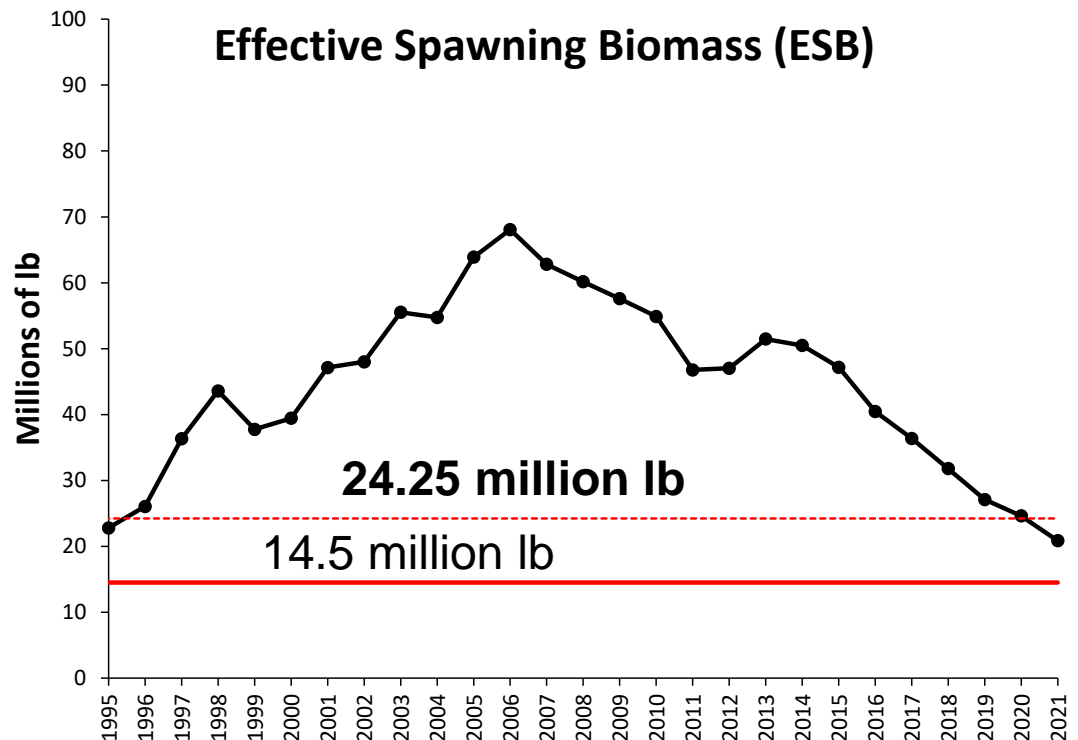


# Analysis of harvest strategies for red king crab, *Paralithodes camtschaticus*, in Bristol Bay, Alaska

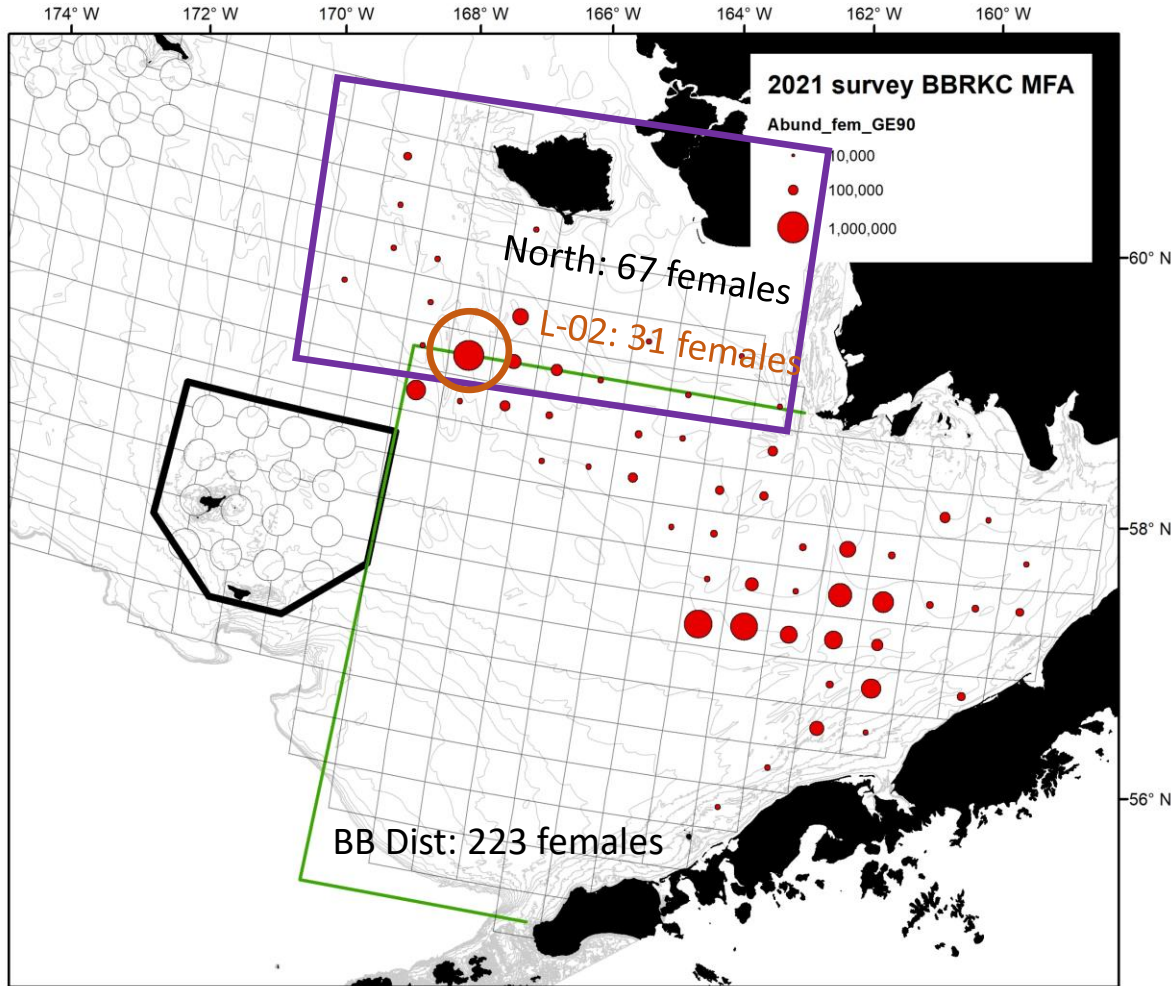
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Early recommendation to increase threshold to 24.25 million lb ESB



# 2021 Survey: Mature females

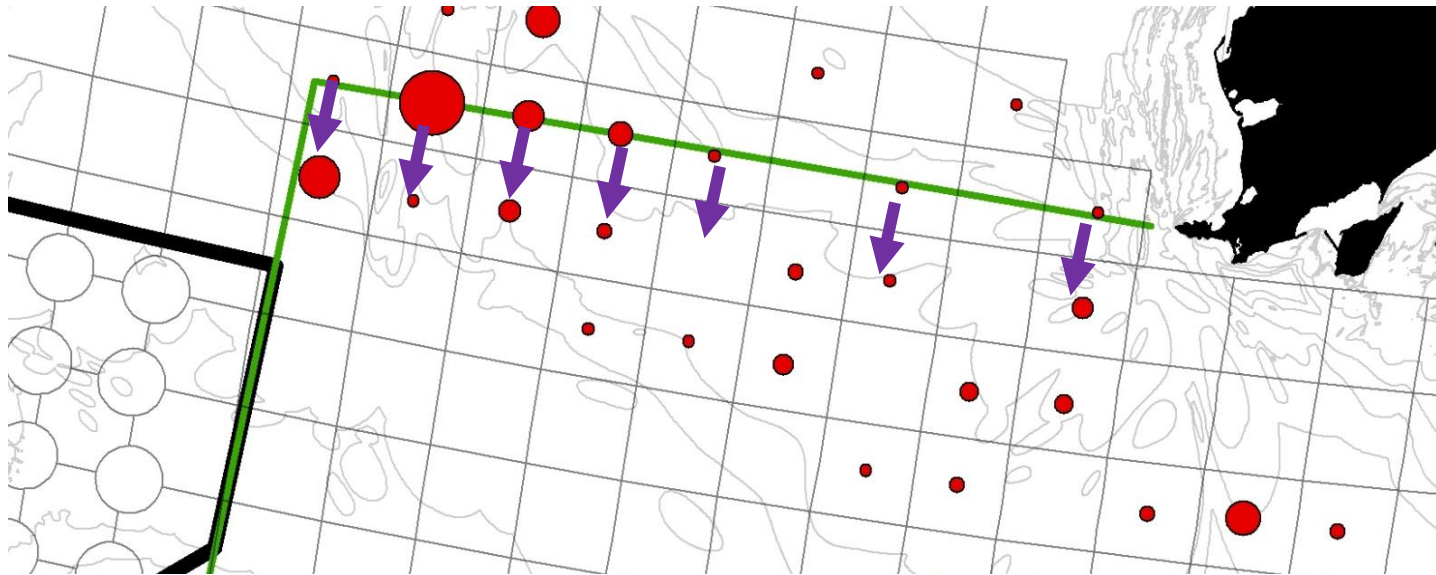


- 223 BB females  $\geq 90$  mm caught in survey
- Net touched  $\sim 0.00345\%$  total BB survey area
- Station crab density averaged, then expanded to full BB district
- Expands to 6.4 million crab

# 2021 Survey: Mature females

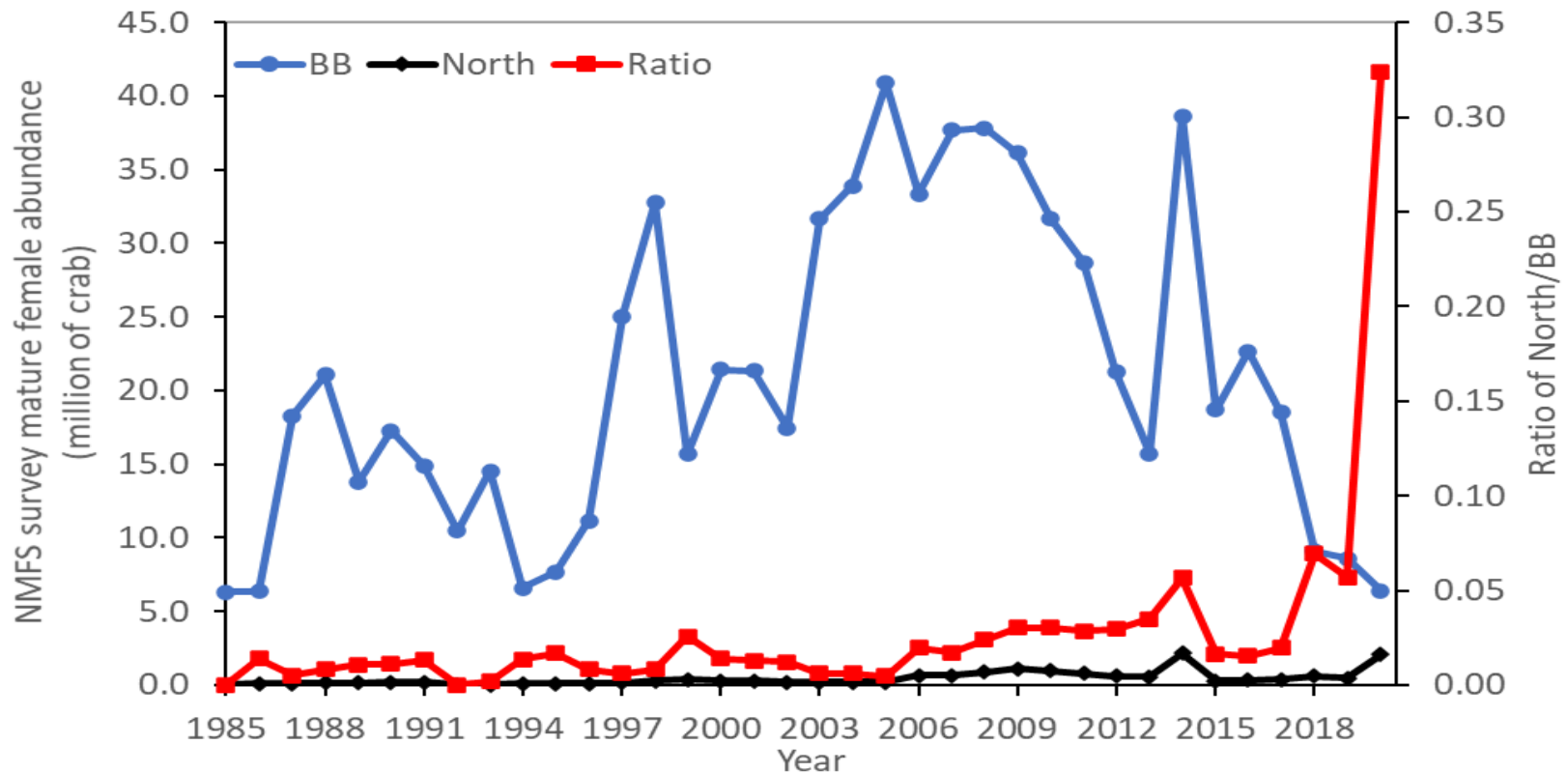
## Thought exercise:

What if all the mature females along the northern border were pooled with the stations below?



- Recomputed area-swept estimate would be **7.8 million** mature females
- **Still below 8.4 million** threshold for opening fishery





- Proportionately, yes, high proportion of mature females north of the BB boundary in 2021
- But, that's mainly due to:
  1. Low abundance of females in BB
  2. 1 large catch (31 crab) in station L-02

# Management Boundaries

## **Why can't we include females north of the BB boundary?**

Bad idea to redraw management boundaries at time when the abundances are among the lowest ever (since the mid 1980s) because we don't know if its appropriate to do so

- Biological implications
- Management strategies may need adjustment
  - Boundaries, closure areas, exploitation rates, etc

# Shifting Management Boundaries

Is it biologically appropriate to do so?

- Are crab north of BB contributing to the population in the management district?
- North-south movement of juveniles and adults?
- Larval advection to the south?
- Genetic population structure
  - Grant and Cheng 2012:

*“The western Aleutian and Norton Sound crabs appear to be isolated from southeastern Bering Sea populations, despite ocean currents that would be expected to promote gene flow between populations.”*

*“The genetically defined groups of red king crabs largely coincide with the State of Alaska’s registration areas. Populations in the northeastern Bering Sea (Q), Bristol Bay (T), and the Aleutian Islands (O) are genetically divergent from one another, because of different biogeographical histories.”*

# Whats next?

- Continue research on recruitment limitations
  - Movement patterns
  - Habitat
  - Larval advection
  - Consider if additional area closures or shifting existing ones is needed
- Examine the harvest strategy
  - Exploitation rates
  - Thresholds for closure
- Consider management boundaries
- Assessment model: work towards including fishery CPUE into assessment

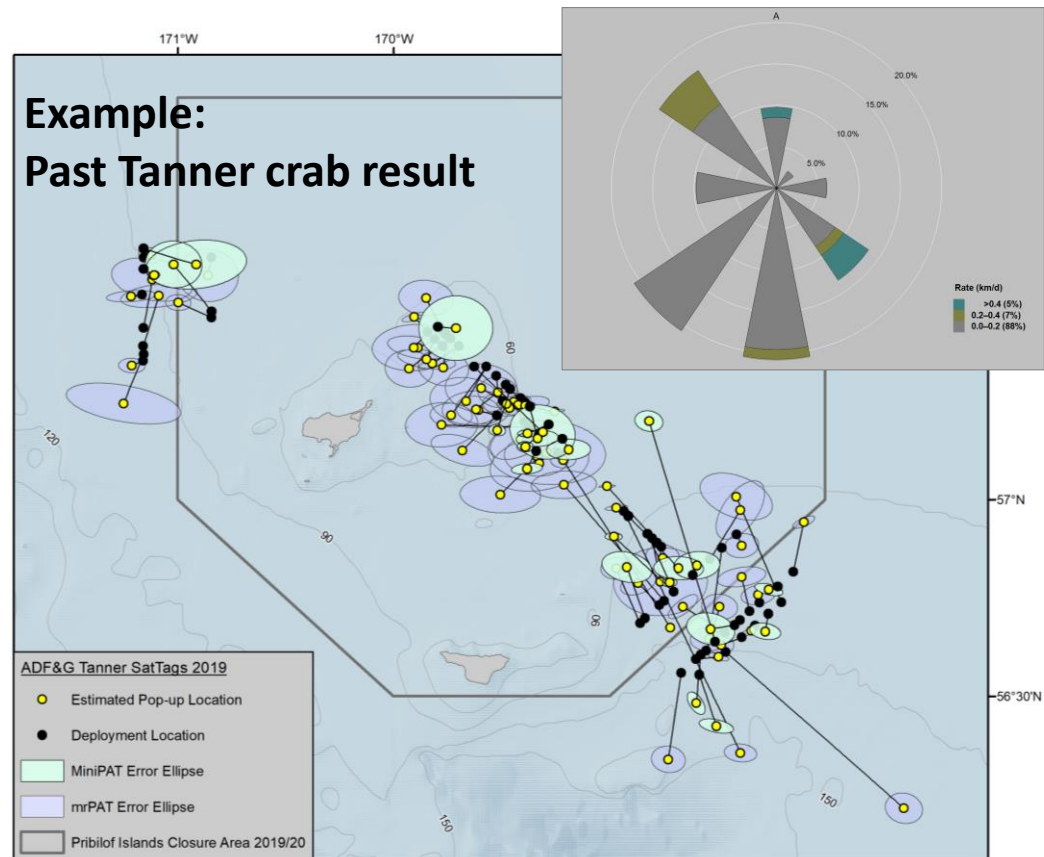
# Adult seasonal movement

Satellite tagging:

Past work on Tanner, BBRKC, NSRKC



Example:  
Past Tanner crab result



# Tentative tagging locations for fall 2021 sat tag project

